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Vegetation dynamics of ephemeral and perennial streams in mountainous headwater catchments

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Abstract: Ephemeral and perennial streams of mountainous catchments in Sabaragamuwa Province of Sri Lanka and Hong Kong of China were studied for two years on vegetation dynamics. Each year, sampling was conducted during a period when ephemeral streams had low surface flows. Sampling was realized contiguously using belt transects. The standing crop biomass (hereafter biomass) of herbaceous vegetation in ephemeral channels was comparatively lower than perennials and so was the herb diversity. Herb diversity showed a peak from 1.5 to 4.5 m from the centerline/thalweg of ephemeral and perennial streams. Out of 24 herbs, only three were common for both. A peak herb biomass zone was observed in perennials in the same region where diversity peaked. In ephemerals, herb biomass increased laterally up to ~1.5 m, and was constant thereafter. Seedling experiment results tallied with the field diversity observations of both stream types, and suggested that seed dispersion was the main reason for herb colonization. Furthermore, it showed sapling emergence to be significantly higher in perennials than ephemerals. Return period of annual maximum monthly rainfall was a strong indicator of age of trees in ephemeral streams, and elucidated the possibility of hindcasting past flow episodes. Electrical conductivity was significantly high in ephemeral streams among all the water quality parameters. The contents of the water nutrients were approximately the same in both stream types. While recommending further studies on eco-hydrology of ephemerals, we recognize ephemeral streams to be valuable references in climate change studies due to their responsiveness and representativeness in long term hydrological changes.

Keywords: Ephemeral streams; Herb diversity; Biomass; Mountainous areas; Perennial streams; Sri Lanka

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Introduction

Not all streams and rivers flow throughout the year, some may flow only for a few hours, days or months. These are known as non-perennial streams and have several different sub-types: ephemeral, intermittent, episodic, seasonal (Datry et al. 2014), and zero-orders (Fritz et al. 2006; Gomes et al. 2017) (in this paper the term ephemeral will be used for all forms of non-perennial streams). In some regions, ephemeral stream length exceeds that of perennial stream sections, and the average extent of ephemeral channel length within river networks around the world is nearly half (Datry et al. 2014; Gomes et al. 2017). The dry stream channel of ephemerals, though less pronounced, has an identifiable stream cross section and may have many morphological characteristics such as meanders, braided channels and mesoscale physical habitats similar to perennial streams.

During the dry phase, ephemeral streams accumulate litter and large particulate organic matter (e.g. woody debris) in bulk quantities (Jacobson et al. 1999). These will ultimately be transported to the perennial sections and subsequently to the downstream reaches. Therefore, ephemeral streams are not just paths of water flow, but also paths of transfer of sediment and litter in large quantities within a relatively short period of time when water flow resumes. Ephemeral streams provide habitats for several types of fauna, especially in disconnected pools before they completely dry (Bonada et al. 2007).

Ephemeral streams unlike their perennial counterparts are not subject to extensive research, especially in the field of freshwater ecology (Datry et al. 2014). Recently, several studies have shown the importance of ephemeral streams referring to its drainage and ecological functions (Friedman and Lee 2002; Fritz et al. 2006). This is a remarkable change of perception as several decades back, ephemeral streams were treated merely as surface flow paths (Meinzer 1923). A review of mainstream scientific literature would suggest disproportionately less emphasis on ephemerals (Stromberg et al. 2009). Furthermore, the role of ephemerals and their importance has not yet been universally agreed upon across different disciplines. As an example several hydrological software treat ephemeral flows similar to surface runoff.

The bulk of ecological studies in ephemeral streams have been done in arid, semi-arid or dry regions (Friedman and Lee 2002) and a few studies on ephemeral streams have been carried out in mountainous regions with large (>2000 mm) annual precipitation, such as tropical regions like Sri Lanka and Hong Kong. The literature on ephemeral streams of Sri Lanka is scarce. The study by Panabokke (2002) had recognized the role of ephemeral streams in linking the cascade system of irrigation reservoirs and a few studies were done in ephemeral ecosystems in Sri Lanka identify important fauna (Gunawardene et al. 2010). However, in many cases ephemerals were not treated as lotic ecosystems, and study periods were limited to the aquatic resident time of the fauna. In the case of ephemeral streams in Hong Kong, the documentation is not uncommon in many geology related publications (e.g. Franks 1999; Dai and Lee 2002). However, most are a mere mention of these streams as a landscape feature or a brief mention of flow after a rainfall event.

Ephemeral streams of mountainous headwater areas have been recommended for future/further investigation by several recent studies (e.g. Bateman et al. 2015, Stromberg and Merritt 2016). The first objective of this study was to observe herb dynamics (diversity, standing biomass production and ecological boundaries) and tree recruitment of ephemeral streams covering the active channel to terrestrial zones and compare patterns with perennial streams. Studying herb dynamics of ephemerals is important due to lack of comprehensive studies, unlike the study of woody plants (Stromberg and Merritt 2016). Correlating tree dynamics to the catchment hydrology to hindcast historical flood events was the second objective. The third and final objective was to investigate the water quality and flood control potential of ephemeral streams.

1 Materials and Methods

1.1 Study areas

Sampling was carried out in selected mountainous regions of Sri Lanka and Hong Kong, China. The Sri Lankan sampling covered not only ephemerals but also the closest comparable (i.e., with similar bankfull channel dimensions) perennial sections. In this regard, streams that connect Walawe river in its upper course (one of the main rivers in Sri Lanka) in Balangoda, Sabaragamuwa Province (Figure 1a) were considered. In Hong Kong only ephemerals were sampled and the data collected was limited for test and validation of the second objective. Ephemerals connecting to Tseng Lan Shue River, Eastern New

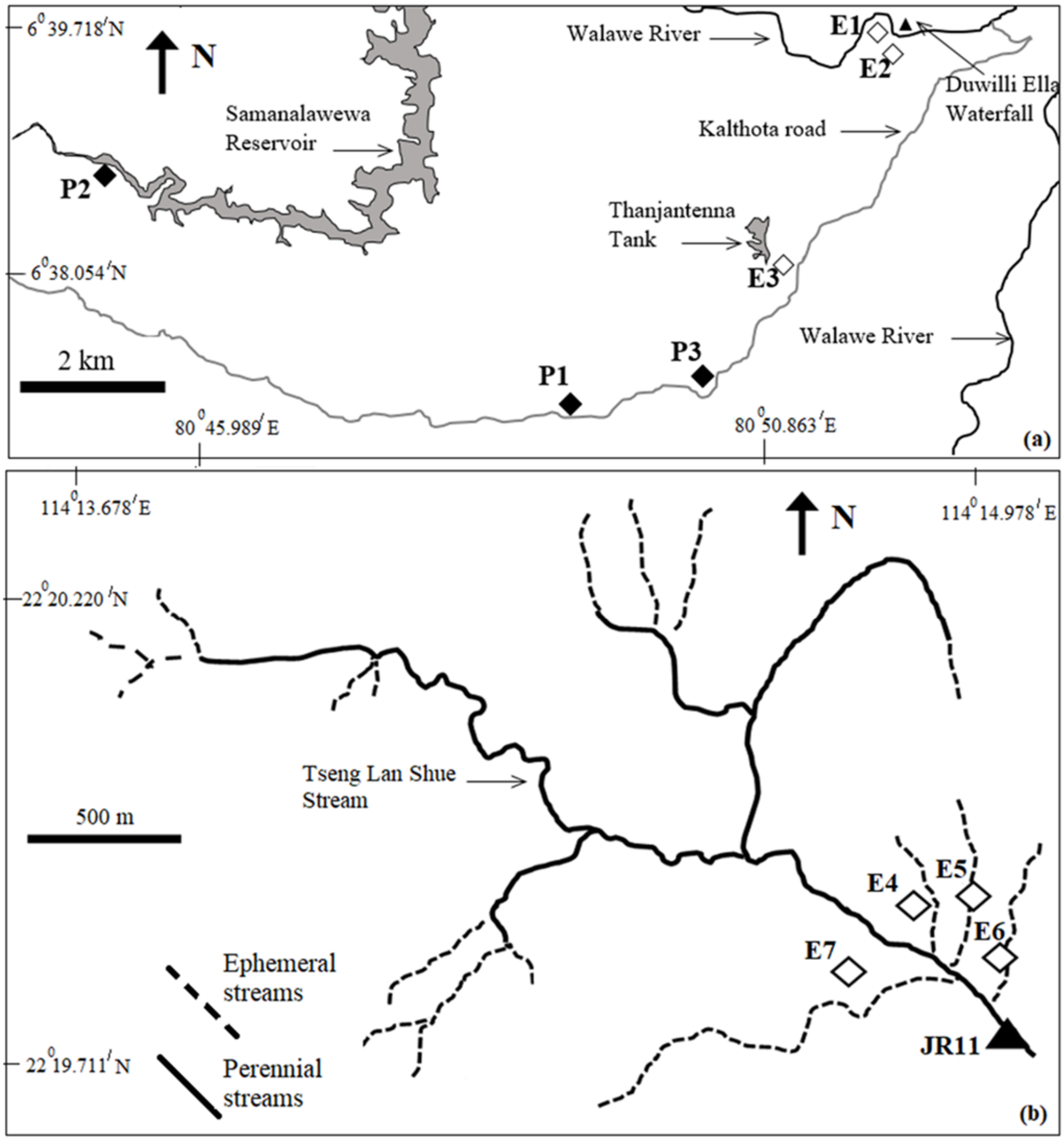

Figure 1 Maps of sampling sites in (a) Balangoda, Sabaragamuwa Province of Sri Lanka (b) in Eastern New Territories of Hong Kong, China. JR11 is a perennial monitoring station of the Tseng Lan Shue stream, and is managed by Environmental Protection Department, Hong Kong, China. (P: Perennial; E: Ephemeral sections.)

Territories were sampled (Figure 1b). All stream reaches of Sri Lanka and Hong Kong were free from significant regulation activities such as straightening, dredging, damming and so forth.

Wet and intermediate zones are two of the main three climate zones in Sri Lanka. The study area in Sri Lanka belongs to the intermediate zone, but very close to the boundary of wet and intermediate zones. Figure 2a shows the rainfall data of Balangoda for 2015 and 2016. Normally, the rainfall commences in the middle of March and continues to April (first inter monsoon) and gradually decreases after May. Again the rainfall increases after August as a result of the later stage of south western monsoon and second inter monsoon (Figure 2a). The second inter monsoon brings rainfalls of high intensity until November and sudden decrease in rainfall can be observed in January, and would continue until February. January-February and July-August are the periods with low rainfall, as was the case during 2015 and 2016. Total annual rainfall in 2015 and 2016 was about 3500 mm and 2000 mm, respectively. The total rainfall in 2015 was exceptional, as it was well above the typical annual rainfall that ranges from 1500 to 2000 mm (Department of Meteorology

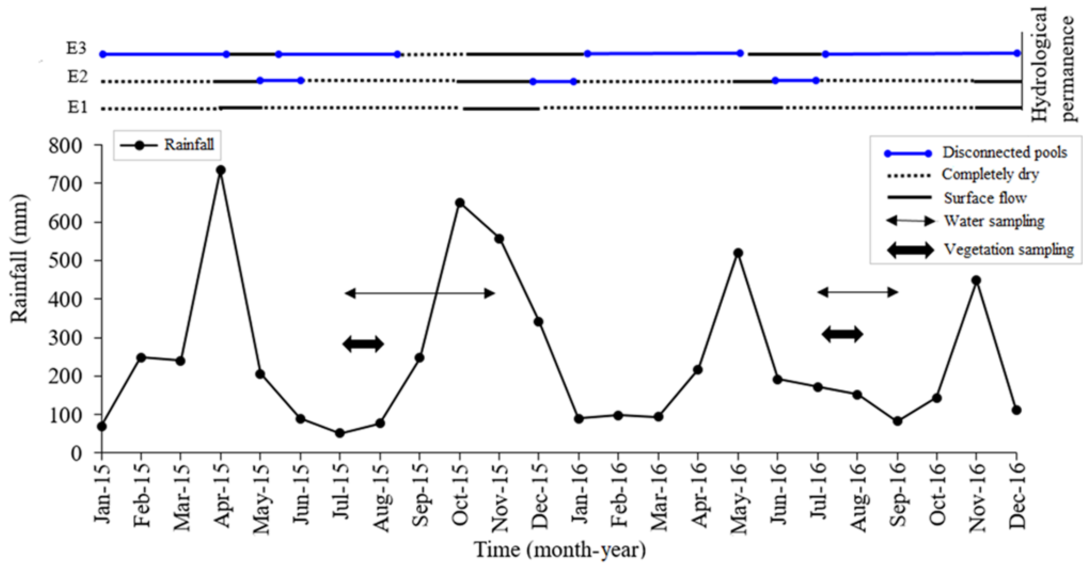

Figure 2 Rainfall, stream flow permanence and sampling schedule at the sampling sites in Balangoda, Sabaragamuwa Province of Sri Lanka.

2017).

The total annual rainfall was about 2000 mm in the Hong Kong study area, where the wet season (March to September) receives about 80% of the total rainfall (Gomes and Wai 2014). Some of the ephemerals, especially the ones that flow to the first order perennial streams through village areas were heavily polluted due to wastewater discharges and were not considered in this study.

1.2 Sampling locations and schedule, and stream hydrology

Six study sites were selected in Sri Lanka; three each from ephemeral (E1, 2 and 3) and perennial (P1, 2, and 3) streams (Figure 1). GPS coordinates were 6°34.698´N 80°51.887´E (E1); 6°39.552´N, 80°51.926´E (E2); 6°38.054´N 80°51.279´E (E3); 6°36.418´N 80°49.084´E (P1); 6°36.659´N 80°44.579´E (P2); and 6°36.658´N 80°49.815´E (P3). All sites had the same geographical, climatic and weather conditions, and were only a few kilometers apart from each other. Elevation of these sites ranged from 350-400 MSL. The identification of ephemerals is not easy as the local knowledge on ephemerals is limited.

Sampling in Sri Lanka was conducted from July to November, 2015 and July to September, 2016. Vegetation sampling was done from July to August (a period with less rainfall and also a growing season) in both years (Figure 2a). Water samples were taken once a month provided that ephemerals were in lotic or close to lotic stage (sampling in disconnected pools were avoided). The details on surface water presence or absence (Figure 2a) during the study period were obtained either by authors via field surveys or from the staff of Duwili Ella special protection area park and villagers.

The initial observations of Hong Kong ephemerals (E4-7; Figure 1b) were made in 2012 (April to September). All these were flowing to the third or the maximum order perennial section. JR11 is a monitoring station (Figure 1b) managed by the Environmental Protection Department, Hong Kong, and has monthly water quality and stream flow data since 1986. The vegetation observations were made during April 2015 and 2016. Unlike the Sri Lankan ephemerals, the Hong Kong ephemerals did not flow continuously for even a week during the wet season. In the dry season, surface flow was not present in ephemerals.

1.3 Vegetation sampling

Three representative study sites with a reach length about 50-100 m were established per stream. Adjacent reaches were separated by a stream distance of 50 – 100 m. Observations for standing crop biomass and diversity were realized by transverse belt transects, 7.5 m long from the center/thalweg in both sides. In all reaches that were selected for sampling, the thalweg and centerline were the same. Transect consisted of 1 m × 1 m quadrats. Each reach was assigned two transects, and in a given year only one transect was sampled. This ensured a temporal replication and also less disturbance to the site due to sampling. One reason for using a contiguous sampling unit such as transects was its ability to characterize boundaries (Jacquez et al. 2000; Fagan et al., 2003; Fitzpatrick et al. 2010). This could be particularly advantageous when the underlying environmental gradients on response variables such as herb diversity and standing crop biomass are unknown. Strictly aquatic plants and lower plants like filamentous algae, liverworts and mosses were not considered. Diversity will be expressed as Shannon-Wiener index H' (Eq.1). P_i is the fraction of the respective herb, and herbs were identified up to the species level. The standing crop biomass and diversity in Hong Kong will not be shown, as comparable perennial sections to ephemerals were not able to be found.

$$H' = -\sum_{i=1}^{r} P_i ln P_i \quad (1)$$

Below and above ground, biomass of herbs and biomass of surface litter were sampled (only herb litter was selected) to calculate the standing crop biomass. Sampled vegetation was washed thoroughly to remove soil and other foreign matter. Each sample was oven dried at 80°C until no weight change was observed. Then biomasses were measured separately as above ground, below ground and litter by using an electronic balance (CTG3101 Citizen, USA), where summation of all three components was considered as the standing crop biomass.

Tree observations (richness and diameter at knee height (DKH)) were made in the longitudinal direction of the entire reach up to the bank-full level. Minimum tree height considered was the knee height (0.5 m). Then DKH were used to derive the approximate tree ages with the aid of allometric relationships developed similar to Asaeda et al. (2010).

To quantify the sediment seed bank, three representative sediment samples were collected from each stream. Sediment was collected up to a depth of 2.5 cm in an area of 0.5 m × 0.5 m close to the stream flow and within the low flow hydrologic floodplain (i.e. about 3-4 m from the centerline). Raw soil samples were placed in pots inside a greenhouse allowed to germinate for two months. No additional nutrients were added and were watered twice a day. During the first two months, the numbers of saplings were counted separately as tree and herb saplings. Counts on different type of herbs were used to calculate the Shannon - Wiener index (Eq. 1).

1.4 Water quality observations

The pH of water just below the surface was recorded using a pH meter (Hach Sension, HACH) and electrical conductivity (EC) was recorded using a conductivity meter (EC meter CM-31P, DKK-TOA corporation). Dissolved oxygen (DO) and temperature was measured using a DO meter (Sension+ DO6, HACH). Nitrogen species and soluble reactive phosphorus (SRP) were measured in situ by HACH methods using HACH pocket colorimeter (model DR/820, USA) (Gomes and Wai 2014). Nitrate and nitrite were measured by cadmium reduction and ferrous sulphate methods, respectively. The Hach-ammonia salicylate (Cat No. 23953-66) reagent powders and ammonia cyanurate (Cat No. 23955-66) were used for ammoniacal nitrogen measurements. For SRP, ascorbic acid reduction method (Murphy and Riley 1962) was used.

1.5 Sediment nutrients and moisture

Total nitrogen of sediment was measured using sodium salicylate method (Gomes and Asaeda 2009). Total inorganic phosphorus was determined by the ignition method (Gomes and Asaeda 2009). The sediment samples were weighed, heated in an oven for 48 hours, cooled in the dry atmosphere of a desiccator, and then reweighed. The weight difference of a wet and dry sediment relative to the dry weight was considered as sediment moisture. This paper only includes sediment moisture and nutrient values observed in 2016 (sediment sampling was conducted in tandem to vegetation sampling).

1.6 Hydraulic variables

Depths and widths were measured using a depth gauge/steel ruler and a measuring tape, respectively. Stream cross sectional profiles were observed for all replicates up to the bankfull level (these were used to identify the thalweg). In all cases velocity was measured at 0.6 of the depth using a propeller type current meter (Flowatch, Switzerland). For areas where the water depth was less than 5 cm, velocity was derived using the float method (Herschy 1995) or by way of a makeshift weir. With velocity, water depth was observed using a steel ruler with the narrow edge in line with the oncoming flow of water. The slope of the water surface was calculated as the difference in elevation between two points on water surface divided by the distance between them measured along the stream.

1.7 Data analysis

Significant difference (P < 0.05) between two and more than two groups were checked by t-test and one-way ANOVA, respectively. SPSS statistical package (IBM V21.0) was used for all statistical analyses.

The rainfall data obtained from meteorological stations were used to derive relationships between rainfall and the return period (Subramanya 2013). The maximum monthly rainfalls for every past year since 1985 were arranged in the descending order, and assigned a number (m), starting from one. Weilbull formula (Eq.2) was used to the find the probability (P) of occurrence (N is the total number of years). The respective return period (T) was calculated using Eq.3.

$$P = \frac{m}{N+1} \quad (2)$$

$$T = \frac{1}{P} \quad (3)$$

2 Results and Discussion

2.1 Herb diversity and standing crop biomass of ephemeral and perennial streams

Figure 3a and 3b show herb diversities of ephemeral and perennial streams of Sri Lanka. Figure 3c shows the average herb diversities of both stream types. One perennial stream (P3) had a bedrock outcrop on its left bank, therefore, vegetation data over it will not be considered in the comparison. The diversities were relatively lower in ephemeral sites than the perennials. Perennial diversities reached values as high as 1.4, whereas in ephemerals it was around 0.8. However, the difference was not significant (t-test; P<0.05), and there were a few similarities. In both stream types, from the centerline (thalweg), the diversity increased and peaked between 1.5 and 4.5 m. Beyond 4.5 m from the centerline, the diversities decreased again. The riparian corridors contain an unusually diverse array of species (Naiman and Decamps 1997), and these herb peak areas should be part of the respective riparian zone. Zones with high herb diversities are not commonly discussed for ephemerals (Stromberg and Merritt 2016), but it was obvious that ephemerals too have such zones.

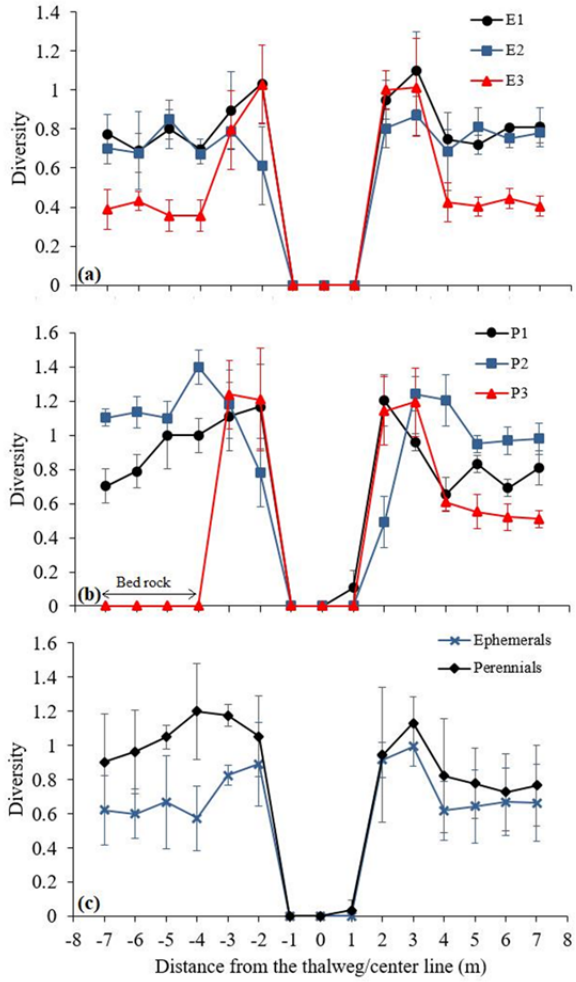

Figure 3 Herb diversity (Shannon-Wiener Index) in the transverse direction of (a) ephemeral and (b) perennial streams of Sri Lanka, (c) average herb diversities of ephemerals and perennials, drawn excluding bedrock out crop areas. Plus values denote right bank whereas minus values denote left bank. For E1, E2, E3 and P1, P2 and P3, please see their locations in Figure 1.

Even though we observed ephemerals to have low herb diversity relative to perennials, Stromberg et al. (2009) observed some ephemeral sites to have better species (including herbs) richness than perennial sites during the wet season. Stromberg et al. (2009) contributed this to a combination of multiple factors including greater light, space, and bare ground. Nevertheless, they observed a low herb diversity in ephemerals in periods characterized by less precipitation.

Table 1 shows the dominant herbs of ephemeral and perennial streams. This inventory includes herbs that had at least a 5% aerial coverage, identified up to 4.5 m from the stream centerline. As the streams were very small, the stream influenced herbs were mostly confined up to the third quadrant. Preliminary survey results revealed that after about 4.5 m away from the centerline, the herb composition was the same in both ephemeral and perennial streams. Only four (*Macaranga peltata*, *Piper nigram,* Ferns and *Pandanus* sp.) out of 36 herbs observed in these two stream types were common, indicating that ephemerals have a unique ecosystem with respect to herbs.

Table 1 Herbs of perennial and ephemeral streams up to 3.5 m from the stream thalweg/center of the sampling sites in Balangoda, Sabaragamuwa Province of Sri Lanka

Perennial	Ephemeral
Cinnamomum sp.	*Ixora coccinea*
Lagenandra ovata	*Macaranga peltata*
Calamus ovoideus	*Cynometra zeylanica*
Sida cordifolia	*Dysoxylum championii*
Trichosanthes cucumerina	*Dichrostachys cinerea*
Syzygium zeylanicum	*Mikania cordata*
Piper nigram	*Piper nigram*
Morinda umbellata	*Polypodium* sp.
Eichhornia crassipes	Fern type (unidentified)
Pandanus sp.	*Pandanus* sp.
Croton lacciferus	
Colocasia sp.	
Stereospermum colais	
Macaranga peltata	
Terminalia arjuna	
Lasia spinose	
Fern type (unidentified)	

Figure 4a and 4b show standing crop biomass of ephemeral and perennial streams of Sri Lanka, respectively. Average standing crop biomass of ephemerals and perennials are shown in Figure 4c. Same as diversity, in perennials peak responses were observed from 1.5 m to 4.5 m. In ephemerals, similar to perennials, the standing crop biomass increased up to 1.5 m from the center line. However, beyond that it was relatively the same. Based on similarities of the diversity and standing crop biomass observations, we will be defining three zones from the centerline: zone 1 (1.5 m), zone 2 (1.5 to 4.5 m) and zone 3 (4.5 to 7.5 m). Zone 1 was always within the active channel, and zone 3 was the upland (i.e. beyond the bankfull areas).

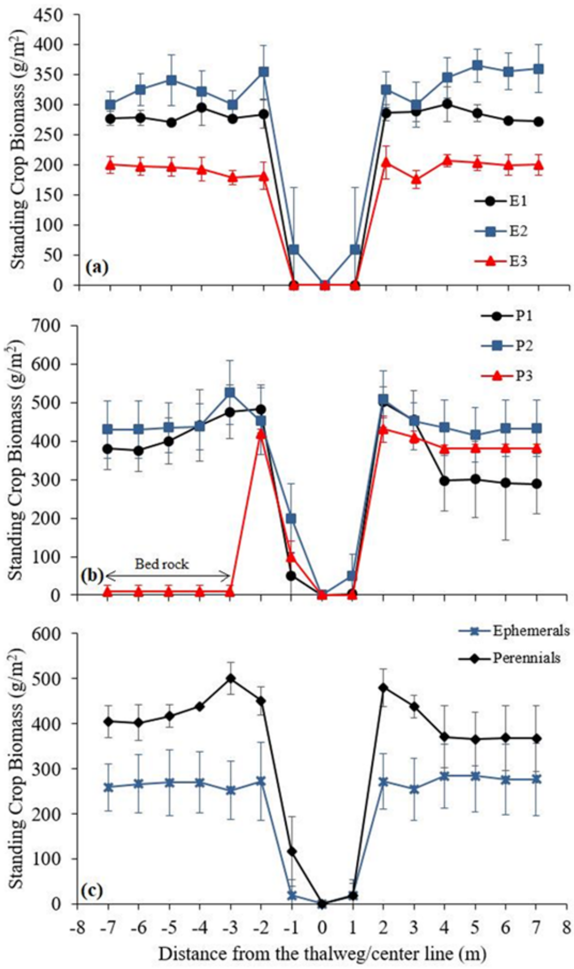

Figure 4 Standing crop biomass in the transverse direction of (a) ephemeral and (b) perennial streams of Sri Lanka, (c) average standing crop biomass of ephemerals and perennials, drawn excluding bedrock out crop areas. Plus values denote right bank whereas minus values denote left bank. For E1, E2, E3 and P1, P2 and P3, please see their locations in Figure 1.

Table 2 shows the summary of diversities and standing crop biomasses in zones 1, 2 and 3. In all cases, diversities in zone 2 and 3 were significantly higher than the diversity of zone 1 (ANOVA; $P < 0.05$). Zone 1 corresponds to and/or overlaps with the active channel, where the ephemeral or

Table 2 Vegetation indices, soil moisture and nutrient contents in the transverse direction of ephemeral and perennial streams in Balangoda, Sabaragamuwa Province of Sri Lanka. Zone 1, 2, and 3 are 0 to 1.5 m, 1.5 to 4.5 m and 4.5 to 7.5 m, respectively (measured from the thalweg). Parentheses show the standard deviation.

	Zone 1	Zone 2	Zone 3
Diversity			
Ephemeral streams	0.0 (0.0)	0.76 (0.21)	0.47 (0.12)
Perennial streams	0.0 (0.0)	1.13 (0.31)	0.60 (0.20)
Primary production (g/m²)			
Ephemeral streams	100 (100)	333 (115)	333 (58)
Perennial	0 (0)	433 (115)	366 (57)
Soil moisture (%)			
Ephemeral streams	5.2 (1.0)	10 (1.2)	8.5 (0.5)
Perennial	16 (2.1)	18.0 (5.0)	16.0 (7.0)
Total nitrogen – soil (mg/kg)			
Ephemeral streams	0.8 (0.2)	0.6 (0.2)	0.8 (0.2)
Perennial	1.1 (0.3)	0.8 (0.2)	0.8 (0.1)
Total phosphorus - soil (mg/kg)			
Ephemeral streams	1.2 (0.3)	1.0 (0.2)	1.5 (0.4)
Perennial	1.4 (0.4)	1.3 (0.3)	1.3 (0.2)

perennial flow disturbances would not allow colonization of flora. Zone 2 showed significantly high diversities than zone 3 in both stream types (ANOVA; $P < 0.05$).

Similar to several studies (e.g. Auble et al. 1994; Stromberg et al. 2009), diversity and standing crop biomass responses in the lateral direction was almost unimodal in perennial reaches. However, in ephemeral reaches only the diversity was unimodal, whereas standing crop biomass showed a logarithmic response. This indicated a competition for resources among different herb species. The total nitrogen and total phosphorus in soil did not vary between stream types, but sediment moisture did (Table 2). Significantly high sediment moisture was observed in herb peak zone of ephemerals (i.e., zone 2) relative to zones 1 and 2 (one-way ANOVA; P<0.05) (Table 2). As the ground water table is very deep in ephemeral stream areas (Butturini et al 2003), high sediment moisture could be due to moisture conservation by curtailed evapotranspiration as results of dense canopy cover and thick litter layer (Seghieri et al. 1997). The litter layer in the 1.5 to 4.5 m region was thicker and more compacted than the zone beyond 4.5 m from the centerline due to periodic flooding. High moisture in turn would help litter mineralization, thus increasing the biologically available soil nutrients (Gomes et al. 2017). Relatively high moisture and nutrient content paved the opportunity for different herbs to colonise (i.e. high diversity) (Gomes and Asaeda 2009). When herbs colonise, it would lead to inevitable competition among different herb types and/or the same type for resources (Enquist et al. 1998). This resulted in a curtailed standing crop biomass. The situation in perennials in the 1.5 to 4.5 m zone was different due to the presence of a shallow ground water table and the perennial sediment-water interface. These would make such zones resource abundant (Naiman and Decamps 1997).

2.2 Tree diversity and dynamics

Figure 5 shows the fraction of trees observed for different age groups in ephemeral sites up to the bankfull level. In perennials, no trees were observed up to the high flow level, but a few young trees and some seedlings were observed close to the bankfull level (data not shown). The ephemerals had trees with DKH 2 to 25 cm (corresponding to about one year to 30 year old trees), and about 75% of these trees were less than five years old. It should be noted about 90% of the trees with the age less than five years were in fact only about two years old. Beyond the bankfull level, most of the trees were mature with a few young (age less than five years) trees. It was also evident that trees corresponding to 10 to 15 year range were exceptional in Sri Lankan ephemeral sites.

2.3 Sapling emergence from seeds

Sapling emergence from seeds was almost five folds in perennials than ephemerals and the difference was statistically significant (t test; P<0.05). The diversities observed in seedling experiments were in good agreement with the field observations for both streams. Seedling plots of ephemeral and perennial sites were observed to have 0.85 ± 0.12 and 1.12 ± 0.24 diversities, respectively and showed no significant difference (t-test; $P<0.05$) with the field observations (see zone 2 of Table 2). Also, the seedling observations tallied with the standing crop biomass (approximated with number of plants) for perennials. However, in the case of ephemerals the seedling was not representative of the standing crop biomass of the field. These suggested that seeds were the main reason for vegetation observed in both streams.

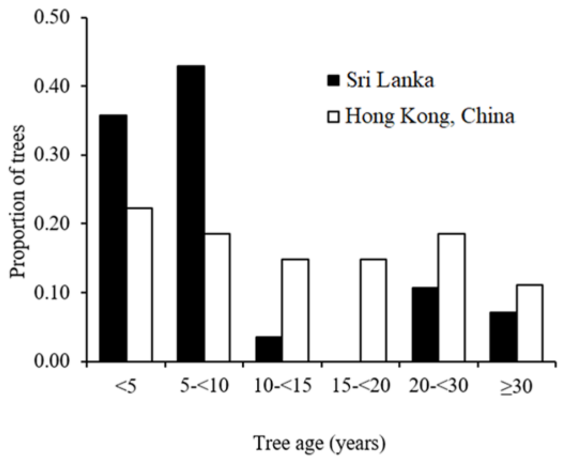

Figure 5 Fraction of trees observed for different age groups for the sampled reaches up to the bankfull level.

2.4 Relationships among catchment hydrology, bankfull flow and tree dynamics

Figure 6 a and b show the rainfall data of the Sri Lankan study area (1985-2010) and the stream discharge data related to the perennial section downstream of the sampled ephemerals in Hong Kong (1985-2016), respectively. Figure 6a and 6b would provide an idea of the seasonal and long term high flow events. The Hong Kong stream gauging station was about 200 m downstream of the ephemeral streams (Figure 1b). Therefore, the discharge data can be used to correlate the flow episodes of ephemerals. In Sri Lanka there was no suitable gauging station. Figure 7 shows the maximum annual monthly rainfall against the return period, of the Sri Lankan and Hong Kong study areas. Here, we have considered that the flow generation was proportionate to the rainfall of the

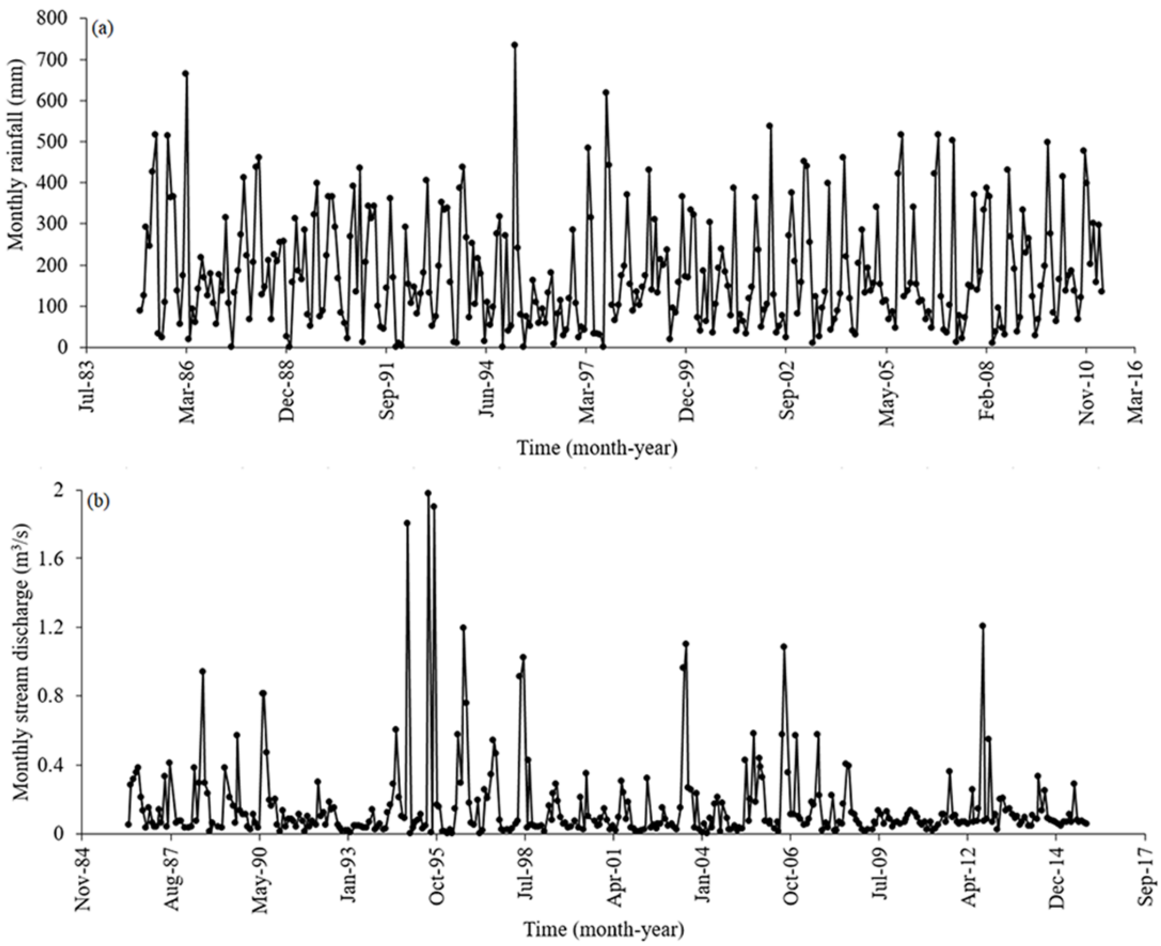

Figure 6 (a) Long term rainfall data of the study sites in Sri Lanka and (b) long term stream discharge data related to the perennial section downstream of the ephemerals in Hong Kong, China.

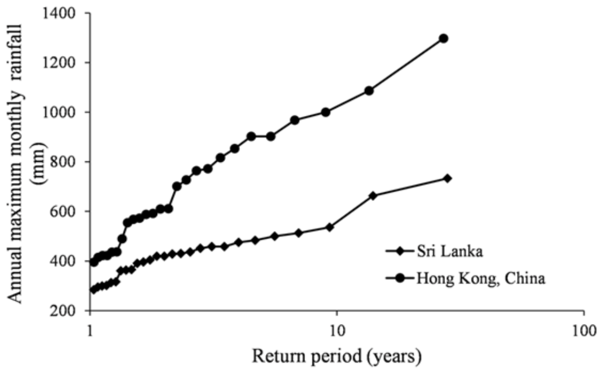

Figure 7 The maximum annual monthly rainfall against the return period, for the study sites in (a) Sri Lanka and (b) Hong Kong, China. Rainfall data: Sri Lanka (Balangoda) and Hong Kong, China (Tseng Kwan O meteorological stations).

catchment. This could be a valid assumption considering the mountainous nature of the study areas, as the lag time between rainfall and peak discharge is shorter (Fritz et al. 2006; Gomes and Wai 2014). Sri Lankan ephemerals seemed to receive a rainfall which is about one third of the total annual rainfall within a single month for every 30 years. Also for every two to five years those streams were subjected to a monthly rainfall which is about one fifth to one fourth of the total annual rainfall, showing a similarity between the magnitude of the seasonal high flow events and flow events with a five year return period. The oldest trees of ephemerals were found to be about 25 to 30 years old and matched well with the flow event that had a return period of 30 years.

The Hong Kong study area catchment's hydrology showed a few contrasting differences to the Sri Lankan catchment. Once in every 30 years, a monthly rainfall which is almost half of the total annual rainfall is seen in Hong Kong (Sri Lanka this was one fifth to one fourth). Unlike in Sri Lanka, the increased rainfall to an increased return period was proportionately high and was more uniform (see the rapid increment in the Sri Lankan study area from a return period of seven years to 15 years). This was why in Hong Kong, trees could be observed for all age groups up to 25-30 years, however, in Sri Lanka trees around 10 -15 years were rather unfound (Figure 5).

Due to the unavailability of past discharge records, bankfull discharge had to be estimated using Manning's equation and using general guidelines on Manning's coefficient (Subramanya 2013). The bankfull discharges of Sri Lankan ephemerals reached values as high as 18 m^3/s. The bankfull discharge per unit cross sectional area (i.e., specific discharge) reached as high as two folds in Sri Lankan perennial streams, relative to ephemerals. This indicated the slow discharge of water in ephemeral streams. Considering the fact that all streams were in the same mountainous region and had similar longitudinal slopes, it was conspicuous that an equal or more prominent role is played by ephemerals in flood control.

2.5 Water quality variation

Table 3 shows nitrate, SRP, DO, pH, and temperature of ephemerals and perennials in Sri Lanka. These two stream types did not show a significant difference (one-way ANOVA; $P<0.05$) for most of the parameters. This also indicates that the water quality did not govern the vegetation dynamics. In case of pH, all waters seemed to be slightly alkaline. Temperature showed similar values due to similar canopy densities and relatively shallow water depths (data not shown). As most of the water samples were collected before but close to the dry stage of ephemerals (i.e. with minor surface flow) it was expected ephemerals to have high denitrification rates (Fisher et al. 2001). This will result in loss of nitrogen to atmosphere. In contrast to the similarities, EC was observed to be significantly high (one way ANOVA; $P<0.05$) in ephemerals than in perennials. The reasons include

Table 3 Water quality of ephemeral and perennial streams of the sampling sites in Balangoda, Sabaragamuwa Province, Sri Lanka. Parentheses show the standard deviation

	Ephemerals			Perennials		
	E1	E2	E3	P1	P2	P3
Electrical conductivity (µS/cm)	166 (29)	106 (11)	208 (14)	52 (5)	48 (5)	53 (7)
pH	8 (0.5)	7.2 (0.7)	7.8 (0.5)	7.5 (0.6)	7.5 (0.8)	7.5 (0.3)
Dissolved oxygen (mg/L)	8.9 (1)	8.7 (0.5)	8.2 (1.1)	9 (2)	7.5 (0.1)	8 (0.5)
Nitrate-nitrogen (mg/L)	0.8 (0.1)	1.1 (0.2)	0.95 (0.0)	0.9 (0.1)	0.75 (0.2)	0.9 (0.1)
Ammoniacal- nitrogen	0.02 (0.00)	0.08 (0.01)	0.01 (0.00)	0.01 (0.00)	0.01 (0.00)	0.00 (0.00)
Soluble reactive phosphorus (mg/L)	0.02 (0.01)	0.025 (0.01)	0.03 (0.02)	0.03 (0.01)	0.02 (0.01)	0.02 (0.01)

high dissolved solids content in the drying stage (water will evaporate concentrating the dissolved solids). Nevertheless, it is expected that the EC values during the early to intermediate stage of ephemeral flows could be similar to perennial flows.

2.6 Current concerns of ephemeral stream management

There are populated mountainous catchments in Sri Lanka with no ephemeral streams; this is due to regulation works. This was more obvious in Hong Kong, and some ephemerals were even concrete lined.

Even though they are situated in remote areas, and somewhat distanced from rural settlements, Sri Lankan ephemerals studied were subjected to indirect anthropogenic disturbances. These included Chena cultivation (an agricultural practice) and bush meat activities in the upland forests. It was observed that certain upland areas close to ephemerals had large grasslands. Natural grasslands known as Patanas are a mountainous ecosystem, but what was observed were grasslands known as Talawe, which are consequences of Chena cultivation. These grasslands could catch fire due to natural reasons, as well as due to bush meat hunting. The fires can extend to nearby tree colonies associated with ephemerals, resulting in reduction of the tree population. This will change the sediment moisture conditions due to the change in ground water table and increased evapotranspiration due to exposure to sunlight. Furthermore, ephemeral ecosystems will be undersupplied with nutrients as a result of reduced mineralization of tree leaf litter. These would ultimately change the herb dynamics of these unique ecosystems. Therefore, it is vital to establish legislative protection of ephemerals and its catchments, something that is absent in many parts of the world. Such legislation would not only protect vegetation of these unique ecosystems but is vital in effective management of mountainous water resources. Mountains are areas that provide disproportionately high quantities of water (Weingartner et al. 2005). However, combination of climate change and anthropogenic disturbances are likely to have consequences on current and future water availability in these areas (Viviroli et al. 2011). It should be noted, surprisingly, that the Sri Lankan study area has drinking water issues, even with a dense headwater stream network, with respect to quality and quantity. This could be due to complex interactions between geology, vegetation, climate and human activities, and studies of this nature would help to find reasons and/or relationships. As an example, temporal changes in vegetation dynamics would indicate a shift in water availability (Nolin 2012). Once a scarcity is identified (advanced identification is possible by looking at vegetation dynamics) precautionary action can be taken. To identify the impact-cause-solution, it is obvious that much more studies connecting hydrologic, ecologic and human components are needed.

3 Conclusion

This study proved the uniqueness of ephemeral ecosystems. It adds additional knowledge to vegetation dynamics of ephemeral streams (e.g. Kolb et al. 1997; Stromberg et al. 2009) and also to mountainous area studies that were as to date mainly conducted for perennial streams (e.g. Sieben 2015). Ephemerals had zones similar to perennials which were rich in diversity. Nevertheless, unlike in perennials, standing crop biomass was not very high and the herbs observed in ephemeral and perennial ecosystems were different.

Vegetation dynamics in ephemeral streams, especially tree ages, correlated well with past flow/rainfall patterns. Therefore, ephemerals ecosystems could be valuable when hindcasting past catchment eco-hydrology, therein for studying climate variability. Also, ephemeral flows could be a valuable component in mountainous sustainable water resources management (Deng et al. 2002).

This study provided herb dynamics in two types of streams. It is recommended to study the annual variations in future studies. This would help to understand the temporal dynamics of the herb peaks observed. It is evident that ephemeral stream hydraulics should be studied in more detail to improve the conclusions made on water quality and flood control capacity.

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