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Elements of indigenous socio-ecological knowledge show resilience despite ecosystem changes in the forest-grassland mosaics of the Nilgiri Hills, India

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ABSTRACT The Nilgiri Hills in the Western Ghats of India constitute a region of high biological and cultural diversity, and include an endangered shola forest-grassland mosaic ecosystem. A mosaic ecosystem is one consisting of adjacent, coexisting patches of highly distinct naturally occurring land states (in this case, shola forest and natural grassland). Changes in the landscape since the nineteenth century have severely impacted the shola-grassland mosaic and challenged the traditional lifestyles of the indigenous Toda people. However, the responses of traditional Toda socio-ecological perspectives and landscape management to these changes have not been explored through population surveys. Here, using a survey method, the article explores traditional Toda perspectives of ecosystem value and landmanagement practices. The survey consists of interviews of 50 respondents belonging to 24 *munds* (villages), covering ten clans, neighbouring mosaic lands, plantations and agricultural areas. The findings show that traditional socio-ecological landscape management is robust and has persisted despite marked ecological and socio-economic changes during the nineteenth and twenty-first centuries, and despite frequent gathering of land management advice from non-Toda. Elements of traditional socio-ecological knowledge that have persisted include prevalent collective traditional decision-making and long-held preferences for a landscape composition with a strong mosaic component. The highly robust nature of Toda socio-ecological culture and land management suggests that the Todas have a valuable role to play in supporting the long-term persistence of the shola-grassland mosaic. Increasing their stewardship role would help conserve this endangered and highly biodiverse ecosystem, while at the same time preserving a unique indigenous culture.

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Introduction

Extensive landscape transformations of natural forest and grasslands into plantations and agricultural lands are an increasingly common global phenomenon, affecting Africa, Australia, southern Asia, Europe, North America and South America (Neke and Du Plessis 2004; Fensham and Fairfax 2003; Zhao et al. 2006; Bredenkamp et al. 2002; Hoekstra et al. 2005; Baldi and Paruelo 2008; Vega et al. 2009). Megadiverse countries like India, harbouring about 200,000 (or 13%) of all known species, are threatened largely by vegetation clearing (Bunyan et al. 2012; Daniels, 1992; Mohandass and Davidar, 2009). In India, this biodiversity is mostly concentrated in the Western Ghats, a 1600 km long mountain range classified as a biodiversity hotspot with a high degree of endemism of flora and fauna, and with many globally threatened species having a very restricted distribution (Myers et al. 2000; Bond and Parr, 2010; Das et al. 2006; Gimaret-Carpentier et al. 2003; Jose et al. 1994). At an elevation range of 1400–2700 m, tropical montane evergreen forests, locally called as sholas (borrowed from the Tamil word "Sholai") naturally coexist with grasslands. The forest-grassland mosaics of the Nilgiri Hills are one of the most diverse and threatened landscapes of the Western Ghats Highlands (Meher-Homji, 1967; Suresh and Sukumar, 1999). Since the mid-nineteen century, land use changes have fragmented the Nilgiri's shola forest-grassland mosaics, and such fragmentation is an increasing focus of ecological studies (Sukumar et al. 1995; Bunyan et al. 2012; Mohandass and Davidar, 2009; Das et al. 2015; Das et al. 2017; Davidar et al. 2007; Davidar et al. 2010; Robin and Nandini, 2012; Thomas and Palmer, 2007; Arasumani et al. 2018).

The Nilgiri Hills are also the home of culturally and genetically diverse indigenous peoples (i.e., Todas, Kotas, Badagas, Irulas and Kurumbas). The Todas, who migrated over 2300 years ago, remain distributed among a number of distinct clans, to which they retain strong identities (the reader is referred to Walker (1986) for a complete description of Toda clans). The Todas have well-established Traditional Ecological Knowledge (TEK) of shola forest-grassland mosaics (Walker, 1986; Walker, 2004; Kathiravan et al. 2011; Krishnan, 2015a; Vishwanathan et al. 2003; Cederlöf and Sutton, 2006). "For millennia the Toda grazed and burned the upper Nilgiri Plateau in the northwest. They also intently maintained an open and grassy landscape. The dominance of grass was anthropocentrically maintained whatever the other biotic and climatic dynamics. Ecologists have suggested that annual fires also facilitate grassland dominance, although the presence of ground frost has also been linked to preventing the establishment of shola forest species. On this open and grassy landscape the Toda herded, penned, and milked their livestock, and sang about these broad-horned beasts and the endless open and green vistas; the landscape was at once a material achievement and a symbolic archive" (Krishnan, 2015b). Todas give a high religious significance to buffalos (the main domestic herbivore of their grasslands) and shola forests; which consist of a series of rituals, permitted uses and taboos regulating the extraction of resources, such as milk that can be obtained from certain buffalo lineages or wood for temple construction (Walker, 2004; Cederlöf and Sutton, 2006; Krishnan, 2015a, 2015b). Therefore, the TEK and traditional management of grasslands that Todas still practice may be directly linked to the maintenance of the high level of biodiversity of shola forest-grassland mosaics in the Nilgiri Hills (Krishnan, 2015b).

As Mauro and Hardison stated "Indigenous peoples themselves have repeatedly claimed that they have fundamental rights to TEK because it is necessary to their cultural survival, and this principle is increasingly being recognised in international law. When benefits are gained outside indigenous communities, they (native people) are entitled to have control over the process and to benefit from the use of their knowledge and traditions" (Mauro and Hardison, 2000). Accordingly, Gadgil et al. (1993) stated: "Indigenous peoples with a historical continuity of resource-use practices often possess a broad knowledge base of the behaviour of complex ecological systems in their own localities. This knowledge has accumulated through a long series of observations transmitted from generation to generation. Such 'diachronic' observations can be of great value and complement the 'synchronic' observations on which western science is based. Where indigenous peoples have depended, for long periods of time, on local environments for the provision of a variety of resources, they have developed a stake in conserving, and in some cases, enhancing biodiversity. They are aware that biological diversity is a crucial factor in generating the ecological services and natural resources on which they depend".

"(Indigenous) people often have rich traditions of biodiversity conservation, but are today either helpless spectators or active participants in the process of non-sustainable use of bioresources and depletion of biodiversity(…)". "Nowadays, traditions have often only a tenuous hold and are gradually giving way to pressures from the market and to increasing demands from the population" (Gadgil, 1993). Paradoxically, TEK is also being increasingly recognised as providing "comprehensive information of the local culture and environment, in addition to stewardship of community-protected habitats (e.g., sacred forests) through customary landscape management practices" (Berkes et al. 2000). These aspects can comprise collaborations among different organisations, administrations and indigenous peoples to include precise knowledge about "ecosystem monitoring and management" (Tester and Irniq, 2008; Alexander et al. 2011; Berkes, 2009). This can occur in several instances of genuine ecosystem change: such as landscape management, resource rotation, multiple species and landscape succession (Mauro and Hardison, 2000). TEK is especially "associated to indigenous traditions having a diverse knowledge of ecology, religion and systems of resource management" (Berkes et al. 2000).

British company and crown governments dramatically changed land management of the Nilgiri Hills (Krishnan, 2015a). They established and expanded tea and eucalyptus plantations beginning in 1837. During World War II, the colonial state promoted wattle, eucalyptus and pine plantations at the expense of highly diverse and resource-rich grasslands and shola forests. Grasslands and sholas were progressively cleared to provide plantation lands and wood (Sivaramakrishnan, 1999; Cederlöf and Sutton, 2006; Krishnan, 2015a). Landscape changes have been also elicited by the colonial and post-independence efforts to transform the lifestyle of tribal communities. This was especially the case for the Toda people, who were compelled to transition from pastoralists to peasants. Grassland afforestation led Todas to practically abandon buffalo raising in favour of land cultivation, although they still maintain the ritual use of shola forests for temple construction (Walker, 2004; Cederlöf and Sutton, 2006; Krishnan, 2015a).

Today, land conversion to plantations, agricultural lands and the construction of hydroelectric dams has resulted in widespread deforestation, except in protected areas (Ramesh et al. 1977; Gadgil, 1979; Menon and Bawa, 1997; Davidar et al. 2010; Satish et al. 2014). Many native shola forests form part of protected areas, but in other areas, widespread eucalyptus and pine plantations contribute to limiting the capacity of local Toda people to extract forest resources (Cederlöf and Sutton, 2006; Münster and Münster, 2012; Lang, 2015). Although the State Forest Department has ceased promoting these plantations in the area and officially there has been a ban on them since 1996, the latest Draft Forest Policy of the central government does promote them.

In shola grasslands in the neighbouring state of Kerala, recent demographic changes have increased dependence on firewood, while the introduction of new crops (i.e., lemongrass) and higher livestock stocking rates have put further pressure on these systems (Chandrashekara et al. 2005). Nilgiri grasslands are also highly threatened, as they are extensively afforested with exotic tree plantations, mainly for energy needs (Venkatesh et al. 2014). According to various studies, the Nilgiri eucalyptus-afforested grasslands suffered from significant hydrological impacts, such as reduced water yield and stream flow, and reduced seasonal runoff volume (Samraj et al. 1988; Sharda et al. 1988; Samra et al. 2001; Sikka et al. 2003). These disequilibria have severely impacted native sholas and grasslands through increased fire incidence and expansion of invasive species (Kodandapani et al. 2004; Srinivasan, 2011).

Several studies have analysed the link between traditional and market-oriented social behaviour, land use and ecosystem stability in the Western Ghats (Alembath, 2010; Davidar et al. 2010). Moreover, it has been suggested that landscape preferences (whether individuals prefer grasslands or forests) can influence the qualitative composition of forest-grassland mosaics over time (Innes et al. 2013; Henderson et al. 2016), but this has yet not been investigated. Our study aims to discern relevant aspects of Toda people's individual and social management practices, perceptions and traditional values associated with the land management history of the Nilgiri Hills in India, a region where the improvement of current knowledge may prove useful for conservation, decision-making and research. We aim to test the following hypotheses: (i) current preferences of landscape composition will reflect the traditional Toda preferences for grasslands and sholas over agricultural plots and plantations, (ii) Toda peasants will express little willingness to change landscape preferences, (iii) Toda people will tend to engage more often in collective decisions than in making individual decisions. We estimate how much of the traditional Toda preference for forest-grassland mosaics (Walker, 2004; Krishnan, 2015a, 2015b) still persists by taking a snapshot at the time this study was made, when the landscape has already been profound altered.

Materials and methods

Study area. The study was carried out in the Nilgiri Hills district, in the Western Ghats Mountains, Tamil Nadu state, southern India. The district has two plateaus: the upper Nilgiri plateau and the lower Gudalur plateau. The upper plateau has an average elevation of 2500 m. above MSL. The shola forest-grassland mosaic is a common landscape formation that possesses a high floristic and faunistic diversity, with many endemic species (Jose et al. 1994), Ranganathan 1938 in Meher-Homji (1967). An estimated population of 1500 Toda inhabit the upper Nilgiri plateau and reside in among 56 munds (hamlets) (Krishnan, 2015a). Nearly 40 Toda munds and 1319 acres of Toda Patta Lands (a common land grant created by the British government in the late 19th century) lie in the western and north-western portions of the plateau. This northwestern region encompasses 19,637 acres and is denominated as the Lord Wenlock Downs, which have been declared as reserved forests since 1900 (Krishnan, 2015a). The Nilgiri plateau spreads much wider and higher, and Todas have another 1179 acres in Avalanche and Glen Morgan areas (Krishnan, 2015 a). We conducted our surveys in 24 munds (Table 1, Fig. 1). In a mund belonging to a particular clan, only members of the same clan reside. The sampling criteria entailed the selection of 19 munds in the Lord Wenlock Downs, which are a contiguous mosaic of shola-grasslands, afforested grasslands and agricultural lands. Glen Morgan ($n = 2$) and Avalanche ($n = 3$), two regions west of the Nilgiri plateau having similar mosaics, were also selected for the surveys.

Toda tribal communities. Todas are one of the five tribes inhabiting the Nilgiris Hills (Todas, Kotas, Badagas, Irulas and Kurumbas). Todas live on the high upland plateau at a higher altitude than any other tribe, between 1829–2286 m above sea level, and distributed among 56 munds (hamlets) (Walker, 2004;

Table 1 Summary of the questionnaire survey data collection conducted in the areas of the Nilgiri Hills inhabited by Todas

Area	Clan	Mund	No. house-holds surveyed	Male respondents	Female respondents	Total number of house-holds surveyed
Wenlock downs	Kiwir	Marlimund Kundakodumund Malevidumund	9	6	3	41
	Omgas	Pagilamund Denadumund Emmekalmund	4	3	1	
	Pir	Tavutakoremund Naregulimund Hanekandikodumund	5	4	1	
	Mortxor	Osamund	1	1		
	Kas	Kandalmund Pagalkodumund	4	2	2	
	Toror	Aretomund Taranadumund	8	6	2	
	Nos	Muttinadumund Kolekadumund	5	5		
	Porxas	Pedukallumund	2	1	1	
	Koror	Tuvalkandimund	2	2		
	Mor	Nattanerimund	1	1		
Glen Morgan	Kiwir	Nirkaccimund	3	2	1	4
	Nos	Talaptterimund	1	1		
Avalanche	Mortxor	Kariakadumund	1	1		5
	Kas	Kadumund	2	1	1	
	Mor	Tebbegudumund	2	2		

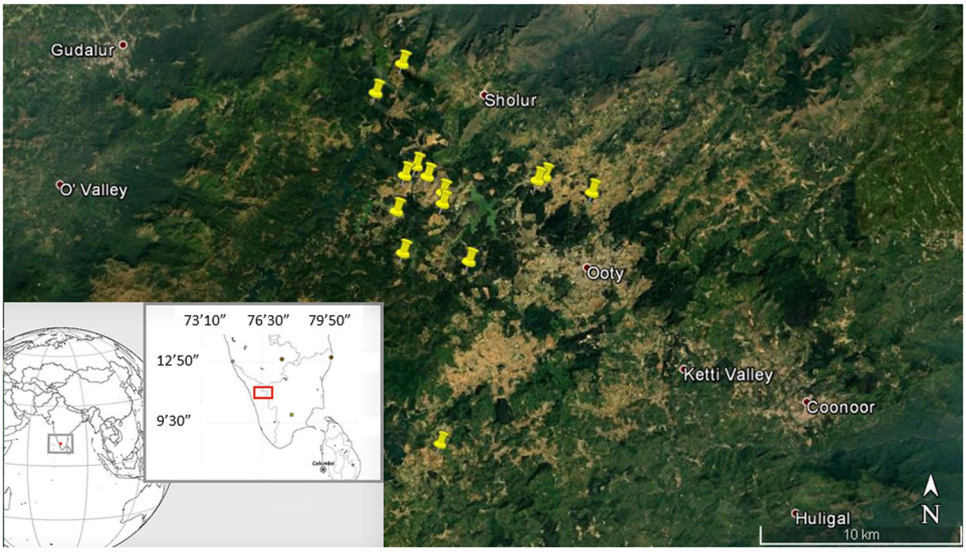

Fig. 1 Map of the study area where questionnaire surveys were conducted. Villages are denoted with the yellow icon. The map was created using Google Earth Pro 7.1.5.1557 (Google, DigitalGlobe). Inset map by Maphill © Maphill. The image is covered by a Creative Commons Attribution Non-Derivative License (CC BY-ND)

Krishnan, 2015a). The origin of the Toda people is unclear, but their migration to the Nilgiris may have occurred by about the 3rd century B.C., when the Dravidian-family Toda language split from the Tamil-Malayalam (Krishnan, 2015b); this coincides with genetic studies made on Toda buffalos showing a divergence time of about 2396 years ago, with closely-related southern India's buffalos (Walker, 1986; Walker, 2004). The traditional lifestyle of Todas was centred on their sacred buffaloes, which also formed an important part of their sustenance, but drastic landscapes changes have occurred in recent decades that led to widespread abandonment of the pastoral lifestyle (Krishnan, 2015a, b; Menon and Bawa, 1997).

Questionnaire and data analysis. Questionnaire survey data were used to assess the attitude and perception of Toda land-owners toward changing landscapes in the Nilgiris. A questionnaire of similar design to Henderson et al. (2016) was used, and consisted of both open and closed ended questions divided into five blocks: landscape composition and preference; composition and preference change; land use influence; regional composition; and restoration (Supplementary Information). The questionnaire was administered to the respondents, and the choices and themes were fixed on the basis of 13 pilot surveys conducted earlier. A non-random and purposive sampling design was adopted for selecting households. Toda members follow active farming and grazing routines and it is difficult to randomly pre-select a household to survey. At all times, only Todas in a mund who were willing and available members to take part in the study were interviewed. As 15 clans exist among the Toda, each with different extents of Toda Patta lands, we tried to ensure maximum coverage of munds belonging to different clans in the Lord Wenlock Downs, Glen Morgan and Avalanche. The households belonging to the native Todas were selected on the basis of convenience sampling depending on the availability of the clans ($n = 10$) and proximity to the mund ($n = 24$) (Table 1). Forty-one households in the munds of the Lord Wenlock Downs, 5 households from Avalanche and 4 from Glen Morgan were surveyed. Data was collected through a structured interview with 50 individuals consisting of both men ($n = 38$) and women ($n = 12$) land-owners. Our conclusions are based on statistically significant results, despite the low sample size. The responses were recorded and later transcribed.

Pooling was made among clans of similar size and geographic area in order to ensure an equal representativity. Thus, we obtained three coherent groups: smaller clans (Koror, Mortxor, Pir and Portxas), medium clans (Omgas, Mor and Nos) and large clans (Kas, Kiwir and Toror). Parametric analyses of variance for one factor (One-way ANOVA, when values followed a normal distribution), or non-parametric Wilcoxon signed rank and Pearson's chi squared tests, were performed for testing significant differences at the $p < 0.05$ level. These tests allowed us to verify the validity of our hypotheses with a 95% probability of accuracy. The tests were conducted in R software version 3.0.3 (R Foundation for Statistical Computing, Vienna, Austria).

Results

Composition and preference. The average settlement size was 13.9 acres. The average settlement size differed significantly among clans ($F_{9,24} = 2.5$, $p = 0.033$), but not among munds ($F_{9,24} = 0.66$, $p = 0.736$) (Q1 from the questionnaire, Supplementary Information). In general, the average land residence time was 31.3 years (ranging from 23 to 40 years from Mor and Koror clans, respectively), and no differences were observed among clans ($F_{8,20} = 0.2$, $p = 0.979$). Seventeen landowners declared to have been on their land since birth, but gave no specific time context; hence they were not included in this analysis.

Landscapes on the surveyed Toda lands have been subject to a high degree of human transformation (Question 2, Q2 in the questionnaire: What is the current landscape composition within 10–20 km of your settlement?). In this region, plantations are the main land use type with an overall average of about 51%, and agricultural lands span about 10% ($V = 8.5$, $p < 0.001$) (Fig. 2). This is the consequence of afforestation by the Forest Department and a shift of Toda lifestyle from pastoralists to agriculturists. However, at the clan level only the Kas ($V = 0$, $p = 0.036$), Kiwir ($V = 0$, $p = 0.016$) and the medium-sized clans (Omgas, Nos and Mor) ($V = 0$, $p = 0.004$) repeated this same pattern, but not Toror ($V = 0$, $p = 0.181$) or the smaller clans (Portxas, Mortxor, Pir and Koror) ($V = 2.5$, $p = 0.115$). Plantations are formed by exotic trees such as eucalyptus and pine, whereas, carrot, potato, cabbage and beetroot constitute the main agricultural crops.

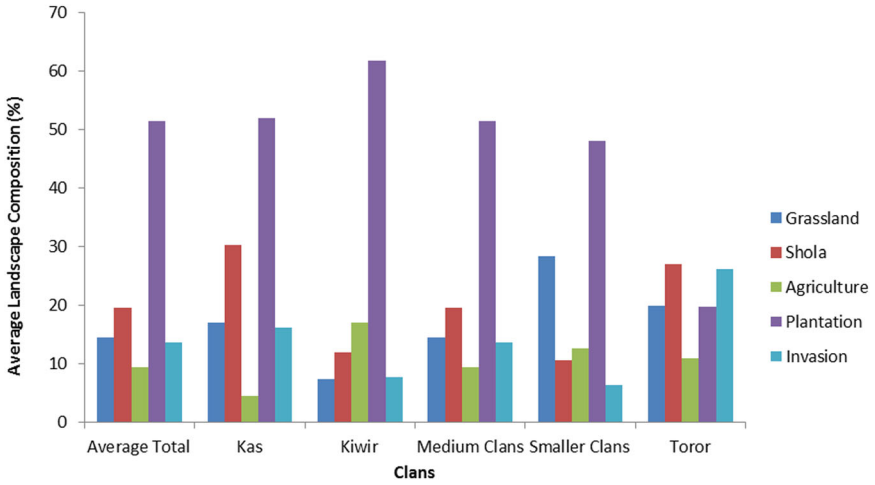

Fig. 2 Landscape composition for each land use type in the region of the Nilgiri Hills inhabited by the Toda people. The dataset presents average total and the average for each of the clans. With a reduced proportion of native grassland and shola, the results show a high degree of land conversion into plantation, agriculture and invaded areas

Based on the perception of respondents, the combined vegetation composition of native shola forests and grasslands comprise approximately 34%, of which about 20% correspond to sholas. There are not overall significant differences in the amount of shola and grassland ($p = 0.076$), but in the lands of the Kas clan the amount of 17% grassland and 30% shola displayed a significant difference ($V = 41$, $p = 0.033$) (Fig. 2). Shola forests comprise a significantly smaller amount of landscape than plantations ($V = 40$, $p < 0.001$), however this is still larger than the amount occupied by agricultural lands ($V = 367.5$, $p = 0.019$). Among clans, shola forests of Kas ($V = 1$, $p = 0.013$), Kiwir ($V = 0$, $p = 0.002$) and medium clans ($V = 3$, $p = 0.024$) represented a smaller proportion than plantations, but the proportion of sholas and agricultural lands was similar (Kas: $V = 20$, $p = 0.058$, medium clans: $V = 8$, $p = 0.098$), and no differences were also observed for the remaining clans. Invasive species, such as gorse (*Ulex europaeus*), systamp (*Eupatorium sp.*) and Scotch broom (*Cytisus scoparius*), are widely scattered (approximately 14%) across forest-grassland mosaics frequently penetrating into shola forests, and just slight differences exist between the two types of formations ($V = 64$, $p = 0.055$), although this pattern did not differ among clans (Fig. 2).

Our results corresponding to Q3 reflect a significant discrepancy between the current and preferred landscape composition. On average, Toda people preferred significantly less plantation ($V = 45$, $p = 0.009$), from the current 51% coverage to a preferred 5% coverage. In place of plantations they preferred a larger amount of: grasslands (49% average preferred coverage), which is over 34% more grassland than the current state ($V = 14$, $p < 0.001$); sholas (39% average preferred coverage), which currently represents about 20% of the perceived landscape composition ($V = 126$, $p < 0.001$); and agricultural lands (over 22% average preferred coverage) which currently represents over 9% of the current perceived landscape composition ($V = 41$, $p = 0.018$; Table 2). When the dataset is disaggregated among clans, the same pattern was observed for the smaller clans; medium clans just preferred a higher proportion of sholas and grasslands, whereas Kas, Kiwir and Toror significantly preferred grasslands over other landscapes (Table 2). The main reasons farmers provided for their preferred landscape composition were that: "grasslands help to support buffalo raising", "shola forests attract more rainfall", and, "sholas are used in cultural rituals and house construction, whereas agriculture generates a family income".

Composition and preference change over time. Overall, landscape composition (based on the perceptions of respondents) has changed significantly over time. There has been a trend towards reduced natural vegetation (relating to Q4 from the questionnaire, Supplementary Information). In the last decade, over 44% of peasants within 10–20 km of their property perceived severe decreases in grassland and shola forests (Q4e). Over fifteen per cent of peasants have noted an increase in plantations and invasive species, and just 20% responded that their area stayed the same ($\chi^2 = 20.2$, d.f. $= 3$, $p < 0.001$). When asked for the main reason for the landscape composition change (Q4f), the expansion of plantations was the answer for almost 79% of respondents. However, Todas stated also other reasons, such as presence of invasive species and removal of cutting orders ($n = 3$). Nonetheless, relating to Q4b, preference for landscape composition has not changed in the last 10 years: 88% of individuals responded negatively. A few respondents ($n = 5$) reported changing their choice, preferring more grasslands, more agricultural lands or a mix of shola-grassland or shola-agricultural lands.

Decision influences and collective decision-making. Most Toda landowners (69%) gather advice about land management primarily from individuals outside their clan (Badaga Lessee and Tamilians in particular), whereas relatives are the primary source of advice on land management for the remaining 31% of Todas, ($\chi^2 = 14.3$, d.f. $= 7$, $p = 0.046$) (referring to the results of Q5). Nevertheless, landowners are significantly more likely to obtain advice from fellow peasants (75% of respondents, $n = 18$) than from other stakeholders, such as workers of the Panchayat Union city administration ($n = 1$) or pesticide sellers ($n = 5$) ($\chi^2 = 19.8$, d.f. $= 2$, $p < 0.001$). This pattern is consistent among clans ($\chi^2 = 14.1$, d.f. $= 9$, $p = 0.119$).

In general, collective decisions involving the clans and/or munds are relatively frequent (Q6a from the questionnaire, Supplementary Information). Twenty percent of peasants make collective decisions frequently, as opposed to those that make them sometimes (44%, $n = 20$), rarely (over 6%, $n = 3$) or never (about 29%, $n = 13$) ($\chi^2 = 11.8$, d.f. $= 3$, $p = 0.008$). The frequency of collective decisions varies significantly among clans ($\chi^2 = 32.6$, d.f. $= 9$, $p < 0.001$), with the large Kas, Kiwir, Koror and Toror clans being the most active, whereas medium and smaller clans never or rarely engage in collective decisions. Corresponding to Q6b, Todas make collective decisions on matters relating to land required for temples (about 39%, $n = 12$),

Table 2 Current and preferred landscape composition (%) for each land use type

	Shola forest		Grassland		Agriculture		Plantation	
Clans	**Current (%)**	**Preferred (%)**	**Current (%)**	**Preferred (%)**	**Current (%)**	**Preferred (%)**	**Current (%)**	**Preferred (%)**
Overall ($n = 46$)	19.6	39.2	14.5	48.9	9.4	22.4	51.3	5.2
Wilcoxon test (V)	$V = 126$		$V = 14$		$V = 41$		$V = 45$	
p-value	$p < 0.001$		$p < 0.001$		$p = 0.018$		$p = 0.009$	
Kas ($n = 13$)	30.2	43.4	17.1	58.4	4.5	25.1	51.9	0
Wilcoxon test (V)	$V = 14$		$V = 0$		$V = 0$		$V = 1$	
p-value	$p = 0.359$		$p = 0.004$		$p = 0.181$		$p = 1.000$	
Kiwir ($n = 10$)	12.0	35.3	7.4	42.5	16.7	36.5	61.8	0
Wilcoxon test (V)	$V = 9$		$V = 2$		$V = 2$		$V = 3$	
p-value	$p = 0.064$		$p = 0.006$		$p = 0.375$		$p = 0.500$	
Medium ($n = 10$)	15.7	49.5	8.5	42.0	4.6	10.3	61.2	16.7
Wilcoxon test (V)	$V = 0$		$V = 0$		$V = 4$		$V = 3$	
p-value	$p = 0.002$		$p = 0.002$		$p = 0.438$		$p = 0.500$	
Smaller ($n = 6$)	10.5	29.0	28.4	46.8	12.6	31.6	48.0	6.2
Wilcoxon test (V)	$V = 126$		$V = 14$		$V = 41$		$V = 45$	
p-value	$p < 0.001$		$p < 0.001$		$p = 0.018$		$p = 0.009$	
Toror ($n = 7$)	26.9	33.1	19.9	56.4	10.9	12.3	19.7	0
Wilcoxon test (V)	$V = 5$		$V = 0$		$V = 5$		$V = 3$	
p-value	$p = 0.313$		$p = 0.031$		$p = 1.000$		$p = 0.500$	

Note: The dataset was compared for the overall clans and for each clan separately

removal of plantations (about 26%, $n = 8$), agriculture (22%, $n = 7$) and, to a lesser extent, about land to be dedicated for grazing ($n = 1$), leasing ($n = 1$) or set-aside ($n = 2$) ($\chi^2 = 4.9$, d.f. $= 2$, $p = 0.086$). We observed significant patterns when results were analysed among clans ($\chi^2 = 16.9$, d.f. $= 8$, $p = 0.031$). Kas, Omgas, Pir and Toror clans engaged in collective decisions primarily about land for temple construction; Mor, Mortxor and Nos about agricultural purposes; and Kas, Kiwir and Omgas about plantation removal.

Regional composition. The perception of change in the regional-level land composition (Q7a from the questionnaire, Supplementary Information) reflects a significant decrease in both types of natural vegetation ($\chi^2 = 29.3$, d.f. $= 4$, $p < 0.001$). A decrease in sholas and grasslands was perceived by almost 47% ($n = 21$) of landowners, whereas 29% ($n = 13$) observed a decrease in grasslands only, and about 7% ($n = 3$) in shola forest only. Alternatively, 15% of landowners noticed no difference. Expansion of plantations was the main reason for 3 out of 4 landowners ($n = 27$), followed by increases in invasive species about 17% ($n = 6$) and agriculture lands ($n = 1$). One respondent noted the change was due to the presence of less buffaloes and another respondent perceived no change in plantation cover.

Toda people are not likely to change their preferences, after being informed of the actual landscape composition in the region (Q8). This was the case for native vegetation (grassland: $V = 12$, $p = 0.236$, shola: $V = 32.5$, $p = 0.260$) and agricultural lands ($V = 6$, $p = 0.181$). Overall, Todas would prefer an average landscape composition of: 49% grassland, 39% shola, 9% agriculture and just 2% plantation. There are several reasons for this preference: sholas are given a cultural consideration and their wood is often used to construct temples, and grasslands provide grazing area and fodder. The majority of the Toda people coincided in having their exotic tree plantations substituted by any of the other landscape types, and no respondent showed preference changes in this regard, which resulted in perfect collinearity ($V = 0$, $p = 1.000$). Notably, the Mortxor clan followed the opposite trend, as they preferred 40% plantations, 28% agricultural lands and about 32% of native vegetation. The Pir clan preferred agricultural lands (42%) over shola (9%) and grassland (40%), and the Mor and Porxas clans displayed the highest preferences for shola (60% and about 67%, respectively).

Restoration. The results relating to Q9 ("Suppose you wanted limited restoration of some natural vegetation on the landscape within 10–20 km of your settlement, which would you prefer to restore?) show that 50% ($n = 21$) of landowners are willing to restore grassland over shola forest, as opposed to 31% ($n = 13$) vice versa. Some respondents ($n = 7$) indicated their preference for both habitats, and one respondent stated no habitat preference ($F_{3,36} = 3.1$, $p = 0.038$). This general pattern is also observed when results are disaggregated clan-wise, except for Mor and Omgas clans whose members would choose to restore native shola forest rather than grassland ($F_{9,30} = 1.5$, $p = 0.204$). There is a significant difference in the amount of native grassland or shola forest that peasants are willing to restore at the expense of the other habitat ($F_{1,38} = 5.0$, $p = 0.031$, Q10a,b). If the regional landscape was only covered by native shola forest (Q10a), on average, Toda people would wish to convert, 40% of the vegetation into grasslands (ranging between 24% to 53%, from Pir and Mor clans respectively, but no significant differences were found among clans: $F_{9,30} = 0.3$, $p = 0.972$). In the opposite case (Q10b), Todas would be willing to substitute about 32% native grassland by shola forest (ranging between 2% to 57%, from Pir and Nos clans, respectively: $F_{9,31} = 1.1$, $p = 0.389$). Regarding compensation in exchange for landscape preservation (Q11b from the questionnaire, Supplementary Information), 42% ($n = 10$) of the respondents would prefer land for agriculture, 33% ($n = 8$) would expect to obtain more grazing rights and 25% ($n = 6$) expected monetary compensation ($F_{2,15} = 0.3$, $p = 0.775$). Landowners expecting monetary compensation would consider receiving between 5 lakhs for 10 cents to 50–90% of the land value.

Discussion and conclusion

Existing national land management policies aimed at increasing exotic tree plantations have profoundly transformed the landscapes of the Nilgiri Hills. These polices caused a significant loss of native shola forests and grasslands; expansion of invasive

species; and the decline of traditional agricultural and livestock activities of the Toda people. However, our results suggest that the Toda retain a strong capacity for traditional collective decision-making, and that the Todas nonetheless tend to show significantly higher preferences for grasslands and sholas (and agricultural lands as well) than for land-intensive plantations, which partially confirmed our first hypothesis. This is the case even after having been compelled to alter their communal livestock breeding lifestyle towards individual farming since the latter half of the 19th century (Walker, 2004; Cederlöf and Sutton, 2006; Krishnan, 2015a, 2015b). Hence, traditional Toda socio-ecological knowledge may be important not only for safeguarding their culture but also for conserving the shola-grassland mosaic.

Krishnan (2015a) argues that "the upper plateau of the Nilgiris, South India, was a grazed, grassy, and open landscape until the mid-nineteenth century when it was subject to colonial rule and commerce". However, small remnants of grassy landscape were indeed conserved: "even as it initiated and institutionalised capitalism, colonial rule also sought to selectively and legally safeguard from the material consequences of modernity and capitalism the pastoral lifestyles of the Toda grazers and the open and grassy biophysicality of their principal grazing landscape", chiefly for serving the recreational purposes of the colonists (e.g., hunting, riding) (Krishnan, 2015a). As previous authors have observed regarding the prevalence of Toda TEK (Walker, 2004; Cederlöf and Sutton, 2006; Krishnan, 2015a, 2015b), Todas prefer shola-grassland mosaics, while continuing to gather advice from people out of their clan and engaging in collective decision-making processes. This supports our hypotheses that Todas will express little willingness to change landscape preferences. Further, they will tend to engage more often in collective decisions than in making decisions individually. The study also shows a remarkable continuity in socio-ecological landscape management. Interestingly, the larger clans (i.e., Kas, Kiwir and Toror), but also Koror, were the most active groups, as opposed to medium and smaller clans (except Koror) that seldom took collective decisions. This can be explained by the fact that the largest clans would normally have a greater number and frequency of public issues to be addressed, such as temple construction, allocation of agricultural land or grazing pastures. The Toda case confirms ecosystem resilience literature, which posits that high "connectivity between different social groups increases information sharing and develops the trust and reciprocity necessary for collective action" (Biggs et al. 2012). However, intra-community differences in collective propensities as evidenced in the Toda case needs further research.

The expansion of exotic tree plantations and exotic invasive species were the main reasons given (with a combined 92%) for the landscape change observed by Todas. The perception of landscape change has had important repercussions for Toda lifestyle resulting from decreases in the number of buffaloes and the size of grasslands. Consequently, Toda people showed a striking difference in the current versus preferred proportion of landscape dedicated to plantations (about 51% current vs. 5% preferred). Likewise, Todas would like to see a higher proportion of the landscape occupied by natural vegetation (88% for grasslands and sholas combined) than the current 34%. If given the opportunity, Toda people would overwhelmingly restore native vegetation (about 98%), preferably grassland over shola, regardless of compensation. This is in agreement with the study of Henderson et al. (2016), which supported the Scarcity Hypothesis stating that "desired resource protection increases when the resource (i.e., shola and grassland in our study) is in jeopardy". Indeed, exotic tree plantations are managed by the Forest Department (Sivaramakrishnan, 1999; Münster and Münster, 2012), and Todas do not perceive any benefits from these exotic tree plantations because Toda access to plantations is prevented. In contrast, they give an intrinsic value to natural vegetation states as sources of grazing pastures and wood resources. Moreover, exotic monospecific plantations have been extensively encouraged since the late 1990s for timber, fuelwood and hillside reforestation in India and other BRICS countries (Brazil, Russia, India, China and South Africa) (Brockerhoff et al. 2008; Puyravaud et al. 2010; Henderson et al. 2016). However, tree harvesting remains un-profitable due to stagnant prices for lumber during the last decade (Soares et al. 2003a, b).

New land use practices linked to the current landscape composition are associated with demographic changes beginning about 40 years ago, such as the arrival of farmers from adjacent Tamil Nadu State and southern Kerala (Krishnan, 2009). This is in agreement with our result of an average land residence of 31.3 years. Previous studies have obtained satisfactory results retrieving historical data from questionnaires (Fensham and Fairfax, 2003; Davidar et al. 2010; Henderson et al. 2016). Our study focused on the changes in landscape composition that have occurred within the previous ten years in order to ensure respondents are able to recall decadal changes in landscape composition. This is in agreement with Fensham and Fairfax (2003). Nonetheless, alternative techniques may then also be used to further explore the changes in landscape composition in the Nilgiri Hills. Combining the analysis of historical series of aerial photographs with questionnaires has already demonstrated the validity of such a combined approach for regional landscape management studies (see Fensham and Fairfax (2003)), but this possibility may not be available for highly isolated rural regions in low-income countries.

This study contributed to understanding the importance of Toda perceptions and land management practices in the conservation of highly diverse ecosystems. Our results suggest potential for the empowerment of Toda stakeholders to help preserve the shola forest-grassland mosaic (although current planning and management instruments supported by local and state governments must also be compatible with this goal). Future research should directly address the analysis of other potential impacts of land conversion in the Nilgiri Hills, such as the influence of the current land management practices on the socio-ecological development of the region; the expansion of invasive species; and habitat changes and biodiversity loss.

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Data availability

The questionnaire used for the study appears in the Supplementary Information. To protect study participant privacy, the collected survey data were not deposited in an open repository, but the survey data can be obtained by contacting the corresponding author.

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Additional information

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Competing interests: The authors declare no competing interests.

Ethical approval and informed consent: The project and questionnaire were reviewed and received ethics clearance through the University of Guelph Research Ethics Board. All methods were performed in accordance with the relevant guidelines and regulations regarding the use and safety of human subjects. Field work was conducted by Toda assistants and speakers of the local Tamil language, which helped to develop trust. Informed consent was obtained from all individual participants included in the study.