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Note and Record

Ethiopian Orthodox church forests provide regulating and habitat services: evidence from stream sediment and aquatic insect analyses

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Introduction

Following centuries of deforestation driven by subsistence agriculture (Gelaw, Singh & Lal, 2014) and fuelwood harvesting (Darbyshire, Lamb & Umer, 2003), some of the only native forest in northern Ethiopia is in small groves surrounding church buildings (Wassie *et al.*, 2009; Cardelús *et al.*, 2013). In these scattered fragments, followers of the Ethiopian Orthodox Tewahedo Church have preserved indigenous forests as sanctuaries for prayer, and as sources of wood, fruit and other forest products to meet the church's needs (Aerts *et al.*, 2006; Bongers, Wassie & Sterck, 2006). Today, thousands of church forests ranging in size from 0.5 hectare to over 300 hectares can be found across the degraded northern Ethiopian landscape (Reynolds *et al.*, 2015).

Past research has emphasized the opportunities church forests offer for the study and conservation of Ethiopia's biodiversity (Aerts *et al.*, 2016; Cardelús *et al.*, 2012; Lowman, 2011; Wassie *et al.*, 2010). But in addition to their biodiversity benefits, cultural values and provisioning services, church forests also provide regulating and supporting services such as pollination, erosion control and water flow regulation (Millennium Ecosystem Assessment, 2005). De Groot *et al.* (2012) reported the global value of tropical forest ecosystem services at \$5264 ha^{-1} annually, of which nearly half was regulating services (\$2529 ha^{-1}). However, to date, there has been no systematic evaluation of regulating services in church forest systems. This study examines stream sediment dynamics and macroinvertebrate communities as integrative indices of water quality along church forest streams in an effort to quantify how streams might be affected by flowing through church forests, and the extent to which church forest buffer effects might improve downstream water quality.

Materials and methods

The study was conducted in January 2014, in the *meher* (postharvest) season, in four church forest streams in the South Gondar Zonal Administrative State (Fig 1).

Total suspended solids (TSS), soil and water temperature were assessed at 50 sampling points located 100 m upstream, 50–100 m within or alongside church forests and 100–250 m downstream. Samples were filtered on-site; the volume of water passing through filters was recorded and filter papers returned to the laboratory to be dried and weighed to measure TSS. Filters were then ashed for at least 4 h at 500°C to determine organic matter content. Higher TSS values and organic matter generally indicate poorer water quality (Getachew *et al.*, 2012).

Macroinvertebrate samples were also collected from church forest streams at 39 upstream, within-forest and downstream locations. Aquatic macroinvertebrate communities are routinely used to assess water quality (Beketov, 2004; Canobbio *et al.*, 2013) and to evaluate nutrient and sedimentation impacts (Ndaruga *et al.*, 2004) including in past studies in Ethiopia (Getachew *et al.*, 2012; Mereta *et al.*, 2012). Samples were taken from one square metre of benthic stones cleaned for all macroinvertebrates present. Macroinvertebrates were stored in 70% ethanol and identified using an ACCU-SCOPE 3079 microscope. Low water quality and low dissolved oxygen is indicated by the presence of stress-tolerant species such as *Diptera Chironomidae* (Yuan, 2004). Higher abundance of sensitive taxa including *Ephemeroptera, Trichoptera* and *Plecoptera* typically indicates higher water quality (Graham, Dickens & Taylor, 2004; Ambelu *et al.*, 2013).

Macroinvertebrate communities at each site were assessed using three biotic indices, namely taxa richness; the percentage of *Ephemeroptera*, *Plecoptera* or *Trichoptera*

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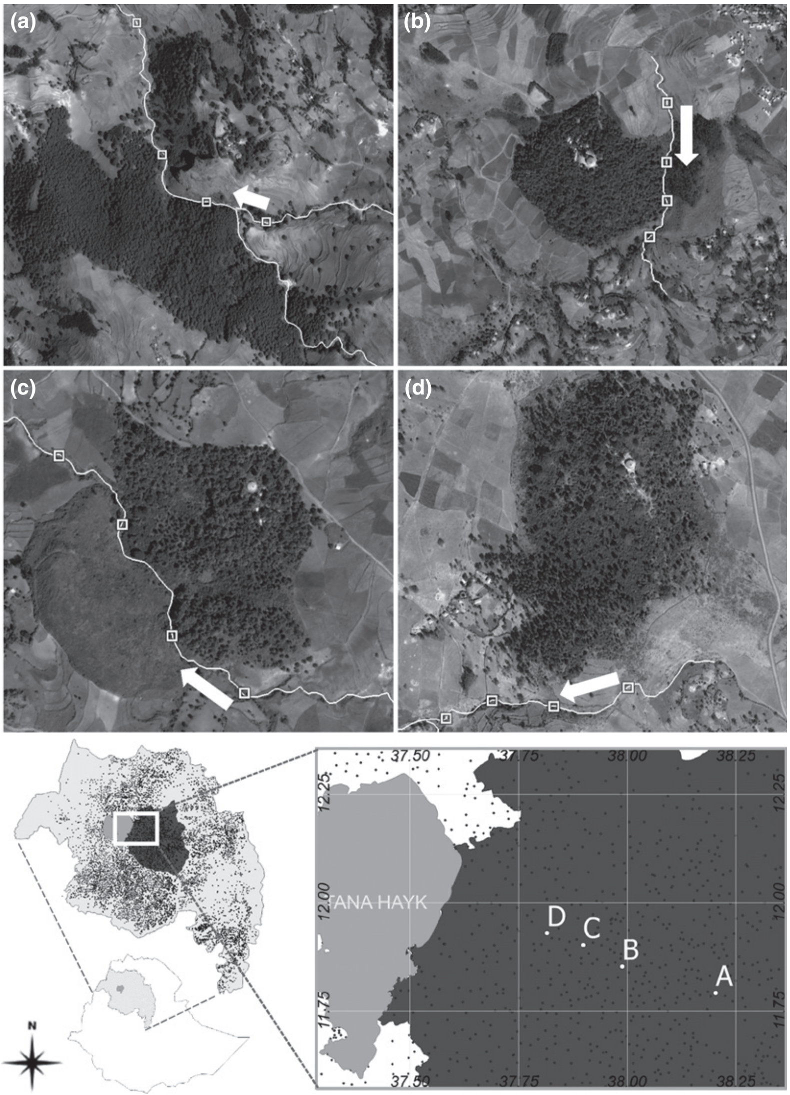

Fig 1 The four study forests (a) Dedim, (b) Debresena, (c) Alem Ber and (d) Woji in the South Gondar Zonal Administrative State (inset map, all sample forests located between latitudes 11.75° and 12.00°N and longitudes 37.75° and 38.25°E; black points denote other church forests in the study area). TSS, organic matter, soil and water temperature and macroinvertebrate communities were assessed at 39 to 50 sampling points located 100 m upstream from church forests, 50 m and 100 m within or alongside church forests and 100 m to 250 m downstream (location of sampling points denoted by white squares; arrows indicate map scale (length=100 m) and direction of stream flow)

(% EPT) in each sample (Yuan, 2004); and the Hilsenhoff Biotic Index (HBI) which takes into account the abundance and tolerance of each taxa to generate a value ranging from 0-10 indicating water quality and level of organic pollution (Hilsenhoff, 1982). Higher water quality is indicated by lower HBI values.

Results

Water quality findings

Total suspended solids (TSS) upstream averaged 0.29 g l^{-1}, but upon flowing through or alongside a church forest TSS dropped significantly to 0.19 g l^{-1} and retained this lower level at points 100–250 m downstream (Fig 2). Organic matter (not shown) followed a similar trend averaging 8 mg l^{-1} upstream and declining to 3 mg l^{-1} within forests and downstream. Soil and water temperature also dropped significantly upon entering a church forest, but the effect was short-lived – returning to upstream temperatures within 100 m downstream.

Macroinvertebrate findings

Species and abundance of the 3039 macroinvertebrates collected from the four church forest streams are summarized in Table 1.

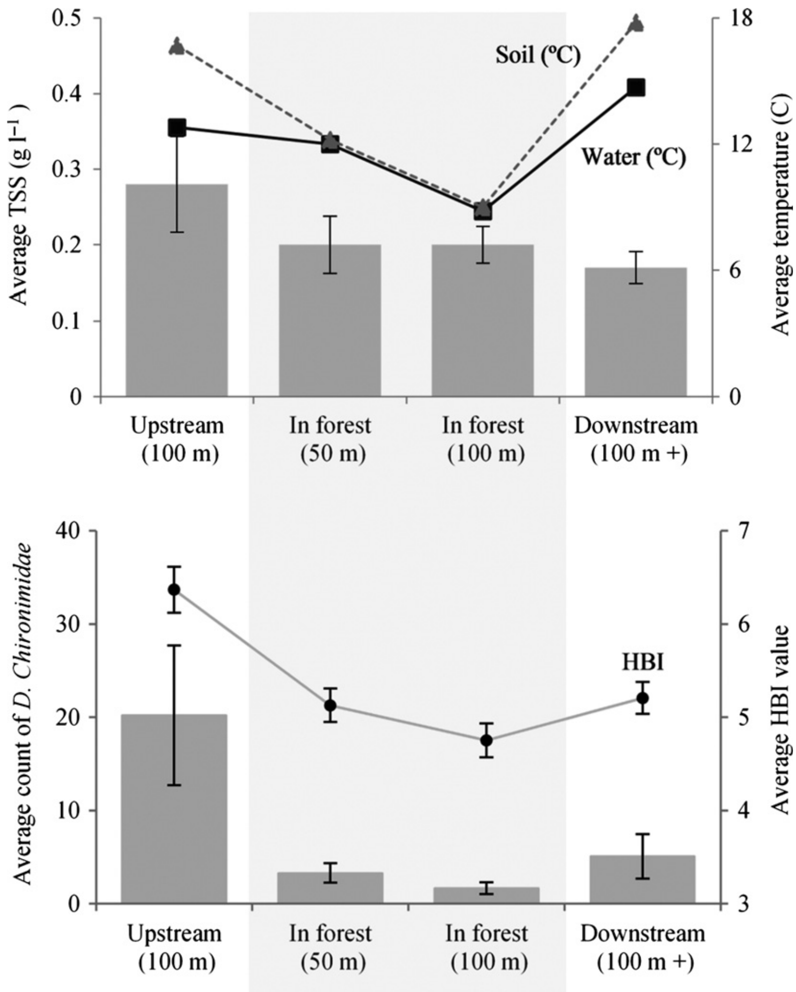

Fig 2 Average TSS (g l^{-1}), water and soil temperature (°C) at 50 sampling points along church forest streams (top graph, ± SE, n = 12, n = 15, n = 6, n = 17) and average count of *D. Chironomidae* present and average HBI value at 39 sampling points along church forest streams (bottom graph, ± SE, n = 10, n = 10, n = 6, n = 13). HBI is calculated as $(\sum n_i a_i)/N$ where n_i = number of specimens in taxa *i*, a = tolerance value of taxa *i* and N = the total specimens in the sample. Average TSS in streams declines upon flowing through church forest vegetation and remains relatively low upon re-entry into degraded agricultural land downstream. Lower counts of *D. Chironomidae* and lower HBI values indicate measurably higher water quality within church forests (shaded areas)

There were no significant differences in taxa richness or %EPT along church forest streams, but significant trends in *D. Chironomidae* and *T. Hydropsychidae* populations emerged in all streams, as did trends in HBI values. As further shown in Fig. 2, stress-tolerant *D. Chironomidae* were most abundant in the upstream locations (mean 20.2 per sample) and decreased significantly upon entry into a church forest (mean 3.3). Populations rebounded slightly within 250 m downstream from the church forest ($F_{3,35}$ = 4.06, P = 0.014).

HBI values along streams reflected similar trends. Higher HBI values were recorded at upstream sites, and lower values – indicating higher water quality – were recorded at sites within church forests. As streams exited the forests, HBI values rose significantly within 250 m, but remained below upstream values.

Discussion

Sacred natural sites represent unique microecosystems whose local and regional ecosystem service potential has only begun to be explored (Lowman, 2011; Aerts *et al.*, 2016). This study represents the first investigation of the potential regulating and habitat services provided by Ethiopian Orthodox church forests in terms of water purification and habitat for aquatic life. The measured effects were significant but relatively short-lived: streams appear to respond, even at a small spatial scale, to the shelter and filtration afforded by church forests' natural forest cover, but upon leaving the forests streams quickly respond to surrounding land uses and return to relatively low quality after flowing back into degraded agricultural land.

Table 1 Species composition and abundance of macroinvertebrates in four church forest streams, sorted by elevation (highest to lowest)

		Church forest and stream characteristics					
		Name (map ID)	Dedim (A)	Debresena (B)	Alem Ber (C)	Woji (D)	
		Area (ha)	36.6	11.5	14.5	22.5	Sample
		Elevation (m)	3037	2690	2153	2017	weighted
Order	Family	Stream order	1st and 2nd	1st	1st	1st	Per cent*
Ephemeroptera	*Caenidae*		3	22	86	21	7.1
	Baetidae		100	38	50	142	10.6
	Leptohyphidae		0	1	0	0	0.0
Trichoptera	*Limnephilidae*		0	13	5	0	0.9
	Hydropsychidae		9	107	63	424	17.6
	[other]		3	62	38	61	6.4
Platyhelminthes	*Turbellaria*		5	44	27	35	4.4
Odonata	*Anisoptera*		0	0	2	0	0.1
	[other]		0	0	1	0	0.1
Diptera	*Chironomidae*		43	143	34	91	11.1
	Simuliidae		680	24	110	449	36.3
	[other]		0	1	1	0	0.1
Hymenoptera	*Platygastridae*		0	1	0	0	0.0
Coleoptera	*Dytiscidae*		0	2	8	0	0.6
	Staphylinidae		0	1	0	0	0.0
Ceratopogonidae	*Forcipomyiinae* spp.		0	1	0	0	0.0
Annelida			0	46	35	0	4.2
Unknown	—		0	1	3	2	0.3
Sampling points			9	8	12	10	

*Sample weighted per cent given by ($\sum (n_j \cdot x_{ij}/x_j))/N$ where n_j is the number of samples taken in forest j, x_{ij} is the count of species i in forest j, x_i is the total macroinvertebrates collected at forest j and N is the total sampling points across all forests.

All sampled streams are perennial first- or second-order streams flowing from upstream agricultural land (wheat, barley, teff or maize) through or alongside church forest vegetation (Fig 1). Invertebrates were collected from 39 sampling points including at least two points upstream, four points within or alongside the church forest and two points downstream. Stream substrates varied from heavy silt to mixed silt, sand and small rocks. All streams showed evidence of human and livestock use upstream and downstream, with less (although nonzero) disturbance within the church forests

Streams in rural agrarian landscapes are integral components of smallholder agricultural systems and overall watershed health (Ndaruga *et al.*, 2004; Gelaw, Singh & Lal, 2014). The findings of this research highlight the potential for church forests to contribute to stream regulating and habitat services. At the same time, the thousands of church forests across northern Ethiopia may also provide valuable natural experiments demonstrating the potential impacts of natural vegetation restoration along streams in different contexts (Reynolds *et al.*, 2015). Further study of church forest streams can therefore inform broader regional watershed conservation strategies in northern Ethiopia.

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