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Cost–benefit analysis as a decision tool for effective conservation planning—The case of the Nyerere Selous-Udzungwa wildlife corridor in Tanzania

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Abstract
Cost benefit analysis (CBA) is used in many fields to ensure efficient allocation of scarce resources but is rarely applied in conservation. By using a common metric to evaluate projects in complex social-ecological systems, CBA can help to maximize the impact of conservation funding. It can also help to interrogate issues of distributional equity, plan for effective community-based conservation, and inform future research and strategic priorities. We demonstrate this using the example of the Nyerere Selous-Udzungwa Wildlife Corridor in Tanzania, a wildlife corridor aiming to restore connectivity between two protected areas to enhance African elephant (*Loxodonta africana*) conservation outcomes and mitigate human–elephant conflict. We combine novel data on elephant crop depredation with crop price and productivity data, elephant valuation methods, and ecosystem service values to analyze corridor costs and benefits from contrasting global and local community perspectives. From the global perspective, we find benefits to outweigh costs by at least 4.6:1. From the communities' perspective, we find that while substantial benefits should secure buy-in to the project, continued subsidy will be required to cover the costs. Our findings support generalized recommendations for application of CBA across diverse systems and conservation priorities.

KEYWORDS
community benefits, conservation planning, cost effectiveness, elephants, human–elephant conflict, Tanzania, wildlife corridor

1 | INTRODUCTION

Despite continued alarming rates of global biodiversity loss, only a fraction of the funds required to meet international conservation goals are available (Deutz et al., 2020; WWF, 2022). Conservation planners must use the limited resources available to them wisely, pursuing strategies that maximize conservation outcomes from every dollar spent (Ferraro & Pattanayak, 2006; Murdoch et al., 2007). Since the allocation of scarce resources is a central question of the economics discipline, economic evaluation tools may help to achieve this goal (Cook et al., 2017).

Recently, significant progress has been made in building evidence on conservation effectiveness through initiatives such as the Conservation Evidence database (Sutherland et al., 2019) and Collaboration for Environmental Evidence (Pullin & Knight, 2009). However, consideration of the costs of delivering conservation outcomes, and the use of economic evaluation methods, remains surprisingly limited in conservation (Pienkowski et al., 2021; White et al., 2022). Planning still largely relies upon "benefit targeting"—selecting interventions according to their likely ecological impact irrespective of costs (Grand et al., 2017). This failure to incorporate costs into planning is likely to result in suboptimal use of resources and underperformance relative to conservation objectives (Moore et al., 2004; Naidoo et al., 2006; Polasky et al., 2001).

1.1 | Cost–benefit analysis

Cost benefit analysis (CBA) is used in many fields to conduct pre-project appraisals or end-of-project evaluations to assess whether the benefits of an action justify its costs. Unlike cost-effectiveness analysis, which assesses the cost per outcome of an action (e.g., cost per square kilometer protected), CBA assigns monetary values to all benefits and compares this value to total costs. Computing a single cost–benefit metric allows for appraisal of projects with multiple diverse outcomes (e.g., combined socioeconomic and environmental outcomes), as well as comparison between different kinds of projects (e.g., comparing investment in wildlife corridors with anti-poaching efforts)—particularly useful when considering multiple potential interventions in complex social-ecological systems, and more in line with the multi-criteria decision making field (Triantaphyllou, 2000). In addition, CBA can be used to compare stakeholder perspectives and distributional implications of a project, which can help in the planning of how costs and benefits should be managed between different actors.

A standard CBA involves (a) quantifying all costs and benefits over the life of the project (forecasting into the future where necessary), (b) assigning monetary values to each factor (including to non-market factors such as environmental impacts), and (c) using a discount rate to calculate present values of costs and benefits (assigning less weight to values arising in future years in order to reflect a general preference for payoffs sooner rather than later) (Boardman et al., 2018). A present value benefit to cost ratio greater than one implies that a project is worth funding.

1.2 | CBA in conservation science

CBA has rarely been used in conservation science (Naidoo & Ricketts, 2006; White et al., 2022). Of the 1987 studies in the current Conservation Evidence databased reviewed by White et al. (2022), only nine (0.5%) featured CBAs. We conducted a Web of Science search for CBA in the field of biodiversity conservation, yielding a further 28 studies. Of these 37 total studies, less than half considered environmental benefits, with most focusing on the financial impact of human-wildlife conflict, wildlife-vehicle collisions, or wildlife tourism (Appendix S1). Geographic coverage is uneven, with most examining projects in Europe and North America.

Moreover, most did not follow CBA best practice (as per Boardman et al., 2018 and elsewhere). Only 41% used a discount rate to calculate present values of projected future costs and benefits (with only two-thirds of these providing a rationale for their chosen rate), and only 30% conducted a sensitivity analysis (an assessment of the sensitivity of the CBA result to variations in underlying cost and benefit components). Overall, only three studies featured a combination of consideration for financial and environmental benefits, discounting with a justified rate, and sensitivity analysis (de Groot et al., 2013; Kasimir et al., 2018; Newton et al., 2012). While CBA is therefore not entirely novel in the field, its use has been extremely limited and inconsistent to date.

1.3 | Barriers to wider use

This limited use of CBA can be attributed to a combination of technical barriers and philosophical concerns. On the technical side, CBA in conservation is complicated by long timescales and difficulties with discount rate selection (Almansa & Martínez-Paz, 2011); significant non-market costs and benefits that lack readily available monetary values (Balmford & Whitten, 2003); distributional issues whereby locally borne costs generate globally diffuse benefits (Green et al., 2018); a high degree of uncertainty around future outcomes (Murdoch et al., 2007); and a lack of available cost data.

However, advances in conservation science are making many of these issues increasingly navigable. Research on ecosystem service valuation, and associated resources such as the Ecosystem Services Valuation Database (www.esvd.net), provide monetary values for many

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environmental factors (Costanza et al., 2014; Foundation for Sustainable Development, 2021; TEEB, 2010). The contentious issue of discounting in long-term environmental projects has been increasingly addressed in both mainstream guidelines (see, e.g., UK Government, 2022) and landmark reports (Stern, 2008). Going forward, distilling these various lines of research into conservation-specific CBA guidelines should help to increase uptake.

On the philosophical side, many conservation scientists remain wary of economic considerations (particularly those perceived as "putting a price on nature"), concerned that market-driven ideologies may come to override ecological goals or the intrinsic value of nature (Arponen et al., 2010). However, CBA is flexible to diverse values. While costs and benefits are necessarily assigned monetary values in the analysis, there is no requirement for a project to make money in the real world—the dollar values of CBA simply serve as a common metric for comparison between heterogenous outcomes, given the familiarity of money as a measure of value. Indeed, when incorporated in CBA, recent developments in valuing the vast and diverse benefits of nature can lend substantial weight to conservation arguments relative to commercial alternatives (Bradbury et al., 2021; IPBES, 2022).

If conservation is to make the most of limited resources, generating the greatest outcomes per dollar spent, work is needed to overcome these technical and philosophical barriers, and to demonstrate the value of CBA as a tool that is flexible to the objectives of conservation planners, applicable to complex ecological problems, and transparent to the public. We demonstrate that this is possible using the example of the Nyerere Selous-Udzungwa Wildlife Corridor (NSUWC) in Southern Tanzania.

1.4 | Costs and benefits of wildlife conservation corridors

Declining habitat connectivity is one of the greatest drivers of biodiversity loss today, as land outside of protected areas becomes increasingly human-dominated (Fahrig, 2003; Fischer & Lindenmayer, 2007; Foley et al., 2005; Newmark, 2008). The establishment and protection of conservation corridors—tracts of protected land connecting two or more larger habitats—has therefore become a popular approach for the mitigation of habitat fragmentation (Hilty et al., 2020). Conservation corridors can help protect migration routes, enhance gene flow, enable (re)colonization of habitats, mitigate human-wildlife conflict, and provide options for range shifting in the face of changing environmental circumstances, particularly in the context of climate change (Gilbert-Norton et al., 2010; Hilty et al., 2020).

Despite their growing popularity, there remains limited evidence on the cost-effectiveness of conservation corridors (Beier & Noss, 1998; Brodie et al., 2016; Simberloff et al., 1992). Conservation corridor costs—including physical infrastructure, compensation for land or displaced persons, and opportunity costs of land (i.e., the foregone financial returns associated with leaving land unutilized)—can be substantial (Nyaligu & Weeks, 2013). To justify these costs to funders and other stakeholders, there is a critical need to demonstrate corresponding benefits from corridor projects.

Like many conservation strategies, corridors also raise significant questions around human well-being and distributional equity. By reducing community access to land and natural resources, setting land aside for corridors can appear contrary to human development goals—particularly in areas of high-density human settlement and economic activity—attracting accusations of green grabbing (Benjaminsen & Bryceson, 2012). While protection of community rights should be the minimum standard for conservation actors, seeking community support can also support the success of conservation initiatives (Bennett et al., 2019).

To explore these questions around the cost-effectiveness of corridor conservation, as well as the wider potential for use of CBA in conservation, we demonstrate how CBA can be used to appraise projects from multiple stakeholder perspectives, seeking to answer two questions—first, does the project represent good value for money in terms of elephant conservation, and second, are local communities likely to be in favor of the project?

2 | METHODS

2.1 | Study area

The NSUWC project, led by the Kilombero District (Ifakara Town Council) and the NSUWC Management Committee and facilitated by Southern Tanzania Elephant Program (STEP, a Tanzanian NGO) and the USAID Tuhifadhi Maliasili project, aims to reestablish connectivity between the Udzungwa Mountains National Park and Nyerere National Park, which has recently been severed by intensive agricultural activity in the Kilombero Valley (STEP, 2018). The wildlife corridor is considered a priority within the country's vast corridor network, both in terms of conservation importance and severity of threat faced (Ministry of Natural Resources and Tourism, 2022). Connectivity loss has led to high and rising rates of human–elephant conflict (HEC)—with elephant migration routes increasingly obstructed by human settlements and agricultural activities, elephants attempting to cross the valley can cause significant crop damage while also posing a risk to human safety, consistent with evidence elsewhere (Buchholtz et al., 2020).

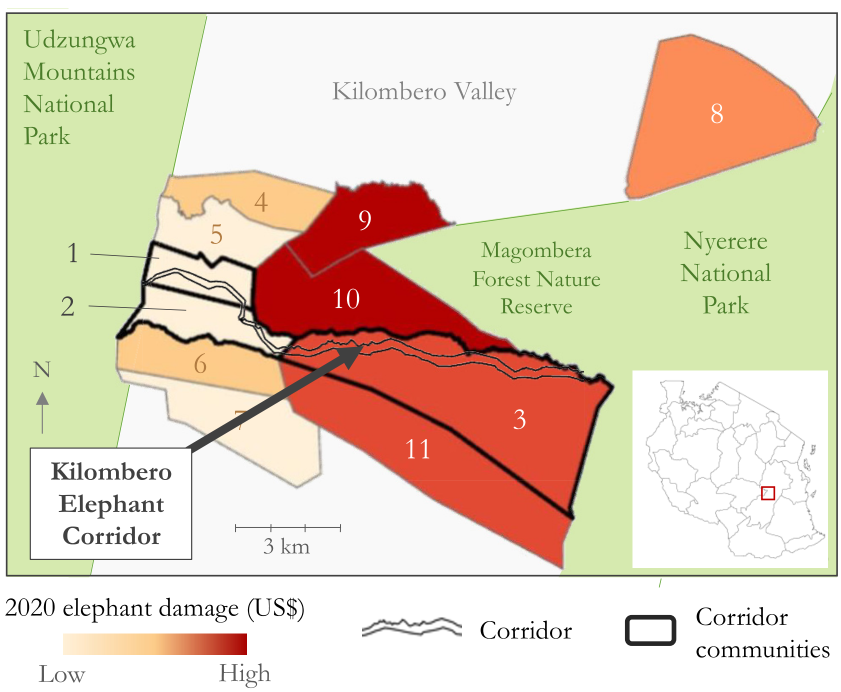
The 174-hectare corridor will feature an electric fence and road and rail underpasses, spanning a narrow 13 km route across the Kilombero Valley through three communities (Kanyenja, Mang'ula A, and Sole villages) (Figure 1). During 2022–23, all households identified as contributing small parcels of land to the corridor were compensated by the Government of Tanzania, using donor funds. All compensated landowners received financial training and are being included in local microfinance groups. Participating villages are also receiving annual conservation payments. The primary long-term benefit to local farmers is expected to be reduction of crop loss from elephants. Since this HEC mitigation benefit is expected to extend beyond the three corridor communities (as managing elephant movement across the valley is also expected to reduce elephant damage on neighboring village land), we broaden the study area to a "corridor landscape" comprising 11 villages.

As well as HEC mitigation, the project is expected to support wider connectivity between Tanzania's southern and western elephant metapopulations and to improve elephant population health in neighboring protected areas by restoring migration routes, gene flow, and dispersal feasibility, while also generating connectivity benefits for a range of other species (Epps et al., 2011; Jones et al., 2012). It is also expected to increase the provision of ecosystem services, such as climate regulation and erosion prevention, by converting existing cropland to a mixture of forest and grassland.

2.2 | Perspectives and standing

To explore distributional considerations, we used three perspectives—a global conservation perspective, a landscape community perspective (11 communities), and a corridor community perspective (three communities contributing land to the corridor). This allowed us to assess not only whether the project represents a sound conservation investment, but also how it might be perceived by local communities.

The issue of standing refers to the question of whose costs and benefits to count. In the conservation perspective, we included all costs and benefits of the project, including all establishment, maintenance, and opportunity costs, plus benefits relating to elephant population health, HEC mitigation, and ecosystem services. In the



#	Community	Elephant damage (2020)
Corridor communities		
1	Sole	$0
2	Mang'ula A	$0
3	Kanyenja	$26,962
Wider landscape communities		
4	Mkula	$223
5	Sonjo	$0
6	Mang'ula B	$193
7	Mwaya	$0
8	Msolwa Station	$2,038
9	Magombera	$43,767
10	Katurukila	$48,162
11	Msalise	$34,462

FIGURE 1 Current elephant damage in the landscape around the proposed Nyerere Selous-Udzungwa Wildlife Corridor. The proposed corridor will re-establish connectivity between the Udzungwa Mountains National Park, Magombera Forest Nature Reserve, and Nyerere National Park via the Kilombero Valley, passing through three "corridor communities" of Sole, Mang'ula A, and Kanyenja. We also consider a further eight communities expected to be affected by the corridor, making up an 11-community "corridor landscape." The total value of elephant damage in each community in 2020 is shown, based on STEP human–elephant conflict (HEC) data.

community perspective, however, we focused only on the community-specific benefits of HEC mitigation (informed by STEP consultations with community members on their priority concerns relating to the corridor). While we recognize that this may overlook conservation values held by the communities, we assumed that most conservation benefits (e.g., the existence value of elephants, or carbon sequestration benefits of forest restoration) accrue nationally and globally.

We compared community benefits not only to the total cost of the project but also to a subset of opportunity and maintenance costs since these may be considered a more reasonable threshold of community contribution to the project. In other words, we asked whether the expected local benefits might justify communities giving up land and contributing to ongoing corridor upkeep.

2.3 | Costs

All cost data were taken from the project budget in STEP (2018). Direct costs were divided into the categories recommended in Iacona et al. (2018) (labor, capital, consumables, and overhead) and presented in 2020 US dollars (Appendix S3). The estimated establishment costs of the NSUWC are just over $2 million, including (a) labor ($399,000, including village game scout salaries, data collection efforts, corridor patrolling and monitoring, and per diems for meetings), (b) capital ($807,000, including 12 km of electric fencing on each side of the corridor, road construction, highway and rail underpasses, vehicles, and habitat restoration) (c) consumables ($275,000, including consultancy and legal fees, fuel, and office equipment), and (d) overheads ($568,000, including organizational costs of STEP and partners). These are spread over a 5-year project, with the corridor being operational from year 3. Maintenance costs are estimated at 6% of construction costs—$7188 per year beginning in year 3 and continuing indefinitely. The replacement cost of infrastructure is expected to be $199,808 every 30 years.

We define opportunity cost of land as the potential income in the counterfactual scenario whereby communities continue to farm the corridor land (Appendix S4). The opportunity cost of land was used in both the conservation and community perspectives to understand the value of land required to be set aside for the corridor. We estimated this using a 2019 Kilombero District land use survey over a 20-hectare sample of corridor (12% of the total area), which found current land use to be predominantly agricultural, with the most common crops being sugarcane followed by bamboo, oil palm, mango, and bananas. Potential agricultural revenue in the area was calculated by multiplying the area planted to each crop in the sample by productivity estimates and price data from Kilombero District Government and FAOSTAT to arrive at sample area revenue, before extrapolating to the wider corridor area. To estimate profits (i.e., remaining revenue after subtracting production costs), assumptions were drawn from the literature on smallholder agriculture profitability in Tanzania (see Appendix S4). The resulting potential annual returns to agriculture in the corridor area (opportunity cost of land) amounted to $73,773 per year.

2.4 | Benefits

Benefits of the corridor include tangible benefits associated with reduced elephant crop damage in communities across the landscape, intangible benefits of reduced human–elephant interaction in and around the communities, increased value of ecosystem services within the corridor area resulting from land restoration efforts, and elephant tourism revenues and existence values associated with improved elephant population health in neighboring protected areas. While all benefits were counted in the conservation perspective, only the benefits of reduced HEC were counted in the community perspective, on the assumption that this is the primary concern of community members.

Tangible HEC benefits were defined as the value of elephant crop damage avoided because of the corridor, relative to the counterfactual of crop raiding continuing at current rates (Appendix S5). While limited data exist on the behavioral response of elephants to corridors, evidence from the Mount Kenya Elephant Corridor (similar to the NSUWC in terms of its physical attributes, social-ecological context, and objectives) suggests that effectively managing elephant movement between protected areas can lead to significant reductions in HEC in nearby communities (S. Weeks, personal communication, October 13, 2021).

We estimated the potential for reduced elephant damage using data on current damage levels gathered by STEP in 10 of the 11 communities in the corridor area in 2020 (one community, Msalise, did not participate). Data were collected through a combination of twice-weekly surveys by local enumerators (paid by STEP to routinely survey elephant activity on village land) and direct community reporting to STEP. Data on each damage incident include details of the crop or tree affected, area damaged, and extent of damage within that area. These data were combined with the data on productivity and crop prices described above to monetize losses. Elephant damage in Msalise, for which no data were available, was modeled by assuming the community experienced comparable levels of damage to its neighbors, scaled by the number of households in each community.

Total elephant damage across the 11-community landscape in 2020 was estimated at $155,807. While data prior to 2018 are not available, STEP staff working in the valley since 2009 report substantial crop losses in the area in each of the last 10 years. In addition, data collected since 2018 reveals a steady annual increase in elephant crop damage in the corridor area between 2018 and 2022. We conservatively assumed that future elephant damage would be comparable to 2020 in the without-corridor scenario.

Finally, a maximum avoidable annual crop damage of $154,838 was estimated by removing the 174-hectare corridor from the calculations (since the land will no longer be cultivated). While STEP monitoring was assumed to be close to a census of elephant damage in the area, the potential for underestimation is considered in the sensitivity analysis (below).

Intangible benefits of the corridor were defined as the reduced intangible costs of human–elephant interactions resulting from the corridor, compared with the same counterfactual level of HEC outlined above. Intangible benefits include reduced fear and stress associated with elephants, reduced time spent guarding crops, increased safety while walking at night, and avoided injury or death resulting from elephant interactions (Barua et al., 2013; Kansky et al., 2014).

While no data exist on the monetary value of such effects, several studies have found intangible costs to outweigh the tangible costs of living with wildlife, including with elephants specifically (Jacobsen et al., 2021; Kansky et al., 2016; Saif et al., 2020). We, therefore, included a conservative estimate that the annual value of intangible benefits may as much as equal the tangible benefits described above. However, given the uncertainty around this nascent research area, we present results with and without intangible benefits.

We modeled ecosystem services values (ESVs) by assuming that the corridor land will undergo a transformation from predominantly cropland to a 50%–50% split of grassland and forest, based on the corridor's habitat restoration plans (STEP, 2018) (Appendix S6). Monetary values of annual ecosystem service flows from each of these biomes were drawn from the Ecosystem Services Valuation Database (Foundation for Sustainable Development, 2021). Summing the average global value of each of the 22 ecosystem services included in the database for each biome gave values of $9174/hectare/year for forests and $6500/hectare/year for grassland. Forest values are primarily made up of erosion prevention, maintenance of life cycles, and climate regulation, while grassland benefits primarily related to soil fertility, air and climate regulation, and esthetic values.

Food production services were removed from the cropland values as they are already included in the opportunity cost of land calculations, leaving a residual ESV of $1261 per hectare per year (primarily relating to pollination and biological control) (Costanza et al., 2014; Power, 2010). We assumed that following the planned corridor landscape restoration efforts, converting cropland to the full ecosystem service provision of a new biome will take 30 years for grassland (Mbaabu et al., 2020) and 40 years for forests (Philipson et al., 2020).

Given the lack of evidence on the impact of corridors on elephant populations, we considered potential elephant population effects in the context of observed recent and potential growth rates and the carrying capacity of the system (Appendix S7). We assigned monetary values using a Total Economic Value framework, counting strictly non-consumptive values (i.e., not hunting), including potential tourism revenues and existence values (the value associated with simply knowing that a species exists) (see, e.g., TEEB, 2010).

The Selous–Mikumi elephant population growth rate (including Nyerere National Park, on the east side of the corridor) is estimated at 0.5% per year—a marked stabilization since the poaching crisis of 2006–2011, but significantly below the potential growth rate of the species, observed at 7% per annum in Tanzania's Tarangire National Park (Foley & Faust, 2010; TAWIRI, 2019). Less is known about the Udzungwa National Park population, but estimates based on several years of observations in the park place it at 500–1000 individuals (T. Jones, unpublished data).

We estimated the total elephant habitat on either side of the corridor at 87,000 km^2 and an associated carrying capacity of 104,572 individuals, based on a maximum population density of 1.2 animals/km^2 (Armbruster & Lande, 1993). At the current growth rate, it would take over 400 years for the current population to reach the carrying capacity of the system, compared with just 30 years at the maximum observed growth rate of 7%. Given the uncertainty around population effects, we explored the potential impact of the corridor using a series of conservative 0.001 percentage point increments above the current growth rate, whereby adding 0.001% to the growth rate would lead to 25 additional animals after 100 years, 52 additional animals at 0.002%, and so forth. Future evaluation of the corridor should seek to refine these estimates.

To attach monetary values to these figures, we took estimates from a 2008 review of elephant economic valuations, which found annual per-elephant values of $1562 from tourism (based on tourism revenues in Kenya) and \$4420 associated with existence value (based on the stated willingness to pay for elephant conservation in European and American households) (Blignaut et al., 2008). Inflating these figures to 2020 US\$ gave values of \$1923 (tourism) and \$5443 (existence) respectively, or a combined value of \$7366 per elephant per year. Applying this to the incremental growth rates above, we see that the 25 additional animals associated with a 0.001 percentage point increase in the growth rate would ultimately be worth over \$180,000/year by year 100.

2.5 | Time horizons and discounting

The choice of time horizon and discount rate (the relative weight assigned to values in the future versus values today) is one of the most debated and subjective aspects of CBA, particularly for environmental projects with very long time horizons (Atkinson & Mourato, 2008). The higher the chosen discount rate, the stronger the preference for faster payoffs. Future values are discounted to arrive at present values using the formula

$$\mathrm{PV} = \mathrm{FV}/(1+r)^{Y},$$

where PV is the present value, FV is the future value, r is the discount rate, and Y is the years into the future.

We used different timeframes and discount rates for our different CBA perspectives, reflecting different stakeholder preferences. Specifically, we assumed that local communities have a shorter-term outlook and more urgent preferences for faster payoffs than global conservation stakeholders, given the high degree of risk and uncertainty associated with rural agricultural livelihoods in the tropics (Cohn et al., 2017). For the conservation perspective, we used a 100-year outlook, following best practice on the use of extended time horizons for environmental projects with significant long-term effects, along with declining discount rates of 3.5% for years 1–50 and 2.5% for years 51–100, intended to place greater emphasis on long-term results (Boardman et al., 2018; O'Mahony, 2021).

For the community perspective, we used a 30-year outlook with a 10% discount rate, based on the expected useful life of the infrastructure before replacement is required, as per best practice in CBA for infrastructure projects (O'Mahony, 2021). The 10% discount rate aligns with those commonly used in international development programming (Bonzanigo & Kalra, 2014).

All annual costs and benefits were discounted to present value 2020 US\$ and summed to give total present value costs and benefits, before calculating the benefit-to-cost ratio, with any result greater than 1 being considered a worthwhile investment.

2.6 | Sensitivity analysis

As a decision tool used to appraise projects prior to implementation, CBA can involve a significant degree of uncertainty around future cost and benefit projections, particularly in long-term environmental projects (OECD, 2006). To address this, we conducted sensitivity analysis on a range of key variables to understand their influence on the overall CBA outcome.

On the cost side, we varied the opportunity cost of land by ±10%, reflecting uncertainty around future profitability of alternative uses of the land. On the benefits side, we explored the potential for the baseline level of elephant damage to be 10% and 20% higher than that captured in STEP's reporting. We also present a range of scenarios for the corridor's potential to mitigate this damage, from 0% to 100% damage reduction. We similarly present a range of elephant population effects from no effect through a series of 0.001 percentage point increments in the population growth rate.

A summary of assumptions and inputs under each scenario is presented in Table 1.

3 | RESULTS

3.1 | Conservation perspective

From a global conservation perspective, the benefit: cost ratio ranges from 4.6 to 6.8, suggesting that the project should justify its costs over a 100-year outlook (Table 2). With a present value of \$20.7 million, the ESV benefits alone are nearly five times the \$4.5 million present value of costs. Judged on HEC benefits, a 40%–50% reduction in HEC would be sufficient to cover the project costs irrespective of other benefits (although a 90% HEC reduction would be required if intangible HEC benefits are excluded).

In terms of elephant population effects, each additional 0.001% added to the growth rate (equivalent to 25 additional animals after 100 years compared with the counterfactual) adds around \$1.5 million to the present value of benefits. Adding a little over 0.003 percentage points to the population growth rate (75 additional animals after 100 years) would more than justify the costs of the corridor irrespective of any other benefits.

Overall, while there is little evidence upon which to make confident forecasts of HEC and elephant population effects, even modest improvements in either of these

TABLE 1 Summary of CBA assumptions and input values.

Factor	Value[a]
Time horizon	Conservation perspective: 100 years Community perspectives[b]: 30 years
Discount rate	Conservation perspective: 3.5% (Y1-50), 2.5% (Y51-100) Community perspectives: 10%
Costs	
Establishment cost	$2,048,800 (years 1–5)
Labor	$399,101
Capital	$806,588
Consumables	$274,922
Overhead	$568,189
Maintenance cost	$7188/year (from year 3)
Opportunity cost of land	$73,773/year (whole corridor area)
Replacement cost	$199,808 (every 30 years)
Benefits	
HEC reduction	
Expected reduction	0%–100%
Tangible HEC benefit value (avoided crop loss)	$0–$25,993/year (3 corridor communities) $0–$154,838/year (11-community landscape)
Intangible HEC benefit value (other avoided HEC costs)	$0–$25,993/year (3 corridor communities) $0–$154,838/year (11-community landscape)
Ecosystem services	
Land conversion	100% cropland—50% forest/50% grassland
Cropland value	$1261/hectare/year
Forest value	$9174/hectare/year
Grassland value	$6500/hectare/year
Total value after restoration	$1,155,473/year (whole corridor area)
Elephant population effects	
Expected growth rate effect	Uncertain; we explore + 0.001 percentage point increments
Elephant value	$7366/elephant/year

[a]All values are justified in the following methods subsections. Dollar values are 2020 US$.
[b]"Community perspectives" refer to both the 11-community landscape perspective and 3-community corridor perspective.

factors, coupled with the wider ecosystem service effects, are likely to justify the project costs from a global conservation perspective.

TABLE 2 Summary of cost–benefit analysis results from the perspectives of global conservation, 11 landscape communities and three corridor communities.

Factor	Conservation perspective (global)	Community perspective (landscape)	Community perspective (corridor)
Costs (present value 2020 US$)			
Establishment	$1,871,069	$1,600,736	$1,600,736
Maintenance	$214,258	$55,286	$55,286
Opportunity	$2,286,025	$679,657	$679,657
Replacement	$113,085	-	-
Total costs	$4,484,438	$2,335,678	$2,335,678
Benefits (present value 2020 US$)			
HEC (tangible)	$0–$4.9 million	$0–$1.5 million	$0–$245,031
HEC (intangible)	$0–$4.9 million	$0–$1.5 million	$0–$245,031
Ecosystem services	$20.7 million	-	-
Elephant population	(Uncertain)[a]	-	-
Total benefits	$20.7–$30.5 million	$0–$2.9 million	$0–$490,061
Benefit: cost ratio	4.6–6.8	0.0–1.2	0.0–0.2
Ex. intangible benefits	4.6–5.7	0.0–0.6	0.0–0.1

[a]From the conservation perspective, a breakeven point based on elephant population benefits alone is achieved if 0.0031 percentage points are added to the elephant population growth rate, resulting in 75 additional animals after 100 years, or $4.5 million in present value benefits.

3.2 | Community perspectives

The present values of all costs and benefits are lower in the community perspective than the conservation perspective due to the shorter time horizon and higher discount rate. Values up to year 30 are more aggressively discounted, and values beyond year 30 are not counted at all. As a result of these effects, the present values of total costs are $4.5 m in the conservation perspective but only $2.3 m in the community perspective—despite the underlying costs being the same.

More importantly, however, the benefit: cost ratios are less favorable since certain benefits (ESVs and elephant population effects) are omitted entirely, making the cost-effectiveness of the corridor from the community perspective depend entirely upon the (uncertain) level of HEC reduction that will be achieved. The implications of this are shown in Figure 2.

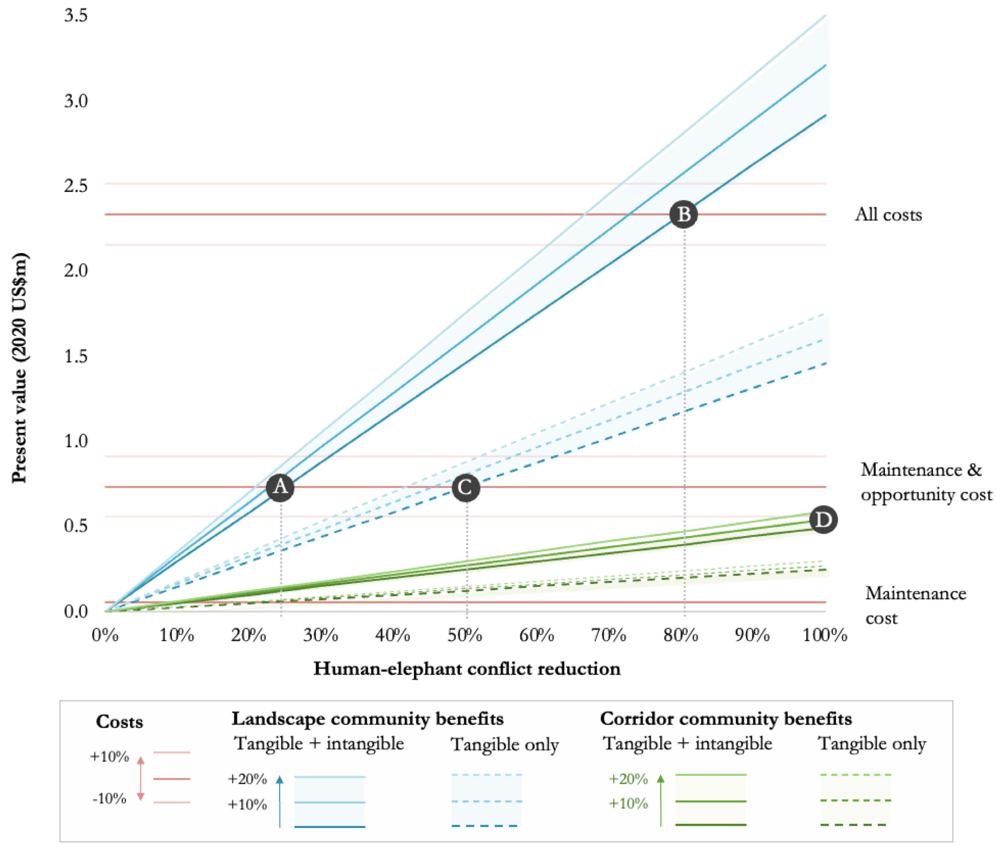


FIGURE 2 Projected community costs and benefits associated with the Nyerere Selous-Udzungwa Wildlife Corridor. At the landscape level, a 25% human–elephant conflict (HEC) reduction would generate enough benefits to cover maintenance and opportunity costs of the corridor (A), while an 80% HEC reduction would cover all costs (B). If intangible benefits are excluded, a 50% HEC reduction is required to cover maintenance and opportunity costs (C), and even a 100% HEC reduction would not cover all costs, necessitating external funding from conservation stakeholders. From the perspective of the three corridor communities, even full HEC eradication is insufficient to cover the maintenance and opportunity costs (D), so substantial external subsidy will be required. Sensitivity analysis is presented for opportunity costs (±10%) and HEC benefits (+10%, +20%).

At the landscape level (11 communities), if both tangible and intangible benefits are considered, a 25% reduction in HEC would justify the opportunity and maintenance costs of the corridor (Figure 2, A), while justifying the entire costs of the corridor would require an 80% reduction in HEC (Figure 2, B). Fully eradicating HEC across the landscape would generate almost $3 m in benefits, giving a benefit: cost ratio of 1.2 (Table 2). If we limit the analysis to tangible benefits only, a 50% reduction in HEC at the landscape level would be required to cover maintenance and opportunity costs (Figure 2, C), but even a 100% reduction in HEC would not justify the full corridor costs.

From the more specific perspective of the three corridor communities, the project costs substantially outweigh the benefits. The benefits of fully eradicating HEC, and counting both tangible and intangible benefits, are valued at $508,000, and a benefit: cost ratio of 0.2 (Table 2)—even at this level, the benefits would fall short of the opportunity cost of land (Figure 2, D).

The full results of the CBA are detailed in Appendix S2.

4 | DISCUSSION

4.1 | Nyerere Selous-Udzungwa wildlife corridor

From a conservation perspective, the expected combination of benefits relating to elephant populations, ecosystem services, and HEC mitigation appears to comfortably justify the costs of the project, notwithstanding the uncertainty in future outcomes. However, since this positive result is largely driven by the ESV benefits, the corridor's effect on elephant outcomes (HEC and elephant population health) will need to be empirically tested once the corridor is operational in order to assess the corridor's cost-effectiveness for elephant conservation specifically. Judged on elephant outcomes alone, the corridor would be considered cost-effective if it achieved either a 40%–50% reduction in HEC, a 0.003% increase in the elephant population growth rate, or some combination of the two.

From the community perspective, the benefit-cost ratios suggest that insufficient incentives exist for the three corridor communities to fund such a project themselves (even if they possess the required resources). In reality, the corridor will be entirely financed from external sources, with participating households being fully compensated for the opportunity cost of land contributed to the corridor. However, if the project is successful in partially mitigating the high levels of HEC in the area, the communities stand to benefit both financially (in terms of avoided crop loss) and through a range of intangible benefits associated with reduced conflict. Delivering on these goals should improve the community's perception of the project. The spillover benefits in neighboring communities should further bolster support for the project in the wider landscape. Developing additional corridor revenue sources for the community (e.g., tourism, carbon finance, agroforestry income) would further lower the threshold for the project's justification.

Finally, while HEC-related deaths and injuries in the corridor were not evaluated due to insufficient data for future projections, two human deaths, and six elephant deaths have been reported in the corridor area between 2019 and 2022 (T. Jones, unpublished data). Under the above CBA methodology, avoidance of six elephant deaths today would be valued at $1.4 million over the 100-year outlook. While valuation of human life is controversial in CBA, it is common practice in many sectors, with the avoidance of a single human death often being valued at multiple millions of dollars (Viscusi & Aldy, 2003 found a median value of $7 million). If the human and elephant deaths from 2019 to 2022 alone could have been avoided by the presence of a fenced corridor, the costs would have been more than justified on these terms.

4.2 | Wider corridor planning

Globally, successful implementation of corridor projects has lagged behind advances in habitat connectivity science, as models of ecologically optimized connectivity come up against complex socioeconomic realities on the ground (Brodie et al., 2016; Correa Ayram et al., 2016). Where projects have succeeded, they have been characterized by an ability to build a common vision and buy-in from diverse stakeholders, and the delivery of socioeconomic benefits for local communities (Keeley et al., 2018). The CBA methodology above can help to identify and prioritize such projects by not only seeking investments with the greatest conservation impact per dollar spent but also balancing this with the interests of local stakeholders.

With reference to Tanzanian corridors specifically, a new national corridor action plan sets out a prioritized list of 61 potential corridor projects across the country, ranked by a combination of conservation value and vulnerability (Ministry of Natural Resources and Tourism, 2022). Conducting CBA on the list of candidate corridors identified in the plan, and specifically incorporating socioeconomic impacts, could help to further prioritize corridor projects that represent the greatest value for money, while also being most likely to meet the success criteria noted in (Keeley et al., 2018). Given the diverse range of corridor contexts, CBA can provide a common metric to compare capital-intensive projects such as the NSUWC (requiring substantial infrastructure and compensation investments in a densely settled landscape) with corridors that face very different types (as well as scales) of costs and benefits (e.g., much larger corridors traversing more sparsely populated areas).

While the methodology presented here is relatively data-intensive, data requirements could be reduced by using satellite imagery to assess prospective land use changes and the associated opportunity costs, compensation payments, and ecosystem service benefits in corridor areas, combined with spatial assumptions on wildlife conflict as used in (Di Minin et al., 2021), and generalized infrastructure costs-per-km depending on corridor type (fenced/unfenced). Such high-level assumptions would decrease confidence in corridor-specific estimates but would serve as a guide for initial prioritization, after which specific projects could be appraised using more site-specific data as demonstrated in the NSUWC case.

4.3 | Wider use of CBA in conservation

Appraising projects using CBA during the design phase can help to ensure that limited funds are directed toward projects that represent the greatest value for money in terms of outcomes generated per dollar spent—a critical concern amidst calls for greater accountability in conservation spending (Adams et al., 2014; Ferraro & Pattanayak, 2006). Moreover, whereas cost-effectiveness analysis and cost minimization exercises require a single narrowly defined outcome (e.g., cost per unit area protected), CBA's common value metric is better suited to the evaluation of (increasingly common) complex projects with multiple social-ecological outcomes, as well as comparisons between projects with different outcomes (Pienkowski et al., 2021). As an evaluation tool, it also lends itself to ready integration within existing planning frameworks that seek to guide conservation interventions within complex social-ecological systems (Schwartz et al., 2018).

From the perspective of local communities, limited conservation resources will be most impactful when local stakeholders support conservation initiatives (Bennett et al., 2019). While such narratives are central to community-based conservation, efforts to date have struggled to deliver on socioeconomic outcomes, and win–wins remain elusive (Adams et al., 2004; Galvin et al., 2018; Salerno et al., 2021). By helping to assess community perceptions of a project, our multi-perspective CBA may be valuable when communicating potential costs and benefits to communities during project design.

While some uncertainties are inevitable at the outset, *ex-ante* CBA can help to guide future project monitoring and evaluation efforts—and associated strategic adjustments—by highlighting the key assumptions on which the success of the project depends. In the NSUWC example, determining through the CBA that a certain level of HEC reduction will be critical for community approval should ensure that this outcome is closely monitored in future, with complementary interventions being deployed as necessary to pursue this goal (Cassidy & Salerno, 2020). Similar principles could apply to projects elsewhere, whereby a range of ecological and socioeconomic impact targets can be set, monitored, and managed based upon an initial CBA appraisal.

Finally, we demonstrate the importance of transparency around the influence of individual cost and benefit components on end results. While developments in quantifying the diverse values of nature increasingly lend weight to arguments for conservation over commercial land uses (Bradbury et al., 2021), many stakeholders are unlikely to be motivated by abstract values unless they can be converted into financial flows through mechanisms such as payments for ecosystem services (Naidoo & Ricketts, 2006). While CBA can incorporate a broad spectrum of values, from agricultural profits to the existence value of species, care must be taken to consider which elements will be prioritized by the target audience, and which are driving the CBA results.

4.4 | Limitations and areas for future research

CBA typically involves a degree of uncertainty around assumptions required to monetize various project elements and forecast them into the future—a challenge exacerbated when estimating outcomes in complex social-ecological systems over long time horizons (OECD, 2006). Our sensitivity analysis seeks to address this uncertainty, and highlights areas for future research, particularly relating to corridor impacts on elephant populations and HEC, for which very limited evidence currently exists.

Other limitations to the NSUWC analysis include assumptions around projecting current observations into the future, particularly with regard to HEC and opportunity costs. While the 2020 snapshot of HEC is considered consistent with broader trends, our assumption that future years will see similar levels of conflict as in 2020 may underestimate the intensification of conflict reported from the project site—crop damage rates were higher in 2021 and comparable to 2020 levels in 2022 (T. Jones, unpublished data)—which would, in turn, underestimate the potential HEC mitigation benefits of the corridor. Similarly, current economic activity in the landscape may be an underestimate of future opportunity costs, particularly if more financially profitable land use options become feasible in future due to, for example, increases in agricultural productivity or the emergence of higher-value economic activities in the manufacturing and service sectors. In the latter case, corridor benefits relative to the counterfactual would be overestimated in the analysis. Finally, while a growing number of studies find intangible costs of human-wildlife conflict to outweigh tangible costs, more work is required to quantify these effects (Kansky et al., 2016).

More generally, CBA for conservation remains challenged by a lack of data (particularly location-specific data) on monetary values for conservation variables, such as the existence value of certain species, the intangible costs of living with wildlife, and the value of ecosystem services (Turner et al., 2003; van de Water et al., 2022). More work is needed to develop site-specific non-market valuation estimates and to make these readily available to researchers and practitioners for input into analysis. This is particularly true for local community values, especially for non-market social phenomena in complex social-ecological systems (e.g., attitudes toward nature). In our CBA, for example, we acknowledge that our reliance on Western existence values of elephants, and our choice to limit community benefits to those related to HEC reduction, likely overlooks local community values associated with elephant conservation or values and benefits associated with nature and benefits from local ecosystem services, potentially leading to underestimation of community benefits from the project (Milheiras et al., 2022). More broadly, while much progress has been made in incorporating nature values into economic analysis in recent years, concerns remain around subjectivity, incommensurability, uncertainty, and "putting a price on nature", all of which require further work to address both technical and philosophical barriers (Sukhdev et al., 2014).

CBA always involves a degree of simplifying assumptions in deciding which costs and benefits to count (Boardman et al., 2018). While our focus is on HEC-related benefits from the community perspective in the corridor area, we recognize that local perceptions of conservation projects may be subject to a broader range of complex determinants. For example, while we have characterized HEC reduction as a benefit to communities, HEC may be perceived by communities as a cost that conservation actors are responsible for addressing, given their work to promote elephant population health in nearby areas. Similarly, we recognize that community costs, and specifically the opportunity cost of land, may be driven by more than the commercial earning potential of the land, including factors such as place-based attachment to landscapes. Future research should seek to better understand the values and perspectives of local communities in relation to conservation initiatives and to quantify and monetize these where possible to enable the incorporation of complex non-market factors into CBA and conservation decision-making. Given the controversies around choice of time horizon and discount rate in environmental CBA (OECD, 2006), further work is also required to build consensus and establish common guidelines within the conservation field on which parameters to use in which circumstances.

The lack of published CBA analyses in the field means that while this individual project appears to justify its costs (from a global conservation perspective), it is hard to say whether it is the best use of funds relative to other potential options. In future, increasing use (and publishing) of CBA in conservation should enable benchmarking of estimated benefit/cost ratios against comparators when deciding whether a proposed project represents good value for money.

Finally, it should be noted that while CBA can provide useful information, it should not be the final say in decision-making. Other critical aspects such as stakeholder consultation, free, prior, and informed consent, recognition of land and resource rights, and conflict resolution and grievance mechanisms all have important roles to play alongside any economic analysis.

Overall, while continued work is needed to overcome both the technical and philosophical barriers to mainstreaming CBA in conservation, recent developments in areas such as non-market valuation of environmental benefits are making it an increasingly viable tool whose application could be central to helping limited budgets deliver against global conservation goals.

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DATA AVAILABILITY STATEMENT

Data sharing is not applicable to this article as no new data were created or analyzed in this study.

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SUPPORTING INFORMATION

Additional supporting information can be found online in the Supporting Information section at the end of this article.

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