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LETTER

How pastoralists weight future environmental benefits when managing natural resources

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Abstract

Natural resource management involves balancing benefits and costs that accrue through time. How individuals and local communities weight such tradeoffs can profoundly influence how they use and conserve resources. Our goal was to understand time preferences of future benefits for goods that are relevant for developing effective conservation strategies. We surveyed >500 Fulani in Benin about their time preferences regarding financial, ecological, and agricultural goods, summarizing these in the form of discount rates. In a discrete-time, constant annual form, our results were much higher (median: 150%) than values often discussed in literature. These discount rates declined through time; people valued the future more than would be assumed based on constant discounting. Discount rates were higher for financial goods than ecological or agricultural goods. We illustrate how our estimates of discount rates change recommendations for optimal management of forest resource harvesting in the tropics. While members of this grazing community discount future benefits at a high rate, they do so in ways that contrast with conventional economic theory and favor long-term use of nontimber forest products.

KEYWORDS

common property, conservation planning, discount rates, dual-rate, hyperbolic, intergenerational, intertemporal, nontimber forest products, optimal control, West Africa

1 | INTRODUCTION

Sustainable management of natural resources involves making an investment for the future with the promise of long-term ecological benefits offsetting near-term opportunity costs. These benefits can include greater ecosystem services, such as increased clean drinking water, recreational opportunities, and ability to cope with natural disasters (IPBES, 2019). Developing optimal conservation strategies for natural resources involves evaluating benefits and costs associated with providing ecosystem services both now and in the future because these benefits often accrue through time (World Bank, 2006).

Discount rates are used to compare costs and benefits that accrue through time (e.g., future harvests versus income today) by converting the value of future goods into present value equivalents. A positive discount rate indicates the future good is valued less than the present

(Cropper, 2012; Lampert, 2019). Discount rates can influence conservation efforts, such as the amount of land restored or conserved (Mazziotta et al., 2016; Verdone & Seidl, 2017), timing of mitigation (Sjølie, Latta, & Solberg, 2013), where to protect land for conservation (Armsworth, 2018), and harvest strategies (Hernández-Barrios, Anten, & Martínez-Ramos, 2015; Lundström, Öhman, Rönnqvist, & Gustafsson, 2016). Many such conservation projects must undergo a cost–benefit analysis. These analyses are highly sensitive to chosen discount rates (Weikard & Zhu, 2005). A small change in the discount rate may alter estimated costs of restoration and conservation by billions of dollars (Gren, Nyström Sandman, & Näslund, 2018). Despite the influence of discount rates on project appraisals, few projects assess their sensitivity to their chosen discount rate (Bonzanigo & Kalra, 2014). Using locally estimated discount rates allows a more accurate representation of the future costs and benefits as valued by local resource users and therefore more relevant analyses of how those individuals make decisions.

There are surprisingly few estimates of discount rates that local resource users employ when weighting benefits and costs through time. In a review of studies on elicitation of discount rates, 83% of all studies were conducted with university students or the general public (Cohen, Ericson, Laibson, & White, 2016). The focus of discounting studies has recently begun to broaden, making heterogeneity in individual choices more apparent. Personal demographics such as age (Attema, Bleichrodt, L'Haridon, Peretti-Watel, & Seror, 2018; Kumar & Kant, 2019) and respondents' country (Wang, Rieger, & Hens, 2016) can explain, in part, differences in individual discount rates. Individuals also discount different domains (e.g., health, financial, environmental) at different rates (Hardisty, Thompson, Krantz, & Weber, 2013; Ubfal, 2016). Hence, our goal was to understand if and how local people discount future benefits when subject to the constraints they face in situ. We sought to do so for goods that are relevant for developing effective conservation strategies.

We studied how traditional resource users perceive benefits and costs through time. To estimate discount rates, we surveyed communities of pastoralists in West Africa, the Fulani, who rely heavily on nontimber forest products (NTFPs) for fodder for their livestock (Gaoue & Ticktin, 2009). To illustrate how our findings would change management prescriptions, we integrated our estimated discount rates into a model for optimizing harvest rates of African mahogany, *Khaya senegalensis*, an emblematic plant species of conservation concern. This application illustrates the importance of using local discount rates while evaluating conservation strategies.

2 | METHODS

2.1 | Study system

Benin has high levels of biodiversity (Miller, Minn, & Sinsin, 2015). Yet, habitat and forest loss has been estimated at 50,000 ha/year (FAO, 2011), largely attributed to land clearing for agriculture and illegal timber and charcoal production. (Lokonon et al., 2019). In eight villages in Benin, we conducted surveys with Fulani, traditional pastoralists (Figure 1). Increased droughts and extreme weather events, in addition to competition with increased agriculture and logging, are causing Fulani to live more sedentary lives (Gaoue & Ticktin, 2009; Heubach, Wittig, Nuppenau, & Hahn, 2011). Despite their changing lifestyles, many Fulani do not own land. Instead they rely on public resources, often operating inside commons-like grazing systems.

On average, NTFPs contribute 53% of Fulani's income (Heubach et al., 2011), creating an intricate link between these communities and their natural resources. As a result, these communities face direct and tangible tradeoffs between financial and ecological costs and benefits through time. Also, perceptions about the distant future in many traditional African cultures are distinct from those in western societies (D'Exelle, van Campenhout, & Lecoutere, 2012), where the majority of literature on time preferences has occurred (Cohen et al., 2016).

We used *K. senegalensis*, a native, culturally important species in Benin to exemplify the impact of discount rates on conservation decisions because (1) it is listed as vulnerable by IUCN and is of high concern for conservation by local communities (Lokonon et al., 2019); (2) its high timber value causes ongoing illegal harvest; (3) Fulani selectively harvest its NTFPs, especially during the dry season, for medicinal purposes, including to treat malaria, and for their livestock (Gaoue & Ticktin, 2009; Houehanou, Assogbadjo, Kakaï, Houinato, & Sinsin, 2011); and (4) discount rates for slow growing species has been central to discounting debates (e.g., Clark, 1973).

We conducted 503 surveys. We used 481 surveys because 22 were incomplete. We conducted 201 surveys in a drier region, 99 surveys in a wetter region, and 181 surveys in a climatic transition zone. The median age was 43 (range 18–90) with only 16 females, reflecting cultural mores within which we were working. Of our respondents, 92% had no formal education and 47% owned or leased land.

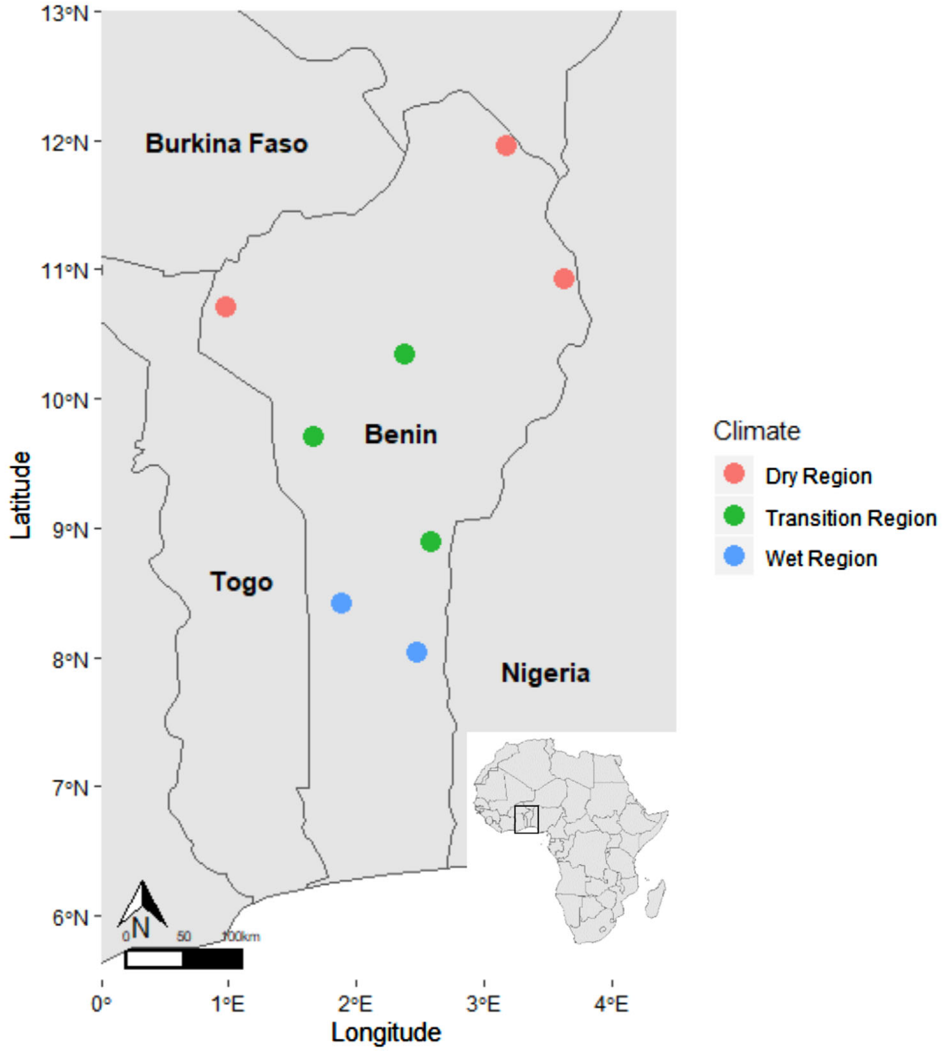

FIGURE 1 Map of study area with village locations. Villages in the drier region of Benin are in red, those in the wetter regions in Benin are in blue, and those in the transition region between the two ecological regions are in green

2.2 | Survey methods

We used verbal choice-based surveys (Hernuryadin, Kotani, & Kamijo, 2019; Ubfal, 2016). Subjects faced hypothetical paired choices of gains tomorrow versus gains to be received next month, next year, and in 3 years. We used fixed-sequence titration methods for each set of discount-rate-related questions (Hardisty et al., 2013). If the respondent always chose the near-term option, we asked at what amount, if any, would they choose the latter option (Appendix S1). Our approach, although common (e.g., Hardisty et al., 2013; Hernuryadin et al., 2019), involves many assumptions (e.g., narrow bracketing), and we recognize alternate designs are possible (Table S1).

We repeated our survey questions for financial, ecological, and agricultural goods. We used fodder from harvestable trees and cows, in biophysical units, to determine ecological and agricultural discount rates, respectively. Subjects were also asked demographic questions (Appendix S1).

2.3 | Functional form for discounting

We calculated discount rates using an exponential specification of time preferences. A subject would be indifferent between two benefits if:

$$V = F \times e^{-\delta_i t},$$

$$\delta_i = -\frac{1}{t}\ln\left(\frac{V}{F}\right), \qquad (1)$$

where V is the present value, F is the future amount, t is the time delay, and δ_i is the individual's discount rate for a

TABLE 1 Ecological model. Additional details and parameter values are provided in Appendix S4

State equations	
Density of plant species $\frac{dx(t)}{dt} = r(t)x(t)(1 - \frac{x(t)}{K}) - E_l(t)x(t)$	
Intrinsic growth rate of plant $\tau \frac{dr(t)}{dt} = r_e - r - \alpha E_n - \beta E_l$	
Notation	Description
$x(t)$	Density of *K. senegalensis* at time *t* (a state variable)
$r(t)$	Intrinsic rate of *K. senegalensis* at time *t* (a state variable)
K	Carrying capacity for *K. senegalensis*
E_n	Rate of effort for nontimber harvest at time *t*
E_l	Rate of effort for timber harvest at time *t*
r_e	Maximum growth rate of *K. senegalensis*
τ	Average lifespan of *K. senegalensis* in years
α	Growth decay rate for nontimber harvest
β	Growth decay rate for timber harvest

specific good. Other choices of functional form to represent discounting are also possible (Appendix S2).

2.4 | Empirical analysis

We assumed each respondent's indifference point was the midpoint of the interval between the questions at which they switched to the delayed option (Hardisty et al., 2013; Johnson & Saunders, 2014). Once we determined indifference points for individuals at each timeframe for each good, we calculated their discount rates (Equation 1). Some respondents said they would always choose the near-term option, implying infinite discount rates (see also Kumar & Kant, 2019). Respondents having infinite discount rates are consistent with economic theory for use of common-pool resources (Hartwick & Yeung, 1997). Others sometimes answered with zero or negative discount rates, again to be expected whether based on theory (Baumgärtner, Klein, Thiel, & Winkler, 2015) or cultural beliefs.

We used generalized linear mixed model with a rank transformation to compare discount rates across timeframes and domains. We then incorporated effects of the climate of the respondent's village, their age, and whether they own or lease lands. Both models incorporated two random error terms to account for heterogeneity across individuals and an individual specific error term to account for the heterogeneity within an individual's responses (Appendix S3). We undertook robustness tests using several alternative specifications (Table S5).

2.5 | Optimization model

To demonstrate the importance of discount rates, we integrated our results into a model that aims to identify optimal harvest rates for *K. senegalensis*. Specifically, we adapted a model for timber and nontimber harvesting from Gaoue, Jiang, Ding, Agusto, and Lenhart (2016). The model accounts for growth of populations, while assuming the intensity of nontimber harvest affects the intrinsic growth rate of the species (Table 1, see also Gaoue et al., 2016). The model assumes a management goal of maximizing net profits that accrue for local human populations from timber and nontimber harvesting, while also assigning a conservation value to maintaining a standing stock of *K. senegalensis* in an open access system. Managers are assumed to maximize the objective:

$$J\,(E_l, E_n) = \int_0^T e^{-\delta(t)t}\,(B_1 E_l\,(t)\,x\,(t) + B_2 E_n\,(t)\,x\,(t) - C_1 E_l\,(t) - C_2 E_n\,(t) - C_3 E_l^2\,(t) - C_4 E_n^2\,(t) + Ax\,(t))dt, \quad (2)$$

where E_l is effort for timber harvest, E_n is effort for nontimber harvest, A is the weighted value of conservation, B_1 and B_2 are aggregate parameters that include prices from the two types of harvest, and C_1 and C_2 describe the cost (including time-cost) of each day of effort spent harvesting timber and nontimber, while C_3 and C_4 are an adjustment to this cost reflecting the fact that marginal costs of each day of harvesting effort may increase the more effort that is being deployed for both timber and nontimber harvesting respectively. We use this model to explore how assumptions about the discount rate $\delta(t)$ would change recommended optimal harvesting strategies.

We compare optimal harvest strategies using survey results with (1) a single, constant discount rate at the median obtained for the financial domain (Gaoue et al., 2016); (2) a single, constant discount rate at the median obtained for the ecological domain; and (3) constant, dual-discount rates using the median values for the financial and ecological domains (Armsworth, 2018). To implement dual-rate discounting, we apply a separate discount rate to the conservation value term (A, Equation 2) and another for valuing harvest income (Appendix S4). Finally, we consider (4) a single discount rate that declines through time paralleling survey results in the ecological domain (Appendix S4). In Equation 2, $\delta(t)$ is the single discount rate applied, which was assumed constant through time for versions 1 and 2, but declined through time for version 4. We used Pontryagin's Maximum Principle to transform the resulting optimal control problem into a boundary value problem, which we solved numerically using forward and backward sweeps in Matlab, version R2019a (Lenhart & Workman, 2007, Appendix S4).

3 | RESULTS

Were we to use a discrete time, annual representation of the discount rate, our median value would be 150%, much higher than the 0–20% range often discussed in the literature. These high discount values correspond to a halving of value in ~8.8 months for the financial domain, ~18.9 months for fodder (ecological domain), and ~13.6 months for cattle (agricultural domain) (Table 2). A total of 168 (34.9%) respondents reported that no amount of goods in the future would make them choose the later-term option for at least one good, implying that they have infinite discount rates.

Delay, domain, and delay-domain interaction were all significant ($p < .0001$; Figure 2; Appendix S3), something that continues to apply if the models are also run without infinite responses (Table S5 for robustness checks). Discount rates decreased through time for all domains, meaning that when considering events in the more distant future, individuals discount less. Moreover, when comparing across domains, respondents discounted

TABLE 2 Statistics for respondents' discount rates in all three domains: Financial, ecological, and agricultural

Good	Number of respondents	Number of respondents with infinite discount rates for at least one timeframe	Median (IQR)	1-Month median (IQR)	1-Year median (IQR)	3-Year median (IQR)
Money	481	144	0.95 (0, 4.87)	11.00 (0, 20.46)	0.96 (0, 2.17)	0.46 (0, 0.95)
Fodder	481	138	0.44 (−0.04, 3.91)	4.87 (0, 18.05)	0.32 (−0.29, 1.48)	0.19 (−0.04, 0.64)
Livestock	481	114	0.61 (0, 2.67)	2.67 (0, 9.73)	0.41 (0, 1.5)	0.44 (0, 0.77)

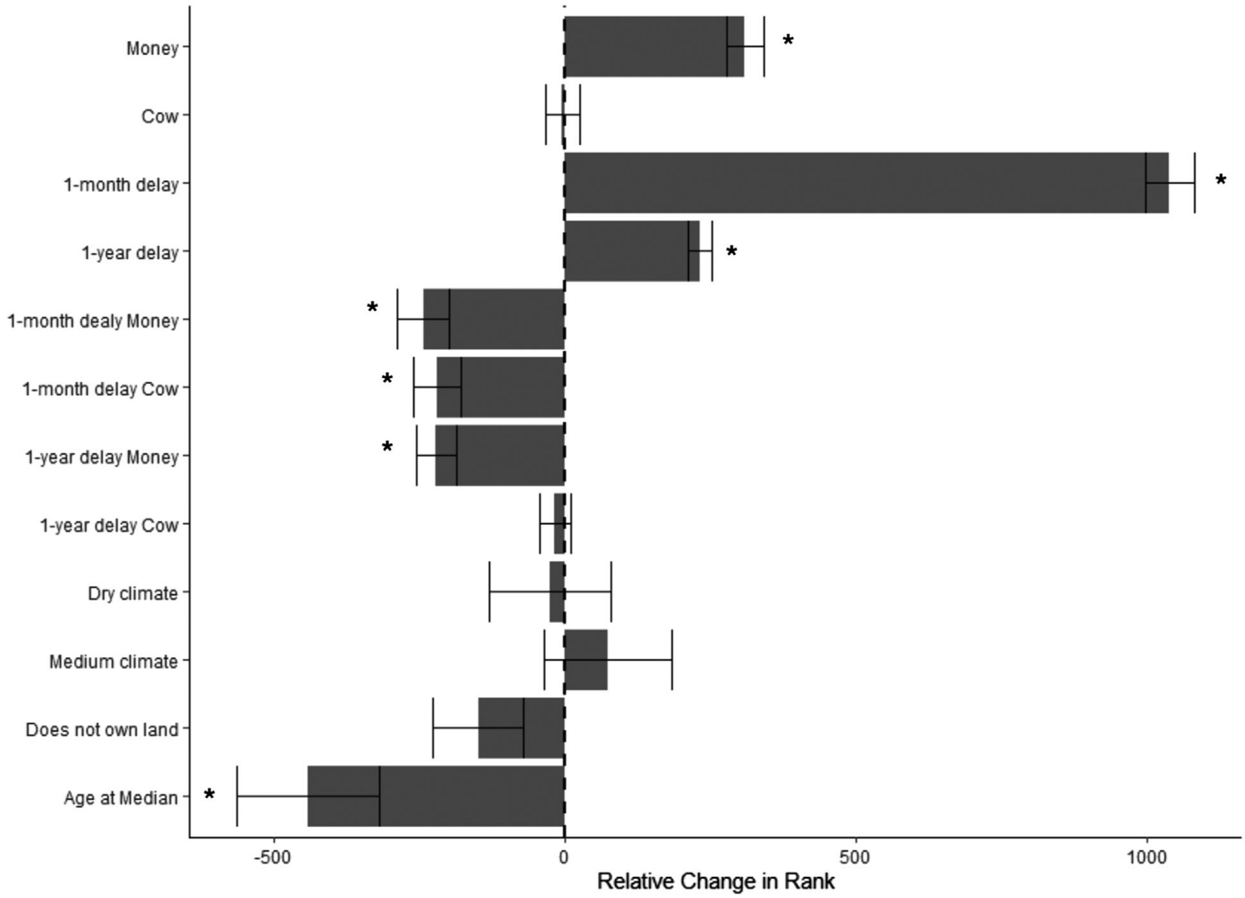

FIGURE 2 Comparative rank coefficients for discount rates for three timeframes (1 month, 1 year, 3 years) over the three domains, cows, money, and trees. Trees, 3-year delay, owning land, and wetter region were reference categories for the model. Age was set to 43, the median age. The bars with an asterisk are significantly different ($p < 0.05$) than the respective reference category

financial amounts significantly more than they would in other domains. Respondents who leased or owned land had marginally significantly higher discount rates ($p = .0586$); older respondents had significantly lower discount rates ($p < .001$); and climatic zone was not significant (Figure 2, Table S4).

3.1 | Optimization models

The optimization models make clear that the variation in discount rates we observed can profoundly affect management recommendations for timber and nontimber harvesting of tropical trees. Our first model uses a single constant discount rate at the median for financial discounting (Figures 3A–C, S1). For this case, there is an initial pulse of timber harvesting and accompanying crash in population size, before timber and nontimber harvesting are abandoned (Figures S1, 3A–C); that is, with high discount rates, sustainable harvest of this slow-growing tree would not be economically efficient. In contrast, when using the lower fodder, median discount rate, nontimber harvesting effort gradually expands through time, while timber harvest is not sustained (Figures S1, 3A). The expansion in nontimber harvesting results in a reduction in the growth rate of remaining trees (Figure 3C). Finally, with dual-rate discounting, nontimber harvesting again increases to begin with, but is abandoned as the conservation value of standing mahogany comes to dominate its harvesting value, resulting in the largest density and growth rate of trees (Figure 3A–C).

We also compare recommendations when assuming a constant discount rate with recommendations if discount rates decline through time as observed in the survey data for the ecological domain (Figures 3D–F, S2). When implementing a nonconstant discount rate, the discount rate is initially very high (to arrive at the same overall median amount). Hence once again, harvesting initially does not look like an economically attractive investment and an initial pulse in timber harvesting suppresses the population before harvesting is abandoned. However, once the discount rate has declined enough, we observe increasing levels of nontimber harvest being optimal again.

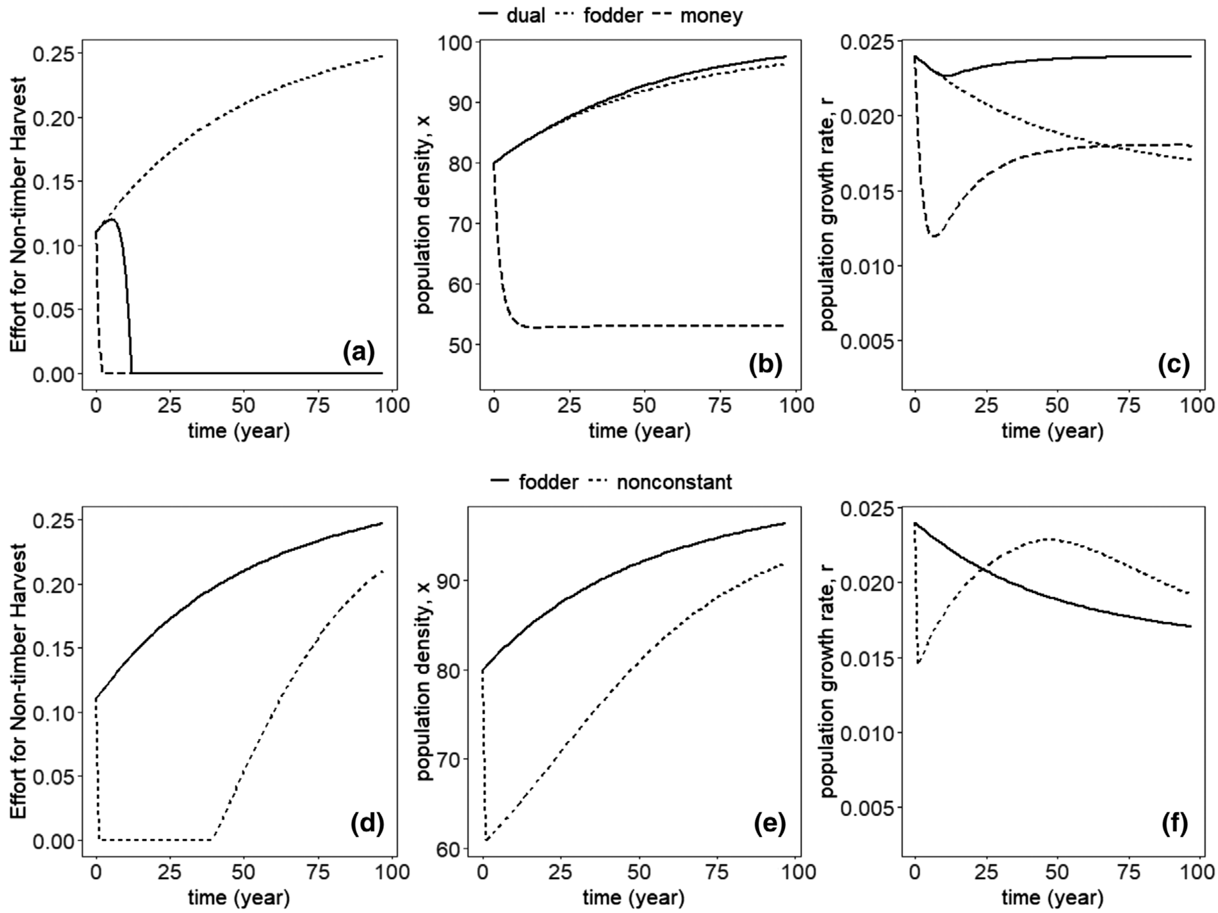

FIGURE 3 Optimal effort for non-timber harvest (A and D) and the respective effects on population density (B and E) and population growth rate (C and F) of *K. senegalensis* over a 100-year time horizon. Panels A–C compare a single rate at the median for the financial domain (long-dashed line), a single rate at the median for the ecological domain (short-dashed line), and multiple-rate discounting incorporating the medians for both the financial and ecological domains (solid line). Panels D–F compare a single constant rate at the median for the ecological domain (solid line) and a single nonconstant rate paralleling declining rates observed in the survey (dashed line)

4 | DISCUSSION

We elicited and calculated discount rates for three domains across three timeframes. Our study reveals that Fulani in Benin do discount and at a high rate on average. Yet two common discounting assumptions do not describe their preferences well: Fulani do not discount domains equally and they do not discount at a constant rate through time. We also found high variation in discount rates, but demographic covariates could explain some of the variation. We applied our survey results to an optimization model for harvest of *K. senegalensis*. In our study, dual-rate discounting resulted in the highest growth rates of *K. senegalensis*. Our work appears to be the first to empirically elicit locals' discount rates and then depict their importance by applying them to a bioeconomic model of management.

Elicited discount rates (median: 150%) are significantly higher than found in other studies (Kumar & Kant, 2019; Ubfal, 2016). High discount rates for the ecological domain would align with theory for common-pooled resources (Hartwick & Yeung, 1997). But high discount rates applied across domains, suggesting these may be due more to uncertainty about the future; for example, Fulani's lifestyles are rapidly changing from transient to sedentary due to climate change and competition for land with logging and agriculture (Gaoue & Ticktin, 2009; Heubach et al., 2011). For *K. senegalensis*, such high discount rates imply sustainable timber harvest will not be economically competitive, putting logging interests and conservation in tension. At the same time, sustained nontimber harvest would be optimal. Currently, most plantations and restoration programs in the region focus on fast growing species, such as *Gmelina arborea* and *Tectona grandis*. Programs that seek to support reliance on NTFPs could help conservation efforts as would programs that seek to deter timber harvest, 90% of which is done illegally (Siebert & Elwert, 2006), by tracing timber sales (FAO, 2020) and by promoting sustainable energy sources in lieu of fuelwood and/or charcoal (World Bank, 2019). For other conservation efforts with high discount rates, the question may become when to operate, in addition to focusing on the value of benefits not just to the organization, but multiple benefits, as we have shown in our model with both local economic and conservation benefits.

Aligning with other recent studies, our results showed people discount domains differently (Green & Richards, 2018; Ubfal, 2016). In our study, dual-rate discounting resulted in the highest growth rates of mahogany. Additionally, Fulani discount near-term benefits and costs at a higher rate than those realized further into the future. With nonconstant discount rates, a waiting period is necessary before nontimber harvest would be optimal. Building upon previous work (Armsworth, 2018; Sumaila & Walters, 2005), our models depict the need for conservation management to account for domain-specific discount rates and nonconstant rates, which can influence the timing, rate, and magnitude of optimal management strategies.

In our study there are potentially other important factors and assumptions that could be addressed. We only asked about three time periods and, hence, only calculated discount rates using one functional form. We provide a sensitivity test to the choice of functional form in Appendix S2, which shows similar patterns in discount rates across domains. Additionally, we did not ask risk-related questions, which could lower elicited rates (Andreoni & Sprenger, 2012). Because Fulani rarely divulge the number of cattle they have, or amount of fodder needed for their cattle, we did not incorporate background consumption. With our illustrative modeling application, we explored parameter space relative to survey results and mahogany, leaving a wider exploration of parameter space for other work. Despite these and other assumptions, our study depicts the importance of including locally derived time preferences in conservation management.

Our study shows that discount rates are much higher for Fulani in Benin than previous literature suggests and that Fulani discount monetary amounts differently than they do some other types of good. This study depicts the nuanced nature of discount rates and the effects that discount rates can have on optimal conservation strategies and natural resource management. Discount rates for conservation decisions and natural resource management cannot be applied across all communities or user groups uniformly; instead, managers need locally grounded estimates. Overall, natural resource management and associated models could be significantly improved with the incorporation of local time preferences.

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AUTHOR CONTRIBUTIONS

Amanda Hyman developed the survey, conducted statistical and mathematical analysis, and was the primary author of the manuscript and SI. Orou Gaoue and Charles Tamou aided in the survey development, data collection, and editing the manuscript. Paul Armsworth aided in survey development, model development and analysis, and editing of the manuscript and SI. All authors gave final approval of manuscript.

ETHICS STATEMENT

The authors adhered to all laws, regulations, and protocols in conducting this research. Survey questions were reviewed by the Internal Review Board at the University of Tennessee—Knoxville and deemed to have minimal risk to subjects (IRB-19-05476-XM).

DATA ACCESSIBILITY STATEMENT

The anonymized data used in this analysis are available by request.

CONFLICTS OF INTEREST

The authors declare no conflict of interest.

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REFERENCES

Andreoni, J., & Sprenger, C. (2012). Estimating time preferences from convex budgets. *American Economic Review*, *102*, 3333–3356.

Armsworth, P. R. (2018). Time discounting and the decision to protect areas that are near and threatened or remote and cheap to acquire. *Conservation Biology*, *0*, 1–11.

Attema, A. E., Bleichrodt, H., L'Haridon, O., Peretti-Watel, P., & Seror, V. (2018). Discounting health and money: New evidence using a more robust method. *Journal of Risk and Uncertainty*, *56*, 117–140.

Baumgärtner, S., Klein, A. M., Thiel, D., & Winkler, K. (2015). Ramsey discounting of ecosystem services. *Environmental and Resource Economics*, *61*, 273–296.

Bonzanigo, L., & Kalra, N. (2014). Making Informed investment decisions in an uncertain world: A short demonstration. *World Bank Policy Research Working Paper*, 1–22.

Clark, C. W. (1973). The economics of overexploitation. *Science (80-)*, *181*, 630–634.

Cohen, J. D., Ericson, K. M., Laibson, D., & White, J. M. (2016). Measuring time preferences. *NBER Working Paper Series*.

Cropper, M. L. (2012). How should benefits and costs be discounted in an intergenerational context? *Resources for the Future*, *2012* (October), 1–20.

D'Exelle, B., van Campenhout, B., & Lecoutere, E. (2012). Modernisation and time preferences in Tanzania: Evidence from a large-scale elicitation exercise. *Journal of Development Studies*, *48*, 564–580.

FAO. (2011). Annex: State of the world's forest. 100–156. Retrieved from http://www.fao.org/3/i2000e/i2000e00.htm

FAO. (2020). Blazing a trail for timber traceability in Benin [WWW Document]. Retrieved from http://www.fao.org/in-action/blazing-a-trail-for-timber-traceability-in-benin/en/

Gaoue, O. G., Jiang, J., Ding, W., Agusto, F. B., & Lenhart, S. M. (2016). Optimal harvesting strategies for timber and non-timber forest products in tropical ecosystems. *Theoretical Ecology*, *9*, 287–297.

Gaoue, O. G., & Ticktin, T. (2009). Fulani knowledge of the ecological impacts of *Khaya senegalensis* (Meliaceae) foliage harvest in Benin and its implications for sustainable harvest. *Economic Botany*, *63*, 256–270.

Green, G. P., & Richards, T. J. (2018). Discounting environmental goods. *Journal of Agricultural and Resource Economics*, *43*, 215–232.

Gren, I.-M., Nyström Sandman, A., & Näslund, J. (2018). Aquatic invasive species and ecosystem services: Economic effects of the worm Marenzelleria spp. in the Baltic Sea. *Water Resources and Economics*, *24*, 13–24.

Hardisty, D. J., Thompson, K. J., Krantz†, D. H., & Weber, E. U. (2013). How to measure discount rates? An experimental comparison of three methods. *Journal of Child Family Studies*, *22*, 1–42.

Hardisty, D. J., & Weber, E. U. (2009). Discounting future green: Money versus the environment. *Journal of Experimental Psychology General*, *138*, 329–340.

Hartwick, J. M., & Yeung, D. W. K. (1997). The tragedy of the commons revisted. *Pacific Economic Review*, *1*, 45–62.

Hernández-Barrios, J. C., Anten, N. P. R., & Martínez-Ramos, M. (2015). Sustainable harvesting of non-timber forest products based on ecological and economic criteria. *Journal of Applied Ecology*, *52*, 389–401.

Hernuryadin, Y., Kotani, K., & Kamijo, Y. (2019). Time preferences between individuals and groups in the transition from hunter-gatherer to industrial societies. *Sustainability*, *11*

Heubach, K., Wittig, R., Nuppenau, E. A., & Hahn, K. (2011). The economic importance of non-timber forest products (NTFPs) for livelihood maintenance of rural west African communities: A case study from northern Benin. *Ecological Economics*, *70*, 1991–2001.

Houehanou, T. D., Assogbadjo, A. E., Kakaï, R. G., Houinato, M., & Sinsin, B. (2011). Valuation of local preferred uses and traditional ecological knowledge in relation to three multipurpose tree species in Benin (West Africa). *Forest Policy and Economics*, *13*, 554–562.

IPBES. (2019). *Global assessment report on biodiversity and ecosystem services*. Retrieved from https://ipbes.net/global-assessment

Johnson, A. E., & Saunders, D. K. (2014). Time preferences and the management of coral reef fisheries. *Ecological Economics*, *100*, 130–139.

Kumar, P., & Kant, S. (2019). Endogenous time preferences of forest goods and community-based forest management. *Ecological Economics*, *163*, 205–214.

Lampert, A. (2019). Over-exploitation of natural resources is followed by inevitable declines in economic growth and discount rate. *Nature Communications*, *10*, 1419.

Lokonon, B. E., Mangamana, E. T., Gnonlonfoun, I., Akpona, T. J. D., Assogbadjo, A. E., Kakaï, R. G., & Sinsin, B. (2019) Knowledge, valuation and prioritization of 46 woody species for conservation in agroforestry systems along Ouémé catchment in Benin (West Africa). *Environment, Development and Sustainability*, *21*(5), 2377–2399.

Lundström, J., Öhman, K., Rönnqvist, M., & Gustafsson, L. (2016). Considering future potential regarding structural diversity in selection of forest reserves. *Plos One*, *11*, 1–16.

Mazziotta, A., Pouzols, F. M., Mönkkönen, M., Kotiaho, J. S., Strandman, H., & Moilanen, A. (2016). Optimal conservation resource allocation under variable economic and ecological time discounting rates in boreal forest. *Journal of Environmental Management*, *180*, 366–374.

Miller, D. C., Minn, M., & Sinsin, B. (2015). The importance of national political context to the impacts of international conservation aid: Evidence from the W National Parks of Benin and Niger. *Environmental Research Letters*, *10*, 1–12.

Siebert, U, & Georg, E. (2006). Potentials and recommendations for combating corruption and illegal logging in the forest sector of Benin, West Africa. *Journal of Sustainable Forestry*.

Sjølie, H. K., Latta, G. S., & Solberg, B. (2013). Dual discounting in climate change mitigation in the forest sector. *Journal of Economics*, *19*, 416–431.

Sumaila, U. R., & Walters, C. (2005). Intergenerational discounting: A new intuitive approach. *Ecological Economics*, *52*, 135–142.

Ubfal, D. (2016). How general are time preferences? Eliciting good-specific discount rates. *Journal of Development Economics*, *118*, 150–170.

Verdone, M., & Seidl, A. (2017). Time, space, place, and the Bonn Challenge global forest restoration target. *Restoration Ecology*, *25*, 903–911.

Wang, M., Rieger, M. O., & Hens, T. (2016). How time preferences differ: Evidence from 53 countries. *Journal of Economic Psychology*, *52*, 115–135.

Weikard, H. P., & Zhu, X. (2005). Discounting and environmental quality: When should dual rates be used? *Economic Models*, *22*, 868–878.

World Bank. (2006). *The role of local benefits in global environmental programs. Part two: Study findings*. Retrieved from https://www.gefieo.org/sites/default/files/ieo/evaluations/lb-global-environmental-programs.pdf

World Bank. (2019). *Increased access to modern energy: Benin*. Retrieved from http://documents1.worldbank.org/curated/en/891701570046002579/pdf/Benin-Increased-Access-to-Modern-Energy-Project.pdf

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