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Research article

Influence of forest management systems on natural resource use and provision of ecosystem services in Tanzania

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A B S T R A C T

Social, religious and economic facets of rural livelihoods in Sub-Saharan Africa are heavily dependent on natural resources, but improper resource management, drought, and social instability frequently lead to their unsustainable exploitation. In rural Tanzania, natural resources are often governed locally by informal systems of traditional resource management (TRM), defined as cultural practices developed within the context of social and religious institutions over hundreds of years. However, following independence from colonial rule, centralized governments began to exercise jurisdictional control over natural resources. Following decades of mismanagement that resulted in lost ecosystem services, communities demanded change. To improve resource protection and participation in management among stakeholders, the Tanzanian government began to decentralize management programs in the early 2000s. We investigated these two differing management approaches (traditional and decentralized government) in Sonjo communities, to examine local perceptions of resource governance, management influences on forest use, and their consequences for forest and water resources. While 97% of households understood the regulations governing traditionally-managed forests, this was true for only 39% of households for government-managed forests, leading to differences in forest use. Traditional management practices resulted in improved forest condition and surface water quality. This research provides an essential case study demonstrating the importance of TRM in shaping decision frameworks for natural resource planning and management.

1. Introduction

Global forest cover is declining at alarming rates (Hansen et al., 2010) primarily driven by agricultural expansion (FAO, 2006) and increasing demand for forest resources by populations whose livelihoods are strongly linked to natural resources (Jha and Bawa, 2006; Ezebilo, 2012) resulting in substantial losses of biodiversity and ecosystem function (Bawa and Seidler, 1998). Environmental degradation is increasingly linked to food shortages and community vulnerability (Franke and Chasin, 1980; Hjort af Ornäs and Salih, 1989), especially in dryland systems where recurrent famine, drought, disease, and conflicts leave populations struggling to meet basic needs (McCann, 1997). Following the release from colonial governance, development in sub-Saharan Africa largely focused on improving infrastructure, education, and the economy. Management of natural resources was commonly moved to centralized governments where national policies of resource use were established, frequently resulting in unsustainable exploitation, leading scholars to question the long-term sustainability of such policies (Brundtland Report, 1987; Redclift, 1984).

In Tanzania, post-independence land management strategies dismantled indigenous systems with policies of forced village settlements giving control of natural resources to centralized government institutions, which gave top-down policy directions to be carried out by village councils (Shivji, 2002). Such institutions governed large tracks of land through sweeping policies of agricultural development and forestry, but were based on management principles devised for temperate regions (Pretty, 2011; Yeager, 1982). The largest blocks of intact forest were placed in Forest Reserves, designated as Catchment Forest Reserves or Nature

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Reserves (managed by the Forestry and Beeking Division of the Ministry of Natural Resources and Tourism), Game Reserves or Game Controlled Areas (managed by the Wildlife Division), or National Parks (managed by the National Parks Authority), and largely became inaccessible to local communities. While these practices succeeded in securing ecological capital that would become the basis of the tourism-driven economy, they did little to ensure the sustainable use of resources by rural communities. Top-down policies governing non-timber forest products and water withdrawals were ineffective, as they did not reflect the natural fluctuations in resource availability (Hall and Bawa, 1993; van Koppen et al., 2004). Nationalized forest management programs failed to adapt to local conditions and conflicted with traditional religious systems (German et al., 2010; Kamara et al., 2004), forcing communities to rely on shrinking areas of natural resources often leading to decades of destructive exploitation.

More recently, governmental and developmental agencies have realized that key improvements in the decision-making process needed to incorporate local participants in a more decentralized manner (Müller and Guimbo, 2011; Wily, 2000). Land tenure policies developed in the 1990's strengthened village level rights, supporting regional governance of forests and legitimized traditional practices and institutions. The 2001 National Forest Program and the Forest Act of 2002 (URT, 2002) officially instituted reform policies that designated the co-management and joint ownership of forests between local communities and regional governments. The goals of this approach were to improve forest health with sustainable use practices, improve livelihoods through appropriate forest uses, and increase the accountability of management institutions (Wily and Dewees, 2001; Tacconi, 2007) while building social capital. A management program built on social capital can have positive ecological as well as economic benefits (Krishna, 2002). When people have confidence that other community members will likewise engage in cooperative resource use behavior, they are less likely to exploit resources unsustainably (Agrawal, 2002). Community-based Forest Management, specifically Village Forest Reserves became a new designation that limited forest threats and protected forest species while addressing livelihood needs (Blomley et al., 2008) and recent research has demonstrated that participating in local forest governance is strongly associated with improved forest outcomes (Persha et al., 2011). These stakeholders also bring local ecological knowledge (LEK) and social capital to the social-ecological system that may improve participation among villagers and achieve larger conservation goals (Berkes et al., 2000).

Decentralizing resource management has become an increasingly important part of development (Mmari, 2005) and is promoted to alleviate rural poverty while conserving biodiversity (Agrawal et al., 2008; Lund and Treue, 2008). In a decentralized system, decision-making power is shifted to lower levels of government—closer to the people who are directly affected by management and more capable of adapting to changing local conditions and needs. This transfer of power is expected to improve the responsibility of managers with the physical proximity to resources, LEK, and improved information all contributing to better and more efficient management (Agrawal and Yadama, 1997; Ostrom et al., 1999). While roughly two-thirds of developing countries utilize some form of decentralization (Agrawal and Ostrom, 2001), the co-management of forests often results in a failure of the regional government to provide adequate protection standards and rarely are management strategies, power, and participation integrated (Wily, 2001). Government institutions frequently resist transferring the appropriate and sufficient power necessary to regional or local governing bodies that would enable them to effectively carry out management goals (USAID, 2000). Further, many policies have provided access to, but not custodial responsibility for forests, offering no incentive to sustain the resources long-term (Wily, 2001). Thus, despite the participation of many communities in these management systems, Tanzania's forest cover has continued to decline—from over 41 million hectares in 1990 to 37 million hectares in 2000, and to approximately 33 million hectares in 2010—an annual decline of over 1% with subsequent lost biodiversity and forest products (FAO, 2011; URT, 2001).

Rural Tanzania provides an excellent example of how differing forest management institutions can influence food and water security (White and Martin, 2002). Most households are directly dependent on natural resources such as hunting, medicinal plants, timber, bee-keeping, charcoal production, surface water for irrigation and consumption, and soil fertility (Shvidenko et al., 2005). Despite the importance of forest management to large portions of the population, the effect of different forest management strategies has not been well quantified (Lund and Treue, 2008; Persha and Bloomey, 2009). This study uses an interdisciplinary approach to examine the influence of two differing management strategies on social and ecological systems among Sonjo villages of Northern Tanzania. The Sonjo are an agriculturally-based society living on the border of some of Africa's greatest biodiversity resources: the Serengeti National Park, Ngnorongoro Conservation Area and Lake Natron. The Sonjo are subsistence farmers dependent on surface irrigation and seasonal rainfall, having occupied permanent villages in this mountainous region for hundreds of years (Gray, 1963). Pre-colonization, the Sonjo were dependent on forests governed by informal practices with oversight by traditional leaders (*mwanamijie*) with social and religious norms influencing resource use behaviors (Adams et al., 1994). As reported in Strauch and Almedom (2011) and Gray (1963), the *mwanamijie* draw from an extensive knowledge base to govern traditional forests and their resources. Presently, forests in the Loliondo Forest Reserve are managed by either traditional practices or decentralized government strategies. Our objectives were to (1) examine local perceptions of each management system; (2) determine if differences in forest use exist; and (3) identify how natural resources such as forest structure, plant use, and water quality differed between forests. We hypothesized that differences in perceptions of forest management strategies result in differences in management compliance; and that this influences resource quality.

2. Methods

2.1. Study site

Data were gathered in the Sale Division of the Ngorongoro District, in northern Tanzania (2° 10′ S, 35° 45′ E). This district is located between the Rift Valley escarpment and the Serengeti Plains, divided by the Loliondo Game Controlled Area boundary (Fig. 1). The region is characterized by steep, forested mountains with sloping valleys and permanent springs feeding streams. The primary crops are maize, various beans, and cassava, with sorghum, millet, bananas, sugar cane, papaya, mango, oranges, onions and tomatoes making up smaller contributions. Of the Sonjo villages in the area, we focused on Samunge, the largest village, Kisangiro, Yasimdito, and Sale. Sale is not exclusively a Sonjo village, but a majority of its inhabitants are Sonjo. These villages were chosen as representative of the nine distinct Sonjo villages. Most villages have access to the Loliondo Forest Reserve (LFR), but many other areas have historically been protected as traditional forests. Villagers use the term "forest" to describe the hillside and riparian regions covered in trees, although woodland is a more appropriate term. In Samunge, the decentralized government-managed forest (GF) is the southern portion of the LFR termed Catchment Forest Reserve,

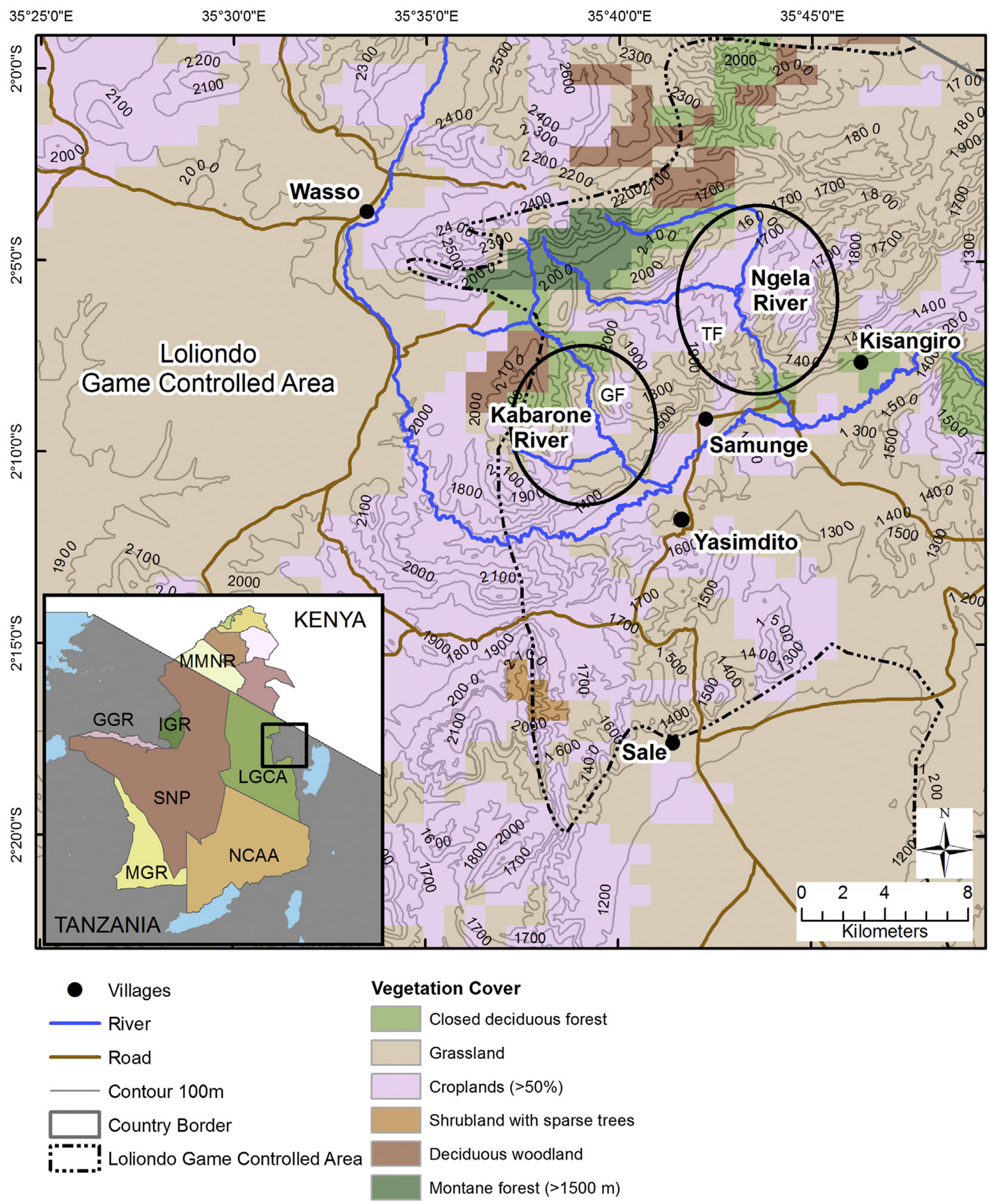

Fig. 1. Map of Northern Tanzania showing the location of the four study villages in relation to dominant vegetation cover, the Loliondo Game Controlled Area (LGCA), the Serengeti National Park (SNP), Ngorongoro Conservation Area (NCAA) and Massai Mara Nature Reserve (MMNR). A general outline of the government forest (GF) and traditionally-managed forest (TF) closest to Samunge are identified with their rivers.

located on the western edge of the village. The traditionally-managed forest (TF) is also part of the LFR, but is more centrally located in the village as a result of historical land-use patterns and is a place of religious, social, and ecological importance (Fig. 1). The Ngela and the Kabarone rivers both originate from the LFR, but the Ngela River flows within the TF and its use is governed by a group of traditional leaders called the *mwanamijie*, while the Kabarone River flows within the GF and is managed by the local government council.

2.2. Regional questionnaires

The authors initially used Participatory Rural Appraisal exercises which included a reconnaissance survey of the villages, participant observations, initial interactive learning and shared knowledge as well as single-gender focus group discussions with key informants (Almedom et al., 1997). These exercises helped frame the follow-up questionnaires. The second author (a Sonjo) gathered quantitative data concerning the management and knowledge of forests in four Sonjo villages. Villages surveyed included Samunge ($n = 30$, 8% of households), Kisangiro ($n = 30$, 9% of households), Yasimdito ($n = 30$, 11% of households), and Sale ($n = 46$, 5% of households). Household questionnaires focused on responses from the household head (often the mother/wife) with other household members supplementing the information. The actual population represented by the household survey is difficult to quantify because in some cases, multiple generations or multiple siblings live in the same household. Each village is composed of a sub-village organized geographically and household interviews were conducted using a stratified-random approach, interviewing a selection of households within each sub-village that ensured a diverse range of wealth and social status. Household responses were coded by gender and information on the age, education, and income of the respondents were recorded. Questions focused on knowledge of governing organizations, forest management policies, and behaviors related to forest conservation. To test the null hypothesis that there was no significant difference in responses between villages, we used a contingency table analysis with a chi-squared (χ^2) statistic ($\alpha = 0.05$).

Additional interviews ($n = 61$) were conducted in Samunge village focusing on the use and conservation status of forest resources using another stratified-random sample. We chose Samunge because it has clear delineations between forests and the sub-villages dependent on them. Villagers ranked the importance of various forest plants for their livelihoods. Rankings were first analyzed with a non-parametric Friedman Analysis of Variance (ANOVA) among categories and then with a Mann-Whitney *U* test between forests. As firewood was identified as the most frequent justification for collecting non-timber forest products, mean ± standard error (SE) of the number of times a household collected firewood from each forest per week was also determined.

2.3. Water quality

Water quality was assessed in the Ngela (TF) and the Kabarone (GF) rivers using both chemical and biological methods. Water samples were taken during base flows from rivers in May, June and July (dry season) from 2007 to 2009. Dissolved oxygen (DO), specific conductivity (EC) and temperature were measured directly in each river using an YSI multipurpose meter (Yellow Springs Inc., Yellow Springs, OH). Orthophosphate (PO_4^{-3}), total ammonia and ammonium (NH_T), and total nitrite and nitrate (NO_x) were measured within four hours of sample collection using standard methods as described in Strauch (2013). Samples were grouped by river for analysis but no statistical tests were performed due to small sample sizes.

Biological water quality was assessed from triplicate samples collected between 12:00 and 13:00 drawn in July, October, and November of 2008 as well as April and June of 2009. Total coliforms and *Escherichia coli* bacteria were quantified using the Colilert-18® and Quantitray-2000® system (IDEXX Industries, Westbrook, ME, USA) as described in Strauch (2011). A Repeated-Measures ANOVA on $\log_{10}(x+1)$ transformed data was used to examine the effects of forest management, month (time) and their interaction on total coliforms and *E. coli*. The sphericity test was significant for *E. coli* ($\chi^2 = 19.2$, $df = 9$, $p = 0.023$) and a Greenhouse-Geisser epsilon correction ($\varepsilon = 0.32$) was used in the univariate tests for *E. coli* within-subject effects, but not for total coliforms. Following a significant time effect, differences between forests were determined within each month using an unequal variance *t*-test. All analyses were computed using JMP statistical software (version 5.0.1.2, SAS Inc.).

2.4. Forest survey

Both forests surveyed face south and span a similar elevation gradient (1400–2000 m). To assess the size distribution of trees in each forest, three, 100 m × 10 m transects were surveyed parallel to each river starting at the bank-full width. All trees within each transect greater than 3 cm diameter at breast-height (DBH) were counted and measured based on Huang et al. (2003). Stem density and basal area were scaled up to the hectare unit. Only the largest stem of multi-stemmed trees was measured. Mean DBH for each transect was weighted based on total number of trees to calculate a mean tree size for each forest. Sizes were grouped into 10 cm size classes for comparison, and the relative frequency for each size-class was also calculated. Differences between size-classes and forests were determined using a two-way ANOVA. Following a significant model, one-way ANOVA using a Tukey's post-hoc multiple comparisons test was used to test for differences between the average relative frequency for each size-class.

3. Results

3.1. Perceptions of forest management

Sonjo villagers identified both decentralized government-managed forests (GF) and traditionally-managed forests (TF) as important sources of natural resources. In particular, forests supplied habitat for wildlife hunted for bushmeat, trees for household construction and fence maintenance, plants for medicinal use, and water for irrigation, consumption and hygiene. Further, TF played an important role in the social and religious customs of the Sonjo. Alternatively, GF were utilized more frequently for livestock grazing. The TF is managed by the *mwanamijie*, a group of religious leaders whose status has been passed from generation to generation for hundreds of years. The *mwanamijie* are important elders that care for the forest and water resources of the village while also settling land and water disputes and leading important ceremonies. Management duties in the GF are carried out by the Village Environmental Committee, with guidance from the district natural resources officer and under the direction of the Village Executive Officer and Village Council. Generally, duties included limiting access to herders for livestock grazing and the harvesting of trees for construction. Across all villages surveyed, 88% recognized that TF were governed by *mwanamijie* ($\chi^2 = 8.34$, df = 6, ns), while 74% recognized that the village government managed GF, with little variation ($\chi^2 = 6.94$, df = 6, ns) between villages (Table 1a). Seventy-seven percent were able to identify the boundaries of TF and 76% claimed that the boundaries were usually respected (not presented). Additionally, 97% claimed to understand the guidelines associated with traditional forest management ($\chi^2 = 1.07$, df = 3, ns), while only 39% of respondents understood the decentralized government's policies which varied significantly ($\chi^2 = 7.33$, df = 3, $p < 0.05$) by village (Table 1b). As expected, the government was rarely believed to be involved in TF and *mwanamijie* were rarely involved in GF. Most households were both actively planting trees and consciously retaining or protecting trees, although the method of conservation varied by village ($\chi^2 = 27.49$, df = 6, $p < 0.001$). This was primarily for water conservation, but also for utilitarian purposes such as for firewood or building materials, and for the demarcation of property boundaries, which also varied significantly ($\chi^2 = 56.7$, df = 6, $p < 0.001$) by village (Table 1c). Villagers in Samunge and Kisangiro reported planting and conserving trees for water conservation more frequently than in Sale or Yasimdito. In Samunge, trees were most frequently planted in traditional forests, while such behavior was less common ($\chi^2 = 29.99$, df = 6, $p < 0.001$) in the other villages (Table 1d). In Kisangiro, trees were most commonly planted within the garden area while tree planting was evenly distributed among the three options in Yasimdito and Sale.

3.2. Forest use behavior

Sonjo households recognized the central importance of forests for providing water, shade, and plant products and wildlife habitat.

Table 1
Proportion (and number) of household respondents who (a) identified each governing organization managing each type of forest, (b) could identify the regulations for each type of forest, (c) identified the particular method and motivation for planting or retaining trees, and (d) the location of tree conservation. Data are based on questionnaires in four Sonjo villages ($n = 30$ except Sale $n = 46$) in northern Tanzania. Percentages may not add up to 100% due to rounding.

	Samunge (n = 30)	Kisangiro (n = 30)	Yasimdito (n = 30)	Sale (n = 46)	All villages (n = 136)
a. Perceived governing organization					
... of traditional forests					
District Government	3% (1)	3% (1)	3% (1)	2% (1)	3% (4)
Village Government	0% (0)	10% (3)	3% (1)	17% (8)	9% (12)
Traditional Leaders	97% (29)	87% (26)	94% (28)	80% (37)	88% (120)
... of government forests					
District Government	27% (8)	17% (5)	10% (3)	11% (5)	15% (21)
Village Government	63% (19)	67% (20)	77% (23)	83% (38)	74% (101)
Traditional Leaders	10% (3)	17% (5)	13% (4)	7% (3)	11% (14)
b. Knowledge of regulations					
... of traditional forests					
Identified	97% (29)	93% (28)	97% (29)	98% (45)	96% (131)
Not identified	3% (1)	7% (2)	3% (1)	2% (1)	4% (5)
*... of government forests**					
Identified	60% (18)	33% (10)	30% (9)	35% (16)	39% (53)
Not identified	40% (12)	67% (20)	70% (21)	65% (30)	61% (83)
c. Conservation of trees					
*... by way of****					
Planting trees	3% (1)	0% (0)	0% (0)	2% (1)	2% (2)
Protecting trees	27% (8)	37% (11)	87% (26)	39% (18)	46% (63)
Both planting and protecting trees	70% (21)	63% (19)	13% (4)	59% (27)	52% (71)
*... as a motivation for****					
Utilitarian	60% (18)	10% (3)	30% (10)	70% (32)	46% (63)
Demarcation of boundaries	0% (0)	20% (6)	50% (15)	20% (9)	22% (30)
Water conservation	40% (12)	70% (21)	20% (5)	10% (5)	30% (43)
d. Location of tree conservation***					
Home garden	33% (10)	63% (19)	40% (12)	28% (13)	39% (53)
On farm	3% (1)	13% (4)	43% (13)	35% (16)	24% (33)
Within forests	63% (19)	24% (7)	17% (5)	37% (17)	37% (50)

*$p < 0.05$, ***$p < 0.001$ based on χ^2 contingency table analysis with $df = 3$ (for two rows) or $df = 6$ for three rows.

As subsistence agriculturalists, the Sonjo are dependent on wild plants for construction, food, forage, medicine, utensils, and fuel. The *mwanamijie* restrict access to and use of traditional forests in an effort to protect the vegetation and water resources through a system of taboos, social capital, fees, ceremonies and local policing. The TF are considered sacred and entrance is restricted by the *mwanamijie* to prevent physical, biological and spiritual contamination. It is believed that spiritually or physically impure people anger religious icons, causing water to stop flowing (Table 2). Reducing access prevents livestock from grazing and trampling the understory, humans from cutting trees for building materials or fuel, and the accumulation of animal or human waste in the forest.

The perceived importance of various types of plant resources did not differ among categories ($\chi^2 = 9.143$, $p = 0.103$) and the only difference between forests was for edible plants (Mann-Whitney $U = 94.5$, $p < 0.01$). Plants used for building materials, grazing livestock, and firewood or charcoal production ranked the highest (Fig. 2). Traditional homes were constructed primarily from forest materials such as sticks, wood poles, mud and thatch. Home construction and fence (made of thorny brush) maintenance occurred during periods of low agricultural activity. While firewood and traditional medicines were gathered continuously, seasonal agricultural activities dominate subsistence lifestyles and determine the frequency of wood products used for construction. Firewood was collected equally frequent (mean ± SE) between households dependent on GF (2.5 ± 0.3 times per week) or TF (2.4 ± 0.3 times per week).

3.3. Impact of forest management on water quality

The Ngela River (TF) had greater DO, lower temperatures, and less PO_4^{-3} and tended to be less contaminated with bacteria than the Kabarone River (GF; Fig. 3). Other values did not vary much between rivers (Table 3). Total coliforms were greatest in July of 2008 and April of 2009 whereas *E. coli* was greatest in October of 2008. There was a significant time effect for both total coliforms (repeated-measures ANOVA $F = 130.9$, $df = 1,16$, $p < 0.01$), and *E. coli* (repeated-measures ANOVA $F = 15.2$, $df = 1,16$, $p < 0.01$). Forest management also had a significant effect on both total coliform ($F = 32.2$, $df = 1,8$, $p < 0.01$) and *E. coli* ($F = 26.2$, $df = 1,8$, $p < 0.01$). There was no significant time*management interaction for total coliforms ($F = 2.18$, $df = 1,8$, ns), but *E. coli* ($F = 6.15$, $df = 1,8$, $p < 0.05$) had a significant interaction. Post-hoc significant differences ($p < 0.05$) between treatments within months are indicated in Fig. 3.

3.4. The impact of forest management on forest structure

Mean (± SE) stem density was greater in the GF (640 ± 71.0 ha^{-1}) compared to the TF (520 ± 26.5 ha^{-1}), but most trees were relatively small (Fig. 4a). The weighted mean (±SE) tree size in the GF was 19.7 cm (±1.6 cm) DBH compared to 30.1 cm (±2.2 cm) DBH in the TF and basal area was almost 50% greater in the TF (66.8 ± 16.9 m^2 ha^{-1}) than in the GF (43.9 ± 25.8 m^2 ha^{-1}). There was a significant size-class effect (two-way ANOVA $F = 7.73$, $df = 1.5$, $p < 0.001$) and size-class*management interaction

Table 2
Response quotes from *mwanamijie* and group discussions regarding traditional or decentralized forest management and their respective water resources.

Traditional forest management	Decentralized forest management
Forest use:	**Forest use:**
"There is a growing number of people and livestock. There is increased demand for irrigation, forage, bathing and livestock watering. We are placing more restrictions on people. If you are found guilty of breaking these restrictions and still deny that you are guilty, the elders will discuss your punishment with the *mwanamijie* and maybe we will make bad things happen to you (hex)."	"The watemi (Sonjo) are surrounded by maasai on all sides. Land for grazing areas and water for livestock are in demand. There is conflict over land from pressure and conflict within watemi, some are fighting over land."
"If a person is dirty or impure, they cannot enter the forest."	
Maintenance of water infrastructure:	**Maintenance of water infrastructure:**
"All the men, especially the youth, must clean the canals once a year together. This takes more than one day. All the main distribution canals have been prepared since the beginning. The private ones can be added on the owners land."	"Although we can get water, it is not clean (not protected from contamination)"
Forest management:	**Forest management:**
"There are norms and cultures that govern water management."	"Not well protected upstream. Livestock graze in the forest and hurt the water."
"The forest is well protected because the *mwanamijie* control this water. We can ask to get water for irrigation but there is not enough."	"There are trees that are endangered and the trees used for building materials are decreasing."
"The *mwanamijie* have the power and control of water resources. They can deny users."	"Sometimes people take their donkeys and pollute the water."
"Special laws were created to protect the water"	
"The *mwanamijie* can speak directly to God."	
Forest conservation:	**Forest conservation:**
"All the villages have protected forests. If the forest is breached, a sheep or a goat must be slaughtered. We then let the blood and entrails run on the land and water to make peace with the Gods."	"There is an increased demand for building materials so people are cutting wild plants."
	"There has been a change in plants/trees."
"Culture makes us strong; it doesn't allow people to destroy the environment."	"Some species of trees have been cut down for building materials."

($F = 3.91$, $df = 1{,}5$, $p < 0.01$), but no management effect ($F = 1.30$, $df = 1{,}5$, *ns*). Tree size in the TF was evenly distributed, with no significant differences between the abundances of each size class ($F = 0.64$, $df = 5{,}11$, $p = 0.68$) or the distribution of relative abundances ($F = 0.74$, $df = 5{,}11$, $p = 0.61$; Fig. 4b). By contrast, there were significant differences in abundances ($F = 11.66$, $df = 5{,}11$, $p < 0.001$) and relative abundances ($F = 11.01$, $df = 5{,}11$, $p < 0.001$) between size classes in GF, with the two smallest size categories having significantly greater abundances ($p < 0.05$).

4. Discussion

While the protection of biodiversity in conservation areas has limited the exploitation of some ecosystems, there are few examples successfully integrating rural conservation goals with development (Pretty, 2011; Scoones, 1996) or the use of LEK to facilitate local conservation goals (Müller et al., 2009). Although Tanzania is often used as a model system to evaluate the benefits of decentralized forest management policies, few studies have actually compared the consequences of differing management strategies for forest and water resources (Babili and Wiersum, 2010; Persha and Bloomey, 2009). Decentralization has improved local responsibilities and ecological outcomes under certain conditions (Pacheco, 2004), but in many circumstances, decentralization has failed to prevent the degradation of ecosystem services (Hall and Bawa, 1993; Persha and Bloomey, 2009). In Sonjo villages, we found that identification of boundaries and knowledge of regulations pertaining to the management of traditionally-managed forests was much higher than that for government-managed forests. We believe this translates to differences in forest use with consequences for both water quality and forest structure. We identified three potential issues with decentralized management: that 1) there is confusion among villagers regarding institutional responsibility; 2) that many villagers do not have an accurate knowledge of rules governing decentralized forest use; and 3) these rules have little social and religious importance and are therefore often ignored. As a consequence, we found differences in resource quality between forests.

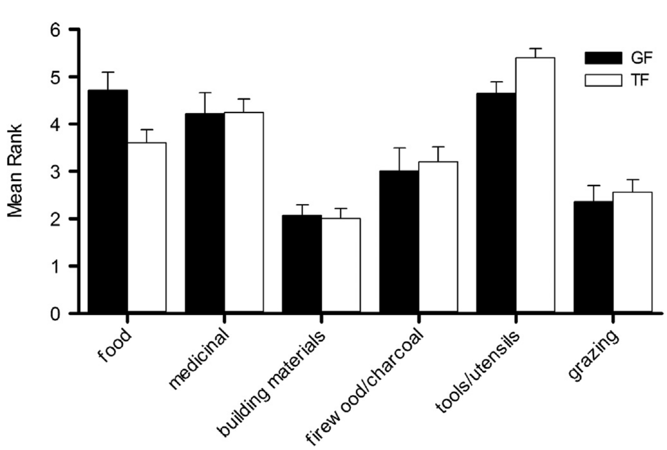

Fig. 2. Mean (±standard error) household ranking (1–6, 1 = most important) of important forest plant uses based on management (GF = decentralized government-managed forest, $n = 25$; TF = traditionally-managed forest, $n = 14$).

4.1. Importance of traditional forest practices to conservation goals

The sustainable management of forests is critically important as global change (climate change, land cover change, disease, invasive species) threatens the health of forest species (Thompson et al., 2009). Despite their cultural and economic importance, the communal management of natural resources is often perceived as maladaptive and blamed for biodiversity loss and soil erosion, (Naimir-Fuller, 2000; Redford and Richter, 1999), although in many instances community forestry promotes the sustainable utilization of natural resources (Persha and Bloomey, 2009). In some situations, despite the recognition that forests play a central role in vegetation, water and soil health, financial gains drive people to sacrifice public services for private profit (Pfund et al., 2011). The Sonjo are highly dependent on natural resources provided by forests to sustain their livelihoods (Gray, 1963), and the social and religious importance of TF provides both greater protection of trees as well as greater replanting of tree species. By instituting important traditions and customs, TRM increases the village's resilience

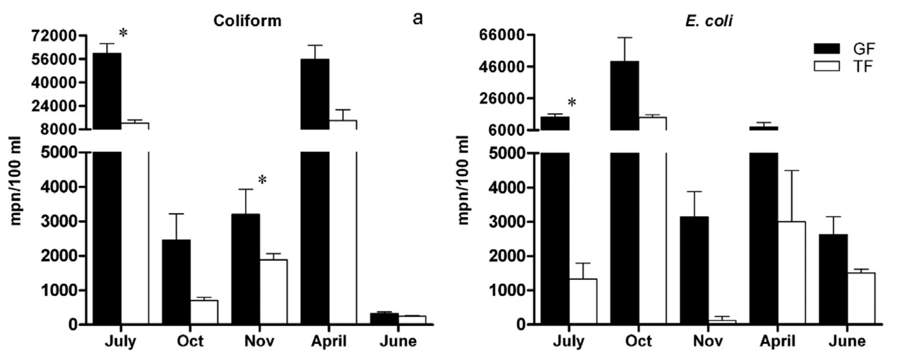

Fig. 3. Mean total coliforms (a) and *E. coli* (b) mpn 100 ml^{-1} in a river from a decentralized government-managed forest (GF) and a traditionally-managed forest (TF) from July 2008 to June 2009. Error bars represent standard error about the mean from replicate samples taken at one time period. *indicates significant post-hoc difference ($p < 0.05$) based on unequal variance *t*-tests of $\log_{10}(x + 1)$ transformed values.

to fluctuations in the social-ecological system (Strauch et al., 2008; Colding and Folke, 2000; Pretty, 2003). The *mwanamijie* have maintained the religious importance of forests by protecting and policing them, establishing rules and preserving the cultural traditions associated with forest use, aiding in their conservation (Goldsmith and Hildyard, 1984; Gray, 1963). Without this cultural relevance, the forest would likely be exploited unsustainably (Müller et al., 2009).

4.2. Influence of forest management on natural resources

Water quality is driven by both direct inputs and runoff as well as cycling processes within streams. Forest and riparian vegetation plays an important role in reducing the transport of sediment and fecal waste into rivers (Mnaya et al., 2006; Sheridan et al., 1999). In this study, there was little variation in the chemical composition of streams from differing management treatments, suggesting that at least during base flows, little differentiates erosion patterns from the two forests. However, it is possible that changes in erosion rates due to forest management are only apparent during storm events when overland flow transports sediment into streams (Coppus and Imeson, 2002). The lower average temperature and higher DO for the Ngela suggests greater riparian vegetation (Epaphras et al., 2007) and improved shading (St-Hilaire et al., 2000). Temporal variations in bacterial load suggest that *E. coli* is influenced by seasonal changes in precipitation and/or behavioral patterns of water users (White et al., 1972). The wet season lasts from December to April with peak rains in February to April. High agricultural activity in July and April coincided with high bacterial loads in surface waters, suggesting that behaviors such as the maintenance of the stream channel for irrigation re-suspends particulates, while reduced bacterial load in the TF relates to increased protection from livestock grazing and improved vegetation buffers (Strauch and Almedom, 2011). Animal usage of riparian and aquatic habitat can significantly degrade surface water resources (Strauch et al., 2009) and fecal contamination by wildlife and livestock is common in streams (Strauch, 2011). Inadequate sanitation facilities may also contribute to fecal waste pollution, posing a significant health risk (Atwill, 1996), especially when water is used for domestic purposes. Water quality and perceptions of water quality are important factors affecting the health of rural communities in East Africa (Strauch and Almedom, 2011; White et al., 1972). Based on water quality standards, both rivers violate the minimum limits established for bacterial water quality, which is

Table 3
Mean (±SE) orthophosphate (PO_4^{-1}), total ammonia and ammonium (NH_T), total nitrate and nitrite (NO_x), dissolved oxygen (DO), electric conductivity (EC), temperature (Temp), and total suspended solids (TSS) from one river each from a traditionally-managed forest (Traditional) and a decentralized government-managed forest (Government). Samples gathered during base flows in the dry season (May–July) from 2007 to 2009.

	Traditional forest	Government forest	n
PO_4^{-1} (mg L^{-1})	0.85 (0.21)	3.36 (1.32)	7,9
NH_T (mg L^{-1})	0.13 (0.06)	0.04 (0.02)	3,4
NO_x (mg L^{-1})	0.053 (0.009)	0.033 (0.003)	3,3
DO (mg L^{-1})	8.04 (0.16)	7.37 (0.30)	5,9
EC (μS cm^{-1})	244.4 (26.7)	191.5 (18.2)	5,9
Temp (°C)	19.4 (0.6)	22.6 (0.8)	5,9
TSS (mg L^{-1})	21.0 (1.53)	16.3 (2.44)	6,8

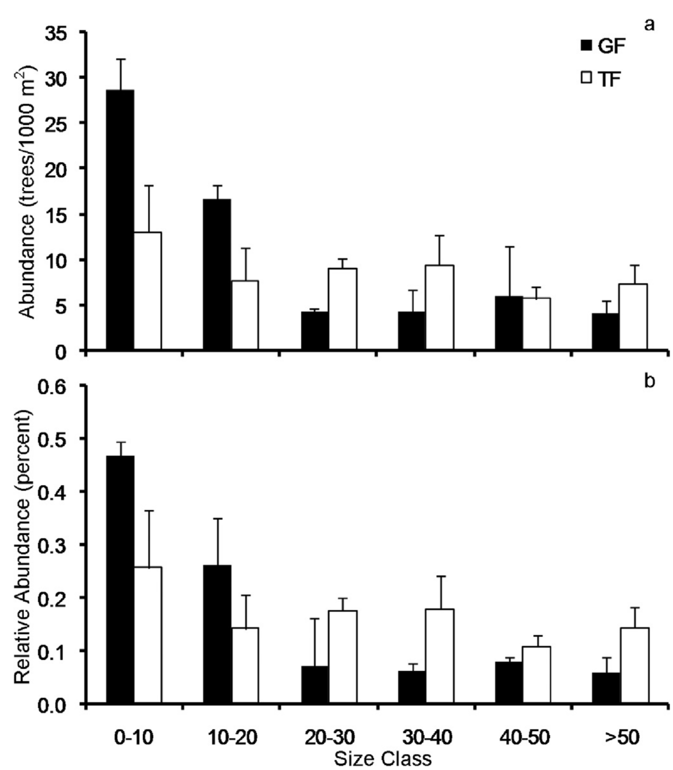

Fig. 4. Mean (±standard error) abundance (a) and relative abundance (b) of trees within each size class from a decentralized government-managed forest (GF, $n = 3$) and a traditionally-managed forest (TF, $n = 3$).

less than 10 mpn 100 mL^{-1} (WHO, 1997).

Forest vegetation is important to the social, cultural, and economic life of Sonjo communities (Gray, 1963; Smith et al., 1996). The government forest was dominated by young trees whereas the traditional forest had a more even size-class distribution. Uneven size-class distributions occur in forests near human populations due to logging and human-associated disturbance which increases the frequency of smaller-diameter trees (Ndangalasi et al., 2007). Manion and Griffin (2001) also concluded that sustainable, healthy forests have a more even size-class distribution maintained by consistent death, regeneration, and growth. Similarly, Huang et al. (2003) found size inequality in intact, mature forests in Tanzania was significantly less than in disturbed forest. Increasing the availability of alternative building supplies could reduce dependence on forest resources.

4.3. Maintenance of traditional forest management despite decentralization

Rural East African communities face insecurity from recurrent drought, unstable political regimes, disease outbreaks, land-use change, human-wildlife conflicts, and population migration (Sinclair et al., 2015). Despite this instability, social-ecological systems have been resilient to change (Lankford and Beale, 2007); resulting in the persistence of communities with few major social, economic, or geographic changes (Potkanski, 1987). Previous studies have described how traditional knowledge contributes to the social-ecological resilience of Sonjo communities, ensuring the sustainability of their livelihoods (Potkanski, 1987; Strauch et al., 2008). The success of these systems results from a combination of social cohesion and the sustainability of locally managed ecosystems (Naimir-Fuller, 2000) as well as their low population numbers maintained by out-migration. Previous research demonstrated the importance of LEK in the conservation of plant (Denevan et al., 1984), animal (Ruddle et al., 1992), soil (Wilson, 1995), and water resources (Strauch and Almedom, 2011).

Access to forest and water resources is an important part of subsistence livelihoods in rural Tanzania (Kangalawe and Liwenga, 2005; Sutton, 1990) and a good knowledge of governance systems and respect for the enforcement of such policies increases their compliance (Ostrom et al., 1999). Although there are similarities between traditional management and decentralized government management, their execution and results differed. First, a majority of villagers could not identify policies established by the government, suggesting a lack of communication or trust between regional policy makers and villagers. By contrast, the *mwanamijie* provide the religious, political, and social structures to effectively regulate access to resources—essentially limiting unsustainable or detrimental behaviors through local mechanisms. There are many examples of rural, semi-arid African communities coordinating the use of forest resources through local authorities (Sheppard, 1991) and Blomley et al. (2008) found that community involvement in forest management was correlated with improved forest condition in Tanzania. Watkins (2009) reported similar results, stating that villager perceptions of forests were important for the sustainable use of wood and water resources, but that attitudes and behaviors are heavily influenced by historical patterns in governance. Second, there are fundamental differences in the institutions governing these forests. Forest policies set by *mwanamijie* combine beliefs developed through LEK regarding the interconnectedness of religion, vegetation, water supply, climate, and the community. In this manner, forest conservation becomes a part of the cultural routine, and not a set of restrictions imposed by the government. Despite some progress with decentralized management, government rules are still developed and imposed top-down and often lack cultural relevance. Similarly, Hagmann and Chuma (2002) found that to develop sustainable natural resource management, policies must influence individual's decisions and behaviors.

5. Conclusions

Tanzania provides an excellent example of the challenges in moving towards a decentralized natural resource management system (White and Martin, 2002). Government-sponsored, basin-level management of water resources have been attempted with some success (van Koppen et al., 2004), although national policies often look at the big picture and ignore the local subtleties that human-environment interactions are based upon (Smith et al., 1999). Conservation policies will inevitably need to restrict the use of certain resources, as populations move into increasingly marginal landscapes, converting natural buffer zones, grazing areas and refuges into cropland (Madulu, 2004). However, when communities are left out of the management process, it often leads to inappropriate resource use (Naimir-Fuller, 2000). A variety of barriers limit the success of government policies in rural populations (e.g., language, culture, transportation, gender, infrastructure), but shifting to a regionally focused set of goals with decentralized policies is the first step to improving local stakeholder participation (Coulibaly-Lingani et al., 2011). At the same time, conservationists are shifting management priorities from a strategy based on maximum sustainable yield to a holistic perspective using an integrated and adaptive approach to environmental management (Berkes, 2007) as policy makers realize that many cultures provide their own mechanisms that limit unsustainable resource use (Feeny et al., 1990). Berkes and Folke (1998) outlined three requirements for successful ecosystem management: building knowledge and understanding of resource and ecosystem dynamics; developing practices that respond to ecological feedbacks; and supporting flexible organizations and adaptive processes. If decentralized management is to be an effective long-term strategy, all stakeholders need to be part of the planning and governance process and incorporating local customs and traditional rules will improve compliance. A network of local conservation plans that can be integrated into larger-scale management goals that limit environmental degradation without sacrificing cultural identity would improve their effectiveness over national policies imposed across landscapes.

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