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RESEARCH ARTICLE

Change of riparian vegetation from upstream to downstream reaches of a tropical river obstructed by a dam: A case study from Sri Lanka

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Abstract: Construction of dams across rivers is a common practice worldwide. However, obstructing free-flowing rivers could result in many negative impacts on riparian ecosystems, and are highly site-specific. In the present study, we evaluate the potential impacts of river regulation on the riparian vegetation by enumerating the vegetation at different distances from the dam/reservoir complex from upstream to downstream reaches of a tributary of the river Mahaweli in Sri Lanka. The tree-dominated riparian vegetation has been evaluated using belt transects located in the immediate and 8 km away from the reservoir/dam towards both upstream and the downstream of the tributary (US-0, US-8; DS-0, DS-8, respectively). A total of 150 species belonging to 58 families were identified, of which 43% were tree species. Approximately 77% of species were found exclusively in the upstream while 8% were recorded in the downstream. Both canopy and understory layers showed a significant decline in terms of richness, abundance, diversity and stem density from upstream to downstream. *Leuceana leucocephala* (Lam.) de Wit, an invasive tree species, showed higher relative abundance in downstream reaches, while riparian species such as *Terminalia arjuna* (Roxb.) Wight & Arn. and *Pongamia pinnata* (L.) showed no marked decline from upstream to downstream. The conditions triggered by reduced water discharges and severe river bank erosion may have contributed to these changes. The results indicate that the extreme water management practices in storage reservoirs have incurred negative impacts on the composition of the riparian vegetation. Introduction of well-coordinated flow management practices may help to mitigate some of these negative impacts.

Keywords: river diversion, riparian vegetation, dam-induced impacts.

INTRODUCTION

Riparian ecosystem occupies the ecotone between terrestrial and aquatic territories and is unusually complex and dynamic in nature compared to other terrestrial ecosystems (Nilsson and Berggren, 2000), possibly due to many natural and anthropogenic disturbances (Naimen *et al.,*1993; Hanlon *et al.,* 1998; Nilsson *et al.,* 1988). Riparian plants prefer distinct micro-environmental conditions compared to other terrestrial plants, including a shallow groundwater table (Shafroth *et al.,* 2000). Therefore, altered flood events and deepened groundwater table following river regulation affect the species composition of riparian forests and transform them into plant assemblages characteristic of upland vegetation (Decamps *et al.,* 1988). Studies conclude that construction of dams (and reservoirs) across rivers alters the hydrology in both upstream and downstream reaches thereby incurring environmental stress on associated plant communities (Gordon and Meentemeyer, 2006; Bombino *et al*., 2014), though the magnitude of these changes could be site-specific. The river regulation imposes inundation of habitats and establishment of new riparian zones in the upstream (Nilsson and Berggren, 2000), while the downstream reaches experiences lack of groundwater recharge and subsiding groundwater table (Nilsson and Berggren, 2000). Such hydrological changes have led to extinction of some riparian species, decrease abundance and alter species composition over time (Stromberg *et al.,* 1996; Merritt and Cooper, 2000). Extreme drought conditions that prevail in the immediate downstream due to low discharges influence plant survival, growth and species composition (Stromberg and Patten, 1991; Rood, *et al.,* 1995; Stromberg *et al.,* 1996), while changes in overbank flooding and floodplain sedimentation strongly influence the riparian vegetation in the downstream (Bendix and Hupp, 2000).

Studies aiming at assessing the impacts of river regulation are relatively fewer in the tropics (Moggridge and Hoggitt, 2014), whereas many reported in developed countries (Merritt and Cooper, 2000; Uowolo *et al.,* 2005; Dixon and Turner, 2006). The absence of detailed hydrological and long-term vegetation records has paved the path towards comparative studies on free-flowing and regulated rivers in order to enhance the current knowledge on dam-induced impacts (Getirana *et al*., 2009; Marcinkowski and Grygoruk, 2017). In the meantime, others attempted evaluating the dam-induced impacts on riparian vegetation by studying the vegetation at different distances away from the dam/reservoir complex towards upstream and downstream reaches (Mallik and Richardson, 2009). In the late 1970's, a major river development project (Accelerated Mahaweli Development Project, AMDP) was initiated in

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Sri Lanka with the aim of generating hydropower and irrigation facilities to dry zone areas. Under this mega project, number of dams and reservoirs were constructed across the river Mahaweli as well as across some of its tributaries. As a part of this project, in 1983 an earth-filled dam was constructed across the Ulhitiya Oya (oya = stream), a right bank tributary of the main river. The present study was conducted with the aim of identifying any dam-induced impacts on the composition, abundance and richness of the riparian vegetation along upstream and downstream reaches of the Ulhitiya reservoir. Due to lack of comprehensive botanical information (apart from a list of plant species) in the Environmental Impact Assessment (EIA) Report published in 1980 prior to the project, the present study compared the riverine vegetation at different distances away from the dam/reservoir complex towards both upstream and downstream, with the assumption that upstream (especially the riverine segment located 8 km upstream of the reservoir) is relatively less affected than that of the downstream due to river regulation. With no significant topographical differences from upstream to downstream reaches and with similar anthropogenic disturbances, we hypothesized that any changes that may observed in the riverine vegetation are direct impacts caused by the construction of dam/ reservoir complex across the Ulhitiya Oya (ULH).

MATERIALS AND METHODS

Study site

Ulhitiya Oya originates from the south-eastern plateau (350 m) of the central massif of the island and drains into the river Mahaweli at Ulhitiya. The study area receives much of its rainfall from the north-east monsoon (October to January), followed by a long dry spell from February to August. The study area comes under the Intermediate Zone with a mean annual rainfall ranging from 1,500 to 1,700 mm and mean annual temperature of 31.5 °C. However, the specific study area receives relatively a low mean annual rainfall of approximately 24 mm as calculated during the period of 10 years from 2003 to 2013 (Source: Hasalaka Weather Station of Irrigation Department, Sri Lanka). The terrain of the study area is relatively flat with an elevation of 350 m asl. The tropical moist semi-evergreen forests and the river-associated forests are the major near natural forest types in the study area (Ashton and Gunatilleke, 1987).

Physical attributes of the Ulhitiya Oya

Spill discharges

The reservoir has a total capacity of 88,000 acre foot with a catchment area of 28,230 ha. Mean monthly spill charges from the Ulhitiya Reservoir recorded in four consecutive years (2012-2015) are given in Figure 1.

Flow velocity and depth

Velocity of the water flow was measured randomly using a flow velocity meter (Valeport, Electromagnetic Flow Meter, Model 108) in different stream habitats (runs, riffles, and pools) in the immediate upstream and downstream of the river during successive wet and dry seasons starting from March, 2014 to February, 2015 (Figure 2). The mean flow velocity was significantly higher in the upstream than in the downstream, though no seasonal differences were observed between the reaches. The immediate downstream of the river was deeper than the immediate upstream (Figure 2).

Experimental layout

Eight river segments (100 m long) located at four different distances (two segments for each distance) from both upstream and downstream reaches of ULH were selected for the study, out of which four were located in the immediate upstream (US-0) and 8 km away from the reservoir (US-8) while the other four located in the immediate (DS-0) and 8 km away from the dam towards downstream (DS-8; Figures 3 and 4).

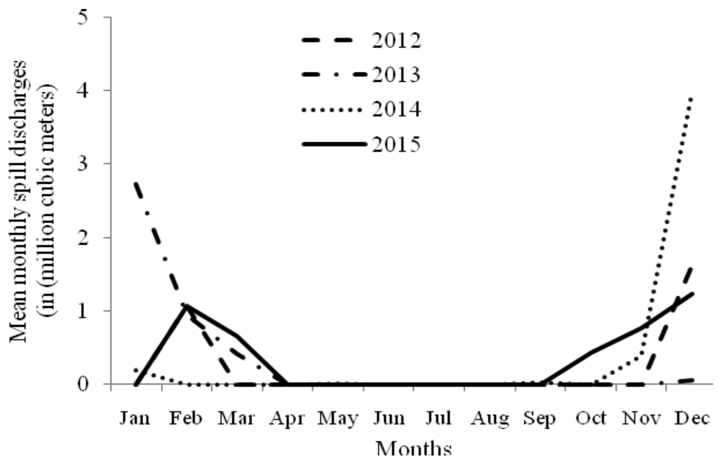

Figure 1: Mean monthly spill discharges (in million cubic meters) from the Ulhitiya Reservoir of four consecutive years, 2012, 2013, 2014 and 2015. Data credit: Mahaweli Authority of Sri Lanka.

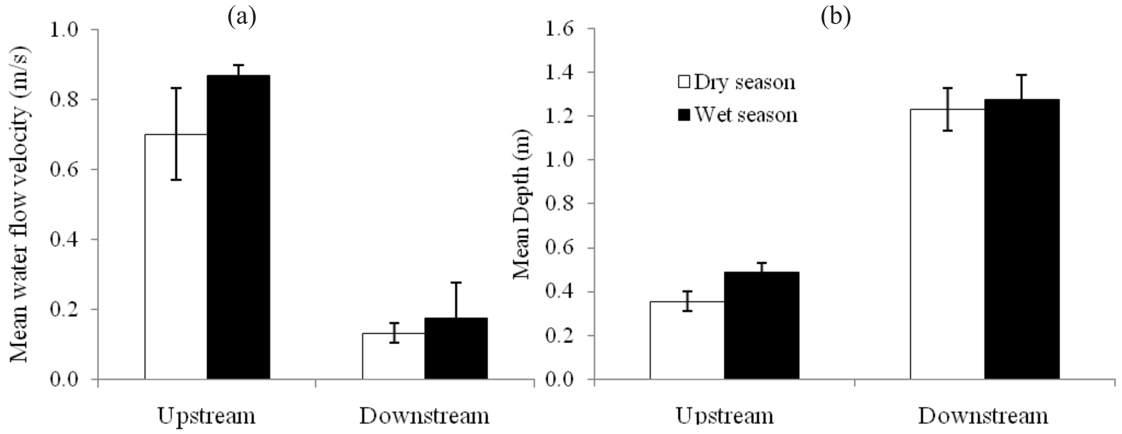

Figure 2: (a) Mean water flow velocity (m/s) in upstream and downstream of Ulhitiya Oya during a dry (March – August, 2014) and a wet season(September, 2014 to February, 2015) (Dry season: P= 1.01e-^{07}, F= 11.9, DF=1 Wet season: P=1.55^{e-12} F = 22.11 df=1) and (b) Mean depth(m) in upstream and downstream of Ulhitiya Oya during a dry and a wet season (Dry season: P=0.2e-^{16,} F= 46.78, DF=1 Wet season: P=0.2e-^{16,}F= 36.16,df=1). Each value is an average of six measurements taken for each parameter during each season.

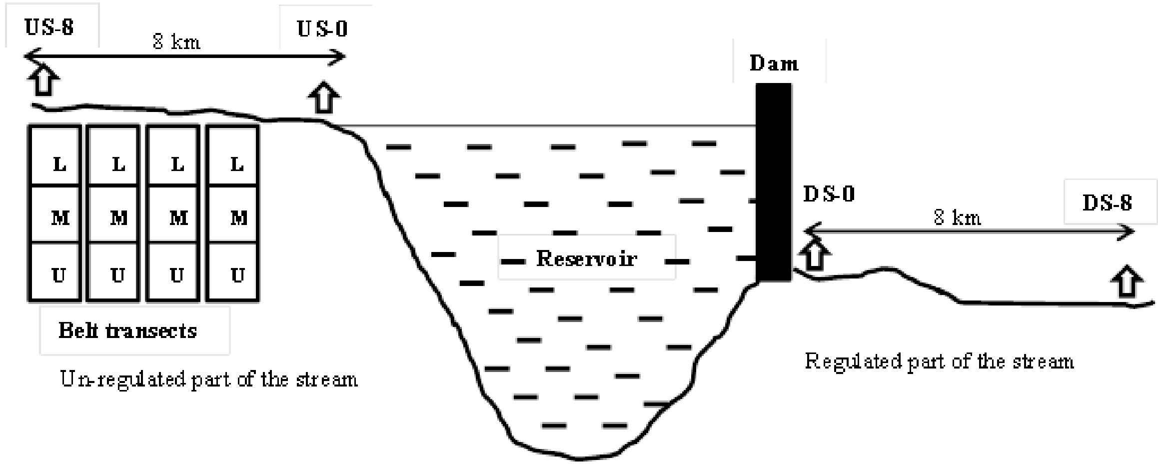

Figure 3: A schematic diagram depicting the locations of the river segments in the upstream (US-0 and US-8) and in the downstream (DS-0 and DS-8) of the Ulhitiya reservoir. Each study segment contained four belt transects established in both left and right banks at each distance totaling 32.

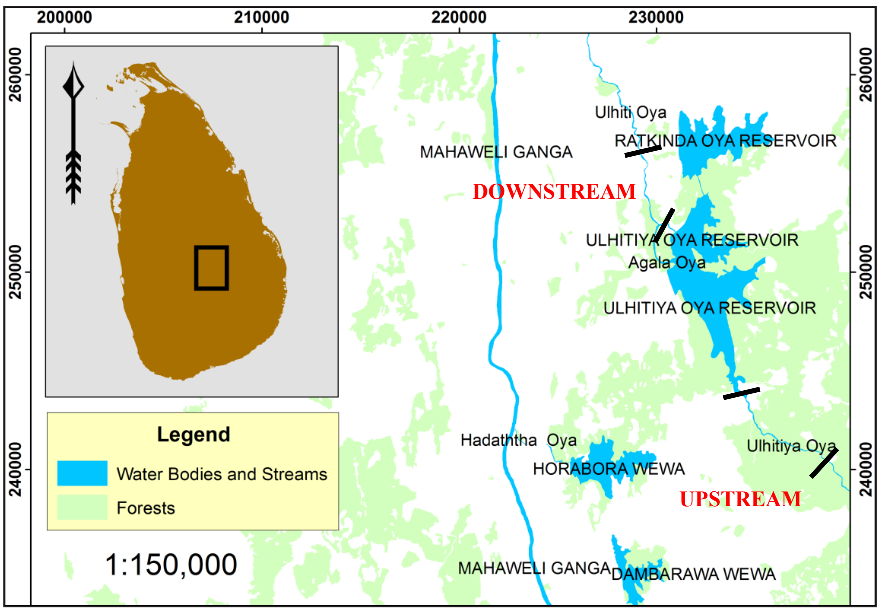

Figure 4: A map showing the study sites located in the upstream (US) and downstream (DS) reaches of Ulhitiya Oya, where study sites were located at different distances away from the dam/reservoir. The approximate study locations at different distances along the upstream and downstream reaches are indicated in black lines.

In each 100 m study segment, four 10 m × 30 m belt transects were established perpendicular to the river flow (totaling 8 belt transects in each distance). Transects started from the shallow waters and was extended along the bank until it reaches the upland vegetation. Each 10 m × 30 m belt transect was divided into three, 10 m × 10 m plots. The 100 m^2 plots closer to the river flow were categorized as lower zone (L), plots furthest to the river flow were marked as upper zone (U) while the plots in between L and U as middle zone (M) (Figure 3).

The study segments of the riverine vegetation were selected more or less randomly avoiding parts of the river devoid of riverine vegetation due to local anthropogenic disturbances. The riverine vegetation was categorized into three main layers (canopy, understory and ground) for the enumeration based on their diameter at breast height (dbh) and height. The 'canopy' vegetation (> 10 cm dbh) was enumerated using 10 m × 10 m plots. The 'understory' vegetation (> 1 m in height with a dbh< 10 cm) was evaluated in two, 5 m × 5 m. For both 'canopy' and the 'understory' layers, number of individuals were counted and identified. The remaining individuals (height < than 1 m) were defined as the 'ground' vegetation and estimated their cover values (as a %) visually in three, 2 m × 2 m plots. Vegetation sampling of the 'understory' and 'ground' layers was carried out twice to represent a dry (February to August, 2013) and a wet season (September to January, 2014) while the canopy layer was sampled only once.

Data Analysis

The density (number of individuals per square meter) and species richness (number of species per sampling unit) were calculated. The data was tested for normality in distribution using the Shapiro-Wilk test in R studio 0.98.490. As the data were not normally distributed, they were transformed into square root values before conducting analysis of variance.

A two factor factorial model (different distances; US-8/US-0/DS/0/DS-8 and riverine zones; L/M/U) was used to analyze the effects of the factors on density and species richness of vegetation. As vegetation sampling was done in two seasons (dry and wet) for the understory and the ground vegetation, the model was modified with another factor (Wet /Dry). The multi-way ANOVA in R studio version 0.98.490was used to analyze the effects of distances (US-8/US-0/DS/0/DS-8), riverine zone (L/M/U) and their interactions on the density and richness of canopy, understory and ground vegetation. When multi-way ANOVA indicated significant effects, one-way ANOVA was carried out with Tukey pair-wise comparison to explore mean separations. The Shannon-Wiener diversity (H') and evenness (E_H) indices were calculated using the following formulae (Shannon and Wiener, 1963; Pielou, 1969).

$H' = - \Sigma (p_i) [L_n (P_i)]$ ----------- (1)

whereas

H' = Shannon-Wiener Diversity Index,

p_i = proportion of total abundance of represented by i^{th} species.

$E_H = H'/L_n S$ -------------- (2)

whereas

E_H = Pielou Evenness Index,

H' = Shannon-Wiener Diversity Index and

S = total number of species.

RESULTS AND DISCUSSION

Composition, richness and diversity

A total of 150 species (65 trees, 24 shrubs, 48 herbs 7 grasses, 5 lianas and 1 fern) belonging to 58 families were recorded in all four study sites, out of which 136 (≈ 91%) were present in upstream plots and 34 (22.7%) in the downstream (Appendix 1; Table 1). There were 9 species (≈ 6%) common to all study sites. The species richness and abundance were markedly higher in upstream plots compared to downstream plots. The diversity was higher in the upstream compared to downstream reaches of ULH. Out of the five liana species, four were found in upstream plots with *Dalbergia pseudo-sissoo* Miq. recorded in both reaches.

Table 1: Comparison of species richness, abundance, diversity and evenness indices among four upstream (US-8 and US-0) and downstream (DS-0 and DS-8) plots at Ulhitiya Oya, Sri Lanka. Canopy layer was evaluated in 24, 100 m^2 quadrats while understory layer in 48, 25 m^2 quadrats and ground layer in 72, 4 m^2 quadrats.

	Upstream		Downstream	
	US-8	**US-0**	**DS-0**	**DS-8**
Species richness	82	96	26	34
Abundance (canopy + understory)	205	211	103	113
Number of exclusive species	40	46	0	5
Shannon-Weiner Diversity Index	3.50	3.24	2.34	1.75
Peulo's Evenness index (J)	0.88	0.84	0.81	0.68
Number of exclusive species	115 (77%)		12 (8%)	
Number of species common to all four study sites	9 (6%)			
Total number of species	150			
#Total number of Individuals	632			

#Only the canopy and understory vegetation layers were considered.

While 115 species (≈ 77%) present exclusively in the upstream, only 12 species (8%) found in the downstream. The downstream-only plant species included *Azardirachta indica* A. Juss. *Calotropis gigantean* R. Br.*, Carissa spinarum* L.*, Carmona retusa* (Vahl.)*, Cassia fistula* L.*, Chromolaena odorata* (L.) R.M. King & H.Rob. and S*amanea saman* (Jacq.) Merr. The present results show distinct differences in species compositions between upstream and downstream communities at ULH, indicating potential dam-induced impacts. A previous vegetation study carried out in rivers, streams and associated vegetation in Minipe area (located in the same climatic zone 34 km south-west of Ulhitiya reservoir) reported 27 tree species, of which only 17 species have been recorded in the present study (IEE, 2014).

Upstream of the reservoir are likely to experience more or less natural flow regimes and as a result the riparian vegetation seems to be relatively undisturbed. The marked decreases in terms of richness, abundance and diversity of the downstream riparian vegetation of the reservoir, support the fact that dam-induced impacts are more severe in the downstream than in the upstream reaches. A similar decline in species richness from upstream to downstream following river regulation was reported in Yampa and Green rivers in USA (Merrit and Cooper 2000). However, Mallik and Richardson (2009) concluded that the differences in plant communities amongst rivers are larger than that between upstream and downstream in a study conducted in three temperate rivers. As the Ulhitiya reservoir is a storage reservoir, the water management strategy is different from other reservoirs built under the AMDP with hydropower generation as the main target. At Ulhitiya, the spill discharges from the reservoir during the wet season have incurred catastrophic impacts in the immediate downstream as it releases copious amounts of water within a short period of time (Figure 1). In contrast, the reservoir discharges relatively less water from April to August (dry season) sufficient for farmers to crop their lands (Senalanadhikara and Manawadu, 2010). As a result, the immediate downstream of the Ulhitiya reservoir is experiencing severe and prolonged drought, especially during the long dry spells. Dott *et al.* (2016) also noted artificially-induced extreme drought in the immediate downstream of the river Dolores in USA and highlighted its negative impacts on the mositure-loving riparian vegetation. Jansson *et al.* (2000) also conclude that storage reservoirs with extreme seasonal fluctuations show lower richness and cover than that of run-of-river impoundments, with small daily fluctuations of water level. Thus, the hydrological droughts are more prevalent in downstream of regulated rivers (Du *et al.* 2011; Guo *et al.* 2011; Li *et al.* 2013). Hydrological drought has been recognized not only as a sociological issue, but also as a problem influencing its associated riparian vegetation.

Leucaena leucocephala (an invasive tree) and *Bauhunia racemosa* (a common dry and intermediate zone forest species) show higher relative abundance in downstream plots compared to upstream (Figure 5). *Terminalia arjuna* (a native riparian species) was more or less similarly distributed in both reaches. *Leuceana leucocephala* is known for its ability to withstand highly degraded and droughty conditions. Previous studies have shown similar observations where invasive plants such as *Tamarix* species colonize successfully in post-dam riparian vegetation

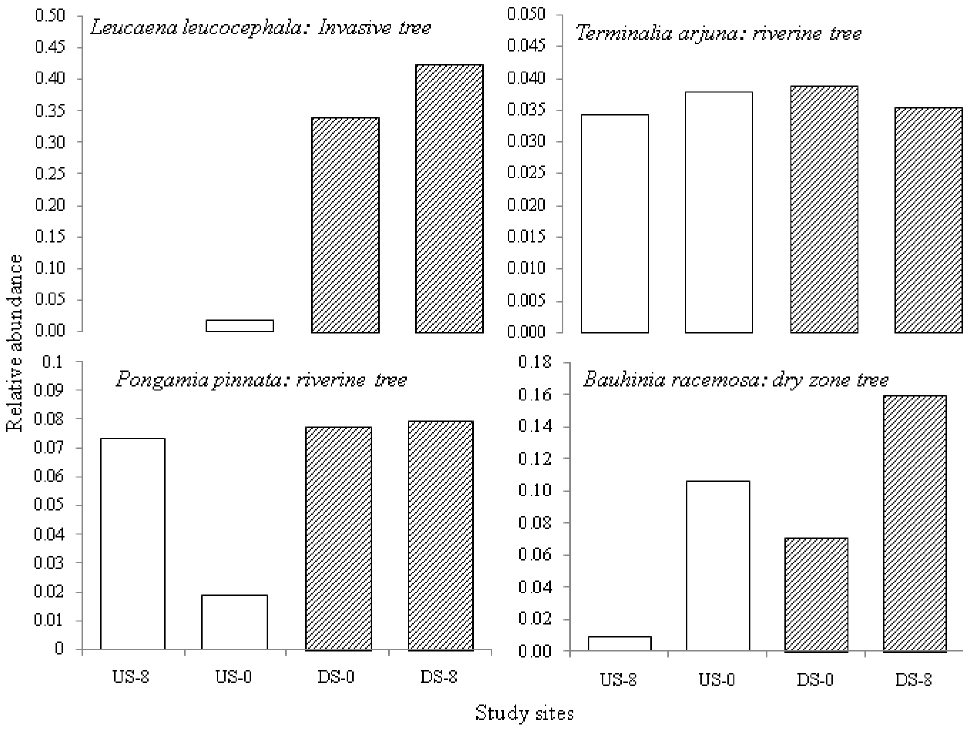

Figure 5: Relative abundance of *Leucaena luecocephala* (introduced, invasive tree), *Terminalia arjuna* (native, riverine tree), *Pongamia pinnata* (native riverine tree) and *Bauhinia racemosa* (dry zone native forest tree) in different distances away in the upstream and downstream reaches of the Ulhitiya reservoir/dam.

(Everitt 1998; Shafroth *et al.* 2002). The present study also observed higher abundance of dry zone forest species (*Bauhinia racemosa* and *Azardirachta indica)* in the downstream than in the upstream. Reduced frequency of riparian-indicator species and increased frequency of upland-indicator species in downstream areas have been observed following river diversion (Caskey *et al.* 2014). However, the common riparian species such as *Terminalia arjuna* and *Pogamia pinnata* showed no drastic reduction in their relative abundances from upstream to downstream reaches at ULH, indicting their resilience to changes caused by river regulation.

Density and richness

The density of the canopy vegetation showed a gradual decline from upstream to downstream (Figure 6). In contrast to canopy and understory layers, the ground vegetation showed no marked reduction in their cover values from upstream to downstream. Species richness of the canopy and understory layers showed a gradual decline from upstream to downstream plots, though not all differences are significant. The decline was marked in the understory layer (Figure 7).

The dam-induced impacts on the riparian plant communities were most conspicuous in the canopy and understory layers indicating their vulnerability. In contrary to the present findings, Klimo *et al.* (2013) observed that the herb layer has shown the most resgistered responses due to changes in the groundwater table following river regulation. The negative influence of river regulation on the riparian vegetation can attribute to subsidence of the water table as riparian species in particular are sensitive to changes in groundwater levels (Webb and Leake, 2006). Mature trees can survive for a short period under rapid drawdown, while saplings cannot (Shafroth *et al.* 2000). During the peak of the wet season, high intensity discharge of water from the Ulhitiya reservoir has contributed to severe river bank erosion in the immediate downstream. This phenomenon may also has contributed negatively to the density and richness of the riparian flora. In favour, Janssen *et al.* (2000) showed evidence to support that rivers that are obstructed by construction of storage reservoirs that undergo heavy fluctuations of water levels in the downstream, had lower species richness and cover than that of free-flowing rivers.

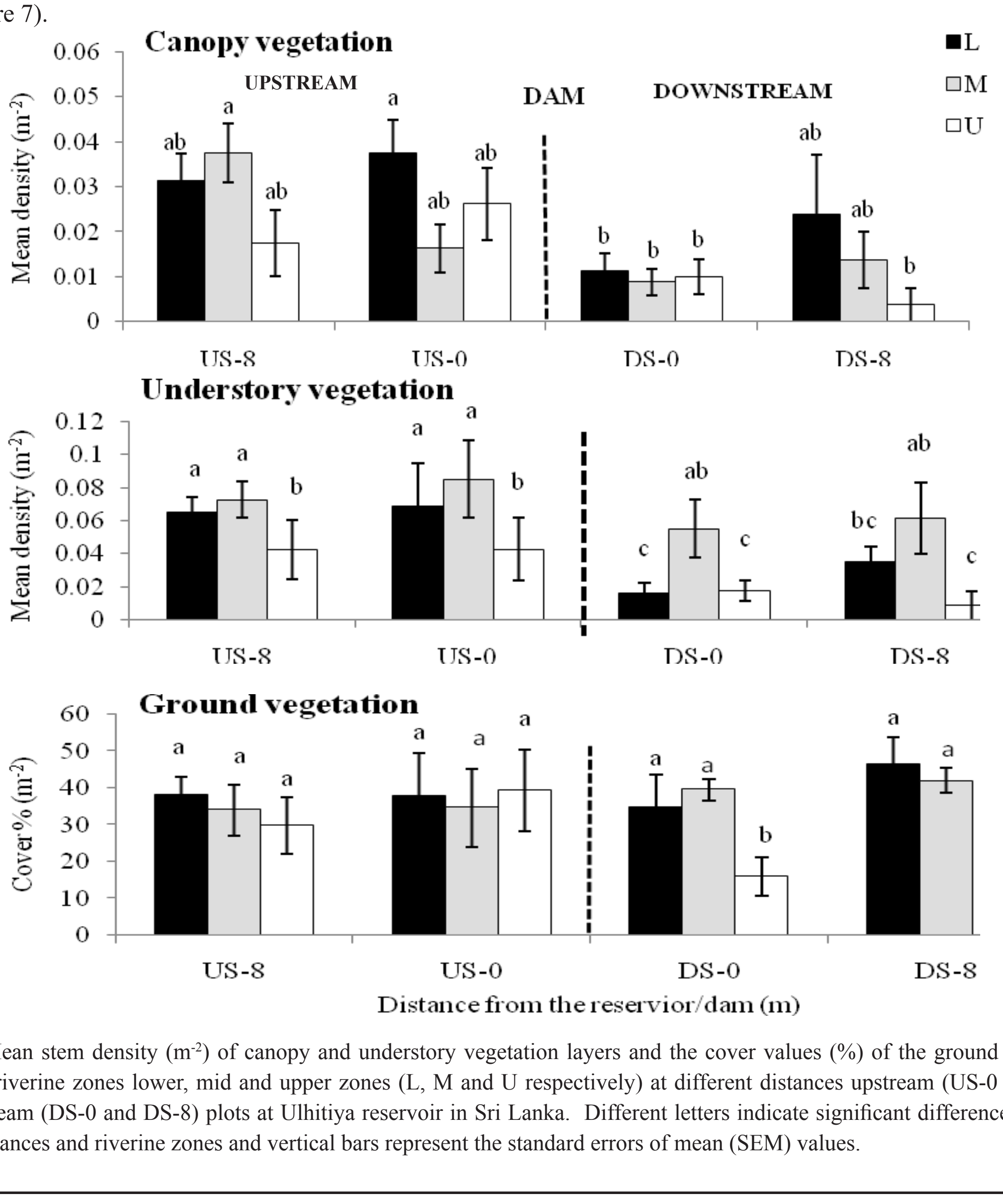

Figure 6: Mean stem density (m^{-2}) of canopy and understory vegetation layers and the cover values (%) of the ground vegetation along three riverine zones lower, mid and upper zones (L, M and U respectively) at different distances upstream (US-0 and US-8) and downstream (DS-0 and DS-8) plots at Ulhitiya reservoir in Sri Lanka. Different letters indicate significant differences between different distances and riverine zones and vertical bars represent the standard errors of mean (SEM) values.

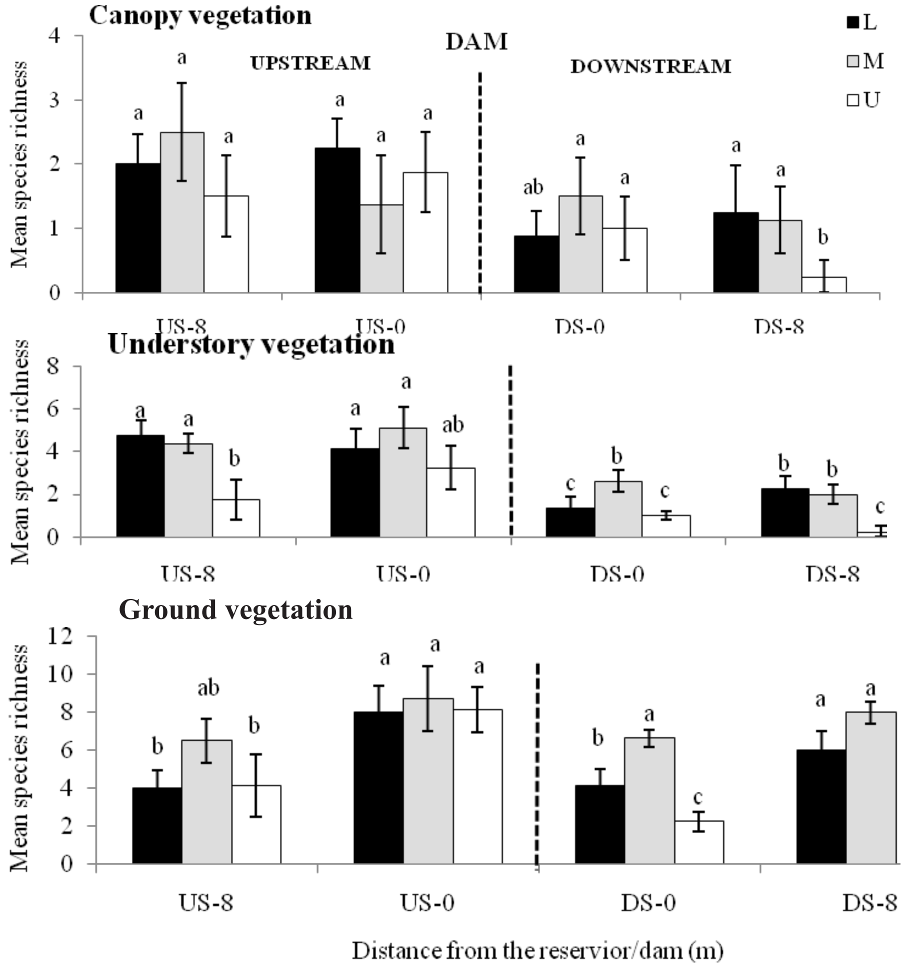

Figure 7: Mean species richness of the canopy, understory and ground vegetation layers along three riverine zones lower, mid and upper zones (L, M and U, respectively) at two distances in the upstream (US-8 and US-0) and in the downstream (DS-8 and DS-0) of the Ulhitiya reservoir. Different letters indicate significant differences between different distances and riverine zones and vertical bars represent the standard errors of mean (SEM) values.

CONCLUSIONS

The present findings at ULH highlighted negative dam-induced impacts on the riverine vegetation. The impacts of river regulation are more marked in the downstream reaches than in the upstream. This could be attributed to harsh environmental conditions in the downstream due to extreme water management practices in the reservoir. As a result, plants with the ability to withstand harsh conditions seem to colonize and thrive in downstream areas altering the composition of the riparian vegetation. In absence of any significant topographic differences from upstream to the downstream and with no consistent differences in anthropogenic disturbances, any changes observed in the riverine vegetation are due to altered habitat conditions since the construction of the dam/reservoir complex. Some detrimental impacts on the downstream riparian vegetation could be mitigated by introducing better coordinated flow regulation practices at the Ulhitiya reservoir.

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APPENDIX

Appendix 1: The total list of plant species including their families, habits and origin identified in upstream (US-8, US-0) and downstream (DS-0 and DS-8) riparian communities in the Ulhitiya Oya, Sri Lanka (√ indicates presence while × indicates absence). Invasive species are marked in bold. Abbreviations used: Habit, T – Tree, S – Shrub, H- Herb, L – Liana and F- Ferns; Conservation Status, Na – Native, En – Endemic and In – Introduced.

	Family	Habit	Origin	US-8	US-0	DS-0	DS-8
Acacia caesia	Fabaceae	L	Na	√	√	×	×
Acacia leucophloea	Fabaceae	S	Na	×	√	×	×
Acacia auriculiformis	Fabaceae	T	In	√	×	×	×
Adenia hondala	Passifloraceae	H	Na	√	×	×	×
Adiantum concinnum	Polypodiaceae	F		√	√	×	×
Ageratum conyzoides	**Asteraceae**	**H**	**In**	√	√	√	√
Allophylus cobbe	Sapindaceae	T	Na	√	√	×	√
Anamirta cocculus	Menispermaceae	L	Na	√	√	×	×
Aponogeton rigidifolius	Aponogetonaceae	H	En	√	×	×	×
Atalantia ceylanica	Rutaceae	S	Na	√	√	×	×
Atalantia monophylla	Rutaceae	S	Na	√	√	×	×
Atylosia trinervia	Fabaceae	H	Na	√	√	×	×
Azadirachta indica	Meliaceae	T	Na	×	×	√	√
Bauhinia racemosa	Fabaceae	T	Na	√	√	√	√
Breynia retusa	Phyllanthaceae	T	Na	√	√	√	√
Bridelia retusa	Phyllanthaceae	T	Na	√	×	×	×
Calotropis gigantea	Apocyanaceae	S	Na	×	×	√	√
Canthium coromandelicum	Rubiaceae	T	Na	√	√	×	×
Capparis zeylanica	Capparaceae	T	Na	√	×	×	×
Carissa spinarum	Apocyanaceae	S	Na	×	×	√	√
Carmona retusa	Boraginaceae	H	Na	×	×	×	√
Caryota urens	Arecaceae	T	Na	√	×	×	×
Cassia fistula	Fabaceae	T	In	×	×	√	√
Cassia saimea	Fabaceae	T	In	√	×	×	×
Cassia spectabilis	**Fabaceae**	**T**	**In**	×	√	×	×
Chloroxylon swietenia	Rutaceae	T	Na	√	×	×	×
Chromolaena odorata	**Asteraceae**	**H**	**In**	×	×	√	√
Chukrasia tabularis	Meliaceae	T	Na	√	×	×	×
Cipadessa baccifera	Meliaceae	S	Na	√	√	×	×
Clidemia hirta	**Melastomataceae**	**H**	**In**	√	√	×	×
Colocasia esculenta	Araceae	H	Na	√	√	×	×
Combretum albidum	Combretaceae	H	Na	√	√	×	×
Commelina diffusa	Commelinaceae	H	Na	×	√	×	×
Connarus monocarpus	Connaraceae	T	Na	×	√	×	×
Cratevaa dansonii	Capparaceae	T	Na	×	√	×	×
Croton aromaticus	Euphorbiaceae	H	Na	√	√	×	×
Croton laccifer	Euphorbiaceae	S	Na	×	√	×	×
Cycas circinalis	Cycadaceae	T		×	√	×	×
Cymbopogon nardus	Poaceae	G	Na	×	√	√	√
Cynometra iripa	Fabaceae	T	Na	√	√	×	×
Dalbergia lanceolaria	Fabaceae	T	Na	√	√	×	×
Dalbergia pseudo-sissoo	Fabaceae	L	Na	×	√	√	√
Derris canarensis	Fabaceae	H	Na	√	×	×	×
Desmos elegans	Annonaceae	T	Na	√	×	×	×
Dialium ovoideum	Fabaceae	T	Na	√	×	×	×
Dichanthium caricosum	Poaceae	G	Na	×	√	√	√
Dillenia retusa	Dilleniaceae	T	Na	√	×	×	×
Dimorphocalyx glabellus	Euphorbiaceae	T	Na	√	√	×	×
Dioscorea pentaphylla	Dioscoreacea	H	Na	√	√	×	×

Diospyros ebenum	Ebenaceae	T	Na	√	×	×	×
Diospyros malabarica	Ebenaceae	T	Na	√	×	×	×
Diospyros ovalifolia	Ebenaceae	L	Na	√	×	×	×
Diplodiscus verrucosus	Malvaceae	T	En	√	×	×	×
Drypetes gardneri	Putranjivaceae	T	En	×	√	×	√
Drypetes sepiaria	Putranjivaceae	T	Na	√	×	×	×
Elaeocarpus serratus	Elaeocarpaceae	T	Na	√	×	×	×
Pancratium zeylanicum	Poaceae	G	Na	×	√	×	×
Erythroxylum moonii	Erythroxylaceae	T	Na	√	√	×	×
Fahrenheitia zeylanica	Euphorbiaceae	H	Na	×	√	×	×
Ficus hispida	Moraceae	T	Na	√	×	×	×
Ficus microcarpa	Moraceae	T	Na	√	×	×	×
Ficus racemosa	Moraceae	T	Na	√	√	×	×
Flueggea leucopyrus	Phyllanthaceae	S	Na	√	√	√	√
Garcinia morella	Clusiaceae	T	Na	√	×	×	×
Gliricidia sepium	Fabaceae	T	In	√	×	×	×
Glycosmis angustifolia	Rutaceae	T	Na	×	√	×	×
Glycosmis pentaphylla	Rutaceae	S	Na	×	√	×	×
Gmelina asiatica	Lamiaceae	T	Na	√	√	×	×
Grewia helicterifolia	Malvaceae	T	Na	√	×	×	×
Grewia orientalis	Malvaceae	T	Na	√	×	×	×
Haldina cordifolia	Rubiaceae	T	Na	√	×	×	×
Helicteres isora	Malvaceae	S	Na	×	×	×	√
Hibiscus eriocarpus	Malvaceae	H	Na	×	×	√	√
Hibiscus micranthus	Malvaceae	H	Na	×	×	×	√
Hiptage benghalensis	Malpighiaceae	H	Na	×	√	×	×
Holoptelea integrifolia	Ulmaceae	T	Na	×	√	×	×
Humboldtia laurifolia	Fabaceae	T	Na	√	×	×	×
Imperata cylindrica	Poaceae	G	Na	×	√	√	√
Ipomoea obscura	Convolvulaceae	H	Na	×	√	×	×
Ixora coccinea	Rubiaceae	S	Na	√	√	×	×
Jasminum angustifolium	Oleaceae	S	Na	×	√	√	√
Lagenandra ovata	Araceae	H	Na	×	√	×	×
Lantana camara	**Verbenaceae**	**S**	**In**	√	√	√	√
Leucaena lecocephala	**Fabaceae**	**T**	**In**	×	√	√	√
Ludwigia perennis	Onagraceae	H	Na	×	√	×	×
Lygodium microphyllum	Lygodiaceae	H	Na	×	√	×	×
Macaranga peltata	Euphorbiaceae	T	Na	√	×	×	×
Madhuca longifolia	Sapotaceae	T	Na	√	√	√	√
Mallotus rhamnifolius	Euphorbiaceae	T	Na	√	√	×	×
Margaritaria cyanospermus	Phyllanthaceae	T	En	√	×	√	√
Mastixia tetrandra	Cornaceae	H	Na	√	×	×	×
Memecylon angustifolium	Melastomataceae	T	Na	√	√	×	×
Memecylon rostratum	Melastomataceae	H	Na	×	√	×	×
Microcos paniculata	Malvaceae	S	Na	×	×	√	√
Micromelum minutum	Rutaceae	T	En	√	×	×	×
Mimosa pigra	**Fabaceae**	**S**	**In**	×	√	×	×
Mimosa pudica	Fabaceae	H	Na	×	√	√	√
Morinda citrifolia	Rubiaceae	T	Na	√	√	×	×
Murraya koenigii	Rutaceae	H	Na	×	√	×	×
Murraya paniculata	Rutaceae	S	Na	×	√	×	√
Nauclea orientalis	Rubiaceae	T	Na	×	√	×	×
Ochna jabotapita	Ochnaceae	S	Na	×	√	×	×
Ocimum americanum	Lamiaceae	H	Na	√	×	√	×
Ocimum tenuiflorum	Lamiaceae	H	Na	×	×	×	√
Pancratium zeylanicum	Amaryllidaceae	H	Na	×	√	×	×
Pandanus ceylanicus	Pandanaceae	S	En	×	√	×	×

Pandanus kaida	Pandanaceae	S	Na	√	√	×	×
Panicum maximum	**Poaceae**	**G**	**In**	**×**	√	√	√
Paramignya monophylla	Rutaceae	T	Na	×	√	×	×
Parsonsia alboflavescens	Apocyanaceae	H	Na	×	√	×	×
Paspalidium flavidum	Poaceae	G	Na	×	√	×	×
Pavetta indica	Rubiaceae	H	Na	×	√	×	×
Phyllanthus amarus	Phyllanthaceae	H	Na	×	√	×	×
Phyllanthus baillonianus	Phyllanthaceae	H	Na	×	√	×	×
Phyllanthus polyphyllus	Phyllanthaceae	H	Na	×	√	×	×
Piper sylvestre	Piperaceae	H	Na	√	×	×	×
Polyalthia coffeoides	Annonaceae	T	Na	√	√	×	×
Polyalthia korinti	Annonaceae	H	Na	√	×	×	×
Pongamia pinnata	Fabaceae	T	Na	√	√	×	√
Pothos scandens	Araceae	H	Na	√	×	×	×
Pterospermum suberifolium	Malvaceae	T	Na	√	√	×	×
Rhinacanthus nasutus	Acanthaceae	H	Na	×	√	×	×
Rungia repens	Acanthaceae	H	Na	×	√	×	×
Samanea saman	Fabaceae	T	In	×	×	×	√
Sansevieria zeylanica	Asparagaceae	H	Na	×	√	×	×
Sapindus trifoliata	Sapindaceae	H	Na	×	√	×	×
Sarcostemma brunonianum	Apocyanaceae	H	Na	×	√	×	×
Schizostigma hirsutum	Rubiaceae	H	Na	×	√	×	×
Schleichera oleosa	Sapindaceae	T	Na	√	√	×	×
Schoenoplectus grossus	Cyperaceae	G	Na	×	√	×	×
Semecarpus gardneri	Anacardiaceae	T	En	×	√	×	×
Sida acuta	Malvaceae	H	Na	×	√	×	×
Solunum americanum	Solanaceae	H	In	×	√	×	×
Stachytarpheta urticaefolia	Verbenaceae	H	In	×	√	×	×
Streblus asper	Moraceae	H	Na	√	√	×	×
Streblus taxoides	Moraceae	S	Na	×	√	×	×
Strychnos minor	Loganiaceae	H	Na	×	√	×	×
Strychnosnux-vomica	Loganiaceae	H	Na	√	√	×	×
Syzygium cumini	Myrtaceae	S	Na	√	√	√	√
Tarmarindus indica	Fabaceae	T	In	√	×	×	×
Tectona grandis	Lamiaceae	T	In	√	×	×	×
Terminalia arjuna	Combretaceae	T	Na	√	√	√	√
Trema orientalis	Cannabaceae	T	Na	√	×	×	×
Tribulus terrestris	Zygophyllaceae	S	Na	√	×	×	×
Trichadenia zeylanica	Achariaceae	T	En	×	√	×	×
Ventilago madraspatana	Rhamnaceae	L	Na	√	×	×	×
Vitex altissima	Lamiaceae	T	Na	√	×	×	×
Walsura trifoliolata	Meliaceae	T	Na	×	√	×	×
Ziziphus lucida	Rhamnaceae	S	En	√	√	√	√
Ziziphus mauritiana	Rhamnaceae	S	Na	√	×	×	×