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Assessing Riparian Floristic Diversity and Vegetation Dynamics in the Vamanapuram River Basin, Kerala: A Comprehensive Analysis

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ABSTRACT

The Vamanapuram River Basin (VRB) is home to a diverse range of plant species, including 152 distinct species from 50 botanical families. Poaceae, Leguminosae, Araceae, and Aseraceae are the most abundant, with 13 species. Euphorbiaceae, Acanthaceae, Apocynaceae, and Rubiaceae also contribute to the biodiversity hotspots. The VRB's vegetation profile is characterized by a dynamic interplay of plant forms and ecological niches, with 74 herbs, 30 shrubs, 12 grasses, 1 liana, and 35 towering trees. The Poaceae family thrives in this environment due to hydrological factors. The sampling sites P6 and P5 exhibit high relative frequency and density, with key species like *Macaranga peltata*, *Ficus hispida*, and *Swietenia macrophylla*. Diversity indices like the Shannon-Wiener diversity index reaffirm the VRB's tropical forest character. Beta-diversity patterns reveal unique plant species distribution dynamics among different panchayaths, emphasizing their ecological complexities. The study emphasizes the demand for specialized management and conservation techniques in this environmentally active region.

INTRODUCTION

The Western Ghats recognized as one of the planet's "hotspots" of biological diversity and a UNESCO World Heritage Site (Myers et al. 2000), stand as a global emblem of biodiversity and endemism (Daniels & Vencatesan 2008). Within this ecological treasure trove, the Western Ghats river basin boasts a wealth of riparian flora, encompassing a diverse array of plant species. These riparian zones, bridging terrestrial and aquatic systems, hold pivotal roles in ecosystem functionality and human well-being (Davis et al. 2006, Holmquist et al. 2011, Jonsson et al. 2017).

Streams and riparian zones serve as vital conduits for the movement of organisms across different landscapes, acting as dispersal routes for both terrestrial and aquatic species (Ament et al. 2014, Bennett et al. 2014, Tonkin et al. 2018). Renowned for their richness, dynamism, and complexity, riparian habitats represent some of the most diverse and intricate ecosystems on Earth yet remain exquisitely sensitive to environmental shifts (Naiman & Decamps 1997). These zones are the linchpin of river and stream ecosystems, nurturing essential functions such as the decomposition of organic matter, nutrient cycling, biological indicators of pollution, and the sustenance of ecological food chains (Holmquist et al. 2011, Jonsson et al. 2017). Furthermore, riparian vegetation offers shading, influences water temperatures and light, impacts nutrient cycling, and stabilizes banks (Gregory et al. 1991, Naiman et al. 1993, 2000, 2010, Tang & Montgomery 1995, Prach et al. 2001, Hood & Naiman 2000).

Despite their ecological significance, rivers continue to be harnessed and controlled to meet the growing demands for energy, irrigation, water supply, and flood control driven by burgeoning human populations, rapid urbanization, and expanding industrial and commercial activities (Nilsson 2005, Lehner et al. 2011). In metropolitan areas, riparian vegetation often faces alteration or loss due to ecological disturbances within riverine watersheds (Morley & Karr 2002, Moore & Palmer 2005). The hydrological cycle, a lifeline for downstream human activities, is significantly impacted by agricultural practices, urbanization, river flow modifications, overexploitation, climate change, biological invasions (Singh et al. 2021), biodiversity depletion (Sultana et al. 2014), and stream pollution (Bere & Mangadze 2014, Schultz et al. 2004, Anbumozhi et al. 2005, Flores-Díaz et al. 2018).

Floral diversity, regardless of habitat type, remains essential for sustaining life on Earth (Cunningham et al. 2015), offering crucial insights for the identification and utilization of plant resources. A comprehensive understanding of this subject forms the foundation for both fundamental and applied research. The southern region of the Western Ghats, characterized by its remarkable diversity of endemic species and floristic composition, stands at the forefront of these efforts. Given the current and anticipated scenarios of declining river health and global environmental changes, there is an urgent call for an integrated approach to riparian zone management (Singh et al. 2021). Close to water bodies, there often exists variation in plant species composition (Scalley et al. 2009), making the maintenance and conservation of riparian areas pivotal contributors to landscape diversity (Sabo et al. 2005).

The objective of this study is to identify and quantify plant species within the riparian zones of the Vamanapuram River Basin. It seeks to assess ecosystem health and monitor the dynamic changes in vegetation. The insights gleaned from this study hold the potential to inform conservation strategies, guide land management practices, promote habitat preservation and restoration, and support sustainable approaches while unraveling intricate ecological relationships within this critical ecosystem.

Study Area

The study area for the present research, the Vamanapuram River Basin (VRB), boasts a vast catchment area spanning 742.34 sq. km, situated within the geographical coordinates of 8°34′30″ to 8°49′38″ N latitudes and 76°43′47″ to 77°12′08″ E longitudes (Fig. 1). Originating from Chemmunji Mottai in the Western Ghats, approximately 1,717 m above mean sea level (msl), this 81-kilometer-long river gracefully flows into the Anjengo Lake within the coastal strand plains of Thiruvananthapuram district (Gopal et al. 2014). The VRB's northern boundary is marked by the Kallada River, while the Karamana River defines its southern limits, with the Ithikara River flowing between the Kallada and Vamanapuram rivers. For administrative and analytical purposes, the Vamanapuram watershed is further divided into 30 sub-watersheds and 52 micro watersheds (John & Brema 2018).

Physiographically, the VRB can be broadly categorized into three distinct zones. The first zone, characterized as the highland on the eastern side, ranges from 1,717 to 76 meters above msl. The second zone, known as the midland, lies between the lowland and highland areas, extending from 76 to 7.6 meters above msl. Lastly, the third zone, the lowland, occupies the western side and spans from 7.6 meters above msl to msl itself (Anon 1986). This area is a part of the midland terrain of the state, featuring lateritic uplands with undulating topography and intermittent valleys, as previously documented (Ajin et al. 2013).

The climatic conditions prevailing in this region are typical of a tropical monsoon climate, characterized by the southwest (SW) monsoon season, which occurs from June to September, and the northeast (NE) monsoon season, prevailing from November to February (Joji & Nair 2014).

The Western Ghats, encompassing the VRB, are renowned for their remarkable floral diversity. Nearly 5800 species of flowering plants have been meticulously documented in the Western Ghats, with an astonishing 56 genera and 2100 species being endemic to this region (http://wgbis.ces.iisc.ernet.in/biodiversity/sahyadri_enews/newsletter/issue38/article/index.htm). The evergreen forests within the Western Ghats harbor an exceptionally high percentage of species that are exclusively native to this region, with an estimated 1,500 endemic plant species (MacKinnon & MacKinnon 1986). Notably, among the evergreen tree species found here, 56% are endemic, solidifying the Western Ghats' status as one of the world's biodiversity hotspots (Myers 1988).

The Vamanapuram River Basin faces significant environmental challenges, with 87% of surface water samples exhibiting marginal water quality and 13% displaying poor quality. High *E. coli* counts and heavy nickel pollution are prevalent, exacerbated by sewage effluents and agricultural activities downstream (Nandakumar 2015). The ecosystem has been transformed by human intervention, with natural components like forests and water bodies being reduced and man-made components like plantations and roads emerging settlements (Gopal et al. 2018). River sediments show elevated iron and manganese concentrations and trace elements in sediment samples are higher than in water samples. These findings highlight the complex environmental challenges faced by the basin (Nair & Kumar 2019).

MATERIALS AND METHODS

Sampling and Data Collection

The comprehensive assessment of riparian floristic diversity and vegetation dynamics in the Vamanapuram River Basin was conducted for one year (2021-2022). The research design encompassed the strategic selection of six panchayaths labeled as P1 to P6, determined through extensive field surveys. Within each of these six panchayaths, a total of five distinct sites were carefully chosen for sampling. The vegetation study entailed meticulous fieldwork involving systematic placement of quadrats to capture the intricacies of the plant community. For the comprehensive evaluation of tree species, 10 × 10 m quadrats were established, whereas shrubs were examined within 5 × 5 m quadrats. Additionally, 1 × 1 m quadrats were designated for the assessment of herbaceous vegetation. The selection of

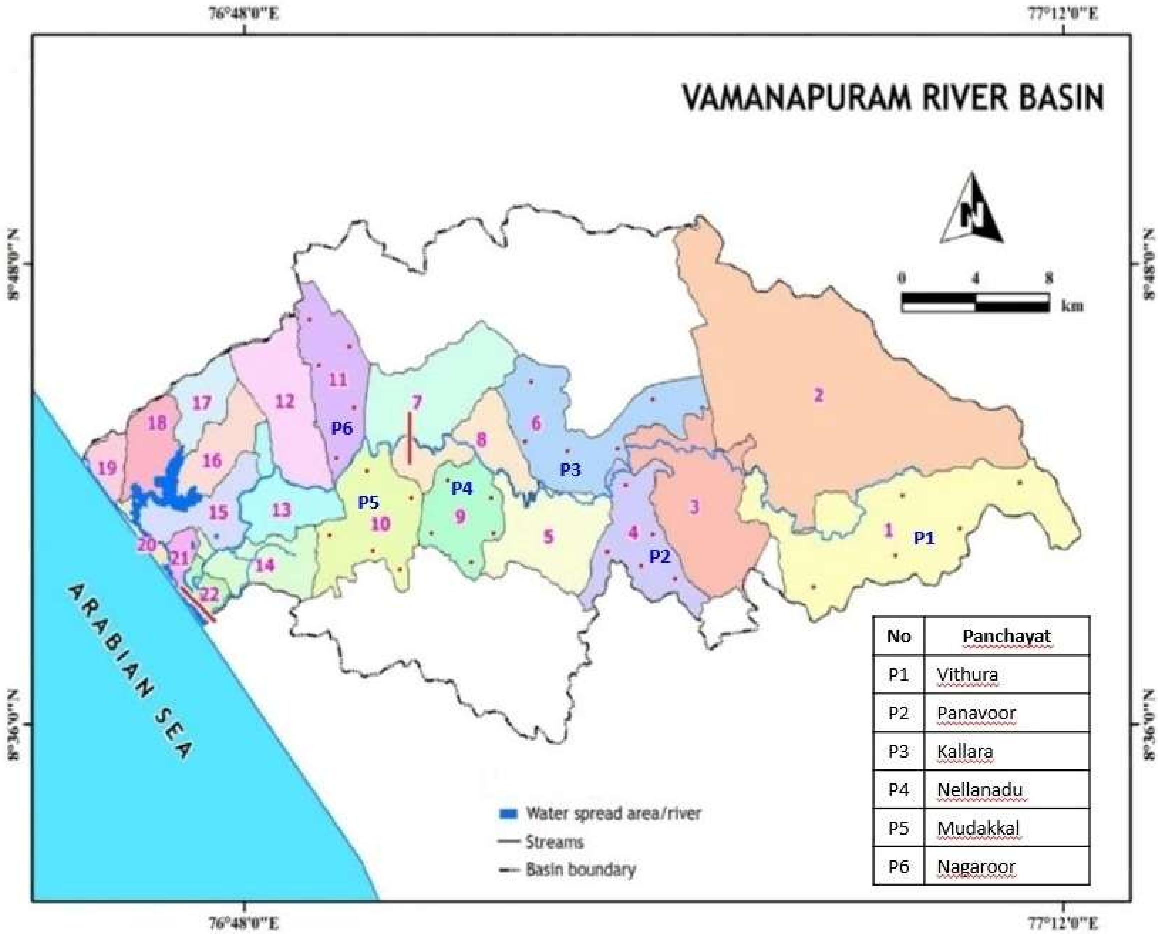

Fig. 1: Sampling sites of six locations of the Vamanapuram River Basin (Gopal et al. 2014).

sampling panchayaths within each site was randomized to ensure unbiased representation.

In the assessment of tree species, specific attention was given to enumerating the various species present within each 10 × 10 m quadrat. Additionally, the girth at breast height (gbh), situated at a standardized height of 1.37 m from the ground, was meticulously recorded for each tree, following the methodology established by Vincy et al. (2015). To derive meaningful analytical insights from the collected data, the approach outlined by Curtis & McIntosh (1950) was adopted. This methodology enabled the computation of crucial analytical parameters, including density, frequency, abundance, basal cover, and importance value (IV). The calculation of IV, a key determinant of species significance, adhered to the methodology outlined by Curtis (1959). This involved the summation of relative density, relative frequency, and relative dominance to establish the overall importance value for each species.

Biodiversity Indices

In the present study, a comprehensive suite of biodiversity indices was employed to unravel the intricacies of this unique ecosystem, guided by established methodologies (Danoff-Burg & Xu 2006). The Biodiversity Calculator was used to measure species diversity using Shannon's index (H'), which includes both abundance and evenness of species distribution (Danoff-Burg & Xu 2006). In addition to evaluating species richness (S), the evenness of species (H'E) using the same tool was also computed, as endorsed by Omoro et al. (2010).

The quest to unravel the similarities between species led us to Jaccard's index (Krebs 1989), offering insights into the shared botanical tapestry within the basin. Beyond these measures, a spectrum of univariate indices was meticulously scrutinized to illuminate different facets of biodiversity within the Vamanapuram River Basin. This array included the Shannon-Wiener diversity index (H′) (Shannon & Weaver 1963), Margalef's species richness

(d) (Margalef 1968), Menhinick's Diversity Index (DMn) (Menhinick 1964), Pielou's evenness (J′) (Pielou 1975), Simpson dominance (D) (Simpson 1949), Gini Coefficient (Damgaard & Weiner 2000), Berger-Parker Dominance Index (Magurran 1988, 2004, Morris et al. 2014), Buzas & Gibson's Index (Krebs & Berteaux 2006), and Fisher's alpha diversity index (Hammond & Pokorný 2020), each providing a unique lens through which to view the basin's ecological intricacies.

The Family Importance Value Index (FIV) was calculated by merging species with similar importance values (IVI) to gain a deeper understanding of their relative importance (Bano et al. 2017, Pereki et al. 2013). An analysis of variance was performed by one-way ANOVA among the six panchayaths within the Vamanapuram River Basin to determine density, frequency, and abundance. To unveil intricate interrelationships among these diversity indices, a correlation matrix was meticulously computed.

Similarity indices helped us understand the interspecific dynamics within plant communities. Both the Sorensen similarity index (Sorensen 1948, Nath et al. 2005) and the Jaccard similarity index (Magurran 2004) were instrumental in quantifying and comparing the resemblances among plant species. In the realm of beta diversity, the Sørensen Dissimilarity Index (βsor) and Jaccard Dissimilarity Index (βjac) were deployed to uncover and evaluate the differences in species composition across various sites. The Vamanapuram River Basin's distinctive plant assemblages were evaluated using these indices.

RESULTS AND DISCUSSION

Floristic Diversity

This comprehensive analysis includes methodologies designed to ensure sustainable protection of biodiversity, a crucial aspect of ecosystem health (Devi et al. 2014). Over a rigorous three-year period, an extensive phytosociological examination and an in-depth floristic study were conducted across six panchayaths situated within the Vamanapuram River Basin.

The floral composition serves as a valuable marker in the present investigation. It provides insights into the presence of diverse environmental elements that contribute to both inter- and intra-specific variations across a spectrum of endogenous environments (Amber et al. 2019). In recent years, many scholars have published floristic checklists of local plants (Peng et al. 2018, Leishangthem & Singh 2018, Ullah et al. 2020, Sahoo et al. 2020, Ghafari et al. 2020, Ao et al. 2021, Hodge et al. 2022, Zibtseva et al. 2022), providing insight into the rich botanical diversity within the region.

It is worth noting that the selected research location within the Vamanapuram River Basin possesses immense potential for nurturing a diverse array of plant species. This potential is attributed to the region's multifaceted topographic characteristics and microhabitats, which collectively contribute to the flourishing of rich and varied plant biodiversity.

Vegetation Profile and Community Structure

A comprehensive exploration of the basin's vegetation profile and community structure reveals a tapestry of remarkable richness, underscored by meticulous documentation (Table 1). A total of 152 distinct species were identified in this study, each belonging to one of 50 botanical families, thus encapsulating the rich floral tapestry of the basin. Among these families, several emerged as veritable hotspots of species diversity. Notably, Poaceae stood out with an impressive array of 13 distinct species, closely followed by Leguminosae with 12 species, Araceae with 10, and Asteraceae with 9. Additionally, Euphorbiaceae and Acanthaceae contributed 7 species each, while Apocynaceae showcased 6 unique species. Rubiaceae and Malvaceae held their own with 5 species each, adding further richness to the basin's botanical mosaic.

The distinctive vegetation profile of VRB reveals a dynamic interplay of plant forms and ecological niches. Within this profile, a diverse assemblage unfolds, featuring 74 herbs (48.68%), 30 shrubs (19.74%), 12 grasses (7.89%), 1 liana (0.66%), and 35 towering trees (23.03%) (Fig. 2). This diversity is a testament to the basin's intricate ecological dynamics, shaped in part by its periodic floodplain disturbances and the prevalence of wetland characteristics. It is noteworthy that members of the Poaceae family have particularly thrived in this unique vegetation profile. This phenomenon can be attributed to the basin's hydrological characteristics, as illuminated by Cherullipadi and Paul (2016).

As demonstrated by the species composition (Fig. 3), a pattern reminiscent of many river basins in Kerala emerges, with plants dominating the landscape, followed by trees and shrubs. This trend resonates with findings in other river basins within the state, such as Pamba (Paul & George 2010), Meenachil (Vincy et al. 2015), and Bharathappuzha (Cherullipadi & Paul 2016). A plausible explanation for the prominence of herbs and the relatively lower abundance of shrubs and climbers may be linked to seasonal clearings in plantations and agricultural areas, a phenomenon documented by Cherullipadi and Paul (2016).

Importance Value (IV)

The Importance Value (IV) calculation has proven to be a

Table 1: List of species and their families.

No.	Species	Family	Habit
1.	*Acacia auriculiformis* Benth.	Leguminosae	Tree
2.	*Acmella calva* (DC.) R.K.Jansen	Compositae	Herb
3.	*Acorus calamus* L.	Acoraceae	Herb
4.	*Adenanthera pavonina* L.	Leguminosae	Tree
5.	*Adiantum hispidulum* Sw.	Pteridaceae	Herb
6.	*Adiantum pedatum* L.	Pteridaceae	Herb
7.	*Aerva lanata* (L.) Juss.	Amaranthaceae	Herb
8.	*Aeschynomene indica* L.	Leguminosae	Herb
9.	*Aganosma cymosa* (Roxb.) G.Don	Apocynaceae	Liana
10.	*Ageratum conyzoides* (L.) L.	Asteraceae	Herb
11.	*Albizia chinensis* (Osbeck) Merr.	Leguminosae	Tree
12.	*Alloteropsis cimicina* (L.) Stapf	Poaceae	Grass
13.	*Alstonia scholaris* (L.) R. Br.	Apocynaceae	Tree
14.	*Alternanthera bettzickiana* (Regel) G.Nicholson	Amaranthaceae	Herb
15.	*Alternanthera sessilis* (L.) R.Br. ex DC.	Amaranthaceae	Herb
16.	*Amorphophallus paeoniifolius* (Dennst.) Nicolson	Araceae	Herb
17.	*Anacardium occidentale* L.	Anacardiaceae	Tree
18.	*Annona reticulata* L.	Annonaceae	Tree
19.	*Areca catechu* L.	Arecaceae	Tree
20.	*Artocarpus hirsutus Lam*.	Moraceae	Tree
21.	*Artocarpus heterophyllus* Lam.	Moraceae	Tree
22.	*Asystasia coromandeliana* Nees	Acanthaceae	Herb
23.	*Averrhoa bilimbi* L.	Oxalidaceae	Tree
24.	*Axonopus compressus* (Sw.) P.Beauv.	Poaceae	Grass
25.	*Azadirachta indica* A.Juss.	Meliaceae	Tree
26.	*Biophytum sensitivum* (L.) DC.	Oxalidaceae	Herb
27.	*Boerhavia diffusa* L.	Nyctaginaceae	Herb
28.	*Brachiaria ramosa* (L.) Stapf	Poaceaea	Grass
29.	*Bridelia retusa* (L.) A.Juss.	Phyllanthaceae	Tree
30.	*Caladium bicolor* (Aiton) Vent.	Araceae	Herb
31.	*Calotropis gigantea* (L.) Dryand.	Apocynaceae	Shrub
32.	*Canscora diffusa* (Vahl) R.Br. ex Roem. & Schult.	Gentianaceae	Herb
33.	*Capsicum frutescens* L.	Solanaceae	Herb
34.	*Carica papaya* L.	Caricaceae	Tree
35.	*Caryota urens L.*	Arecaceae	Tree
36.	*Cassia alata* L.	Leguminosae	Herb

Table Cont....

No.	Species	Family	Habit
37.	*Catharanthus roseus* (L.) G.Don	Apocynaceae	Herb
38.	*Ceiba pentandra (L.) Gaertn*.	Malvaceae	Tree
39.	*Centella asiatica* (L.) Urb.	Apiaceae	Herb
40.	*Centrosema molle* Benth.	Leguminosae	Herb
41.	*Chromolaena odorata* (L.) R.M.King & H.Rob.	Compositae	Shrub
42.	*Chrysothemis pulchella* (Donn ex Sims) Decne.	Gesneriaceae	Herb
43.	*Cinnamomum verum* J.Presl	Lauraceaea	Tree
44.	*Cleome rutidosperma* DC.	Cleomaceae	Herb
45.	*Cleome viscosa* L.	Capparidaceae	Herb
46.	*Clerodendrum infortunatum* L.	Lamiaceae	Shrub
47.	*Clidemia hirta* (L.) D. Don	Melastomataceae	Shrub
48.	*Cocos nucifera* L.	Aracaceae	Tree
49.	*Coffea arabica* L.	Rubiaceae	Shrub
50.	*Colocasia antiquorum* Schott	Araceae	Herb
51.	*Colocasia esculenta* (L.) Schott	Araceae	Herb
52.	*Commelina diffusa* Burm.f.	Commelinaceae	Herb
53.	*Costus speciosus* (J.Koenig) Sm.	Costaceae	Herb
54.	*Couroupita guianensis* Aubl.	Lecythidaceae	Tree
55.	*Crotalaria striata* DC.	Leguminosae	Herb
56.	*Cyclea peltata* (Lam.) Hook.f. & Thomson (Lam.) Hook. f. & Thoms.	Menispermaceae	Shrub
57.	*Cynodon dactylon* (L.) Pers.	Poaceae	Grass
58.	*Cyperus compressus* L.	Cyperaceae	Herb
59.	*Cyperus pangorei* Rottb.	Cyperaceae	Herb
60.	*Cyperus tenuispica* Steud.	Cyperaceae	Herb
61.	*Datura stramonium* L.	Solanaceae	Herb
62.	*Desmodium triflorum* (L.) DC.	Leguminosae	Herb
63.	*Dieffenbachia seguine* (Jacq.) Schott	Araceae	Herb
64.	*Eclipta prostrata* (L.) L.	Asteraceae	Herb
65.	*Eichhornia crassipes* (Mart.) Solms	Pontederiaceae	Herb
66.	*Elephantopus scaber L.*	Asteraceae	Herb
67.	*Emilia sonchifolia* (L.) DC. ex DC.	Asteraceae	Herb
68.	*Eragrostis unioloides* (Retz.) Nees ex Steud.	Poaceae	Herb
69.	*Ficus hispida* L.f.	Moraceae	Tree
70.	*Ficus racemosa* L.	Moraceae	Tree
71.	*Heliotropium indicum* L.	Boraginaceae	Herb
72.	*Hemigraphis colorata* W.Bull	Acanthaceae	Herb
73.	*Hevea brasiliensis* (Willd. ex A.Juss.) Müll.Arg.	Euphorbiaceae	Tree

Table Cont....

No.	Species	Family	Habit
74.	*Hewittia malabarica* (L.) Suresh	Convolvulaceae	Herb
75.	*Hibiscus furcatus* Roxb.	Malvaceae	Shrub
76.	*Hibiscus hispidissimus* Griff.	Malvaceae	Shrub
77.	*Hygrophila ringens* (L.) R. Br. ex Spreng.	Acanthaceae	Herb
78.	*Hygrophila schulli* M.R.Almeida & S.M.Almeida	Acanthaceae	Herb
79.	*Hygroryza aristata* (Retz.) Nees ex Wight & Arn.	Poaceae	Grass
80.	*Hyptis suaveolens* (L.) Poit.	Lamiaceae	Herb
81.	*Ipomoea aquatica* Forssk.	Convolvulaceae	Shrub
82.	*Ipomoea triloba* L.	Convolvulaceae	Shrub
83.	*Ixora coccinea* L.	Rubiaceae	Shrub
84.	*Justicia adhatoda L.*	Acanthaceae	Shrub
85.	*Kirganelia reticulata* (Poir.) Baill.	Euphoribiaceae	Shrub
86.	*Kyllinga nemoralis* (J.R.Forst. & G.Forst.) Dandy ex Hutch. & Dalziel	Cyperaceae	Shrub
87.	*Lagenandra nairii* Ramam. & Rajan	Araceae	Herb
88.	*Lagenandra toxicaria* Dalzell	Araceae	Herb
89.	*Lantana camara L.*	Verbenaceae	Shrub
90.	*Leersia hexandra* Sw.	Poaceae	Grass
91.	*Leucas aspera* (Willd.) Link	Lamiaceae	Herb
92.	*Loranthus macrantherus* (Eichler) Hemsl.	Loranthaceae	Herb
93.	*Ludwigia hyssopifolia* (G.Don) Exell	Onagraceae	Herb
94.	*Macaranga peltata (Roxb.) Muell.-Arg.*	Euphorbiaceae	Tree
95.	*Mangifera indica L.*	Anacardiaceae	Tree
96.	*Manihot esculenta* Crantz	Euphorbiaceae	Shrub
97.	*Melastoma malabathricum* L.	Melastomataceae	Shrub
98.	*Merremia tridentata* (L.) Hallier f.	Convolvulaceae	Herb
99.	*Mikania micrantha Kunth*	Asteraceae	Herb
100.	*Mimosa pudica L.*	Leguminosae	Shrub
101.	*Mimosa diplotricha* Sauvalle	Leguminosae	Shrub
102.	*Mitracarpus verticillatus* (Schumach. & Thonn.) Vatke	Rubiaceae	Herb
103.	*Mukia maderaspatana* (L.) M.Roem.	Cucurbitaceae	Herb
104.	*Murdannia loriformis* (Hassk.) R.S.Rao & Kammathy	Commelinaceae	Herb
105.	*Musa paradisiaca* L.	Musaceae	Herb
106.	*Ocimum sanctum* L.	Lamiaceae	Herb
107.	*Oplismenus hirtellus* (L.) P.Beauv.	Poaceae	Grass
108.	*Oxalis corniculata* L.	Oxalidaceae	Herb
109.	*Pachystachys coccinea* (Aubl.) Nees	Acanthaceae	Shrub

Table Cont....

No.	Species	Family	Habit
110.	*Passiflora foetida* L.	Passifloraceae	Shrub
111.	*Pennisetum polystachion (L.) Schult*.	Poaceae	Grass
112.	*Phyllanthus amarus Schum. & Thonn*.	Phyllanthaceae	Herb
113.	*Phyllanthus emblica* L.	Phyllanthaceae	Tree
114.	*Physalis minima* L.	Solanaceae	Herb
115.	*Piper nigrum* L.	Piperaceae	Herb
116.	*Pothos scandens L.*	Araceae	Herb
117.	*Psidium guajava* L.	Myrtaceae	Tree
118.	*Psychotria curviflora* Wall.	Rubiaceae	Herb
119.	*Pueraria phaseoloides (Roxb.) Benth*.	Leguminosae	Shrub
120.	*Ricinus communis* L.	Euphorbiaceae	Shrub
121.	*Ruellia prostrata* Poir.	Acanthaceae	Herb
122.	*Saccharum spontaneum* L.	Poaceae	Grass
123.	*Sauropus androgynus* (L.) Merr.	Phyllanthaceae	Shrub
124.	*Sebastiana chamaelea* (Linn.) Müll. Arg.	Euphorbiaceae	Herb
125.	*Setaria barbata* (Lam.) Kunth	Poaceae	Grass
126.	*Setaria pumila* (Poir.) Roem. & Schult.	Poaceae	Grass
127.	*Sida cordifolia* L.	Malvaceae	Shrub
128.	*Solanum torvum* Sw.	Solanaceae	Shrub
129.	*Spermacoce ocymoides* Burm.f.	Rubiaceae	Herb
130.	*Spilanthes acmella* (L.) L.	Asteracea	Herb
131.	*Spirodela polyrrhiza* (L.) Schleid.	Araceae	Herb
132.	*Stachytarpheta indica* (L.) Vahl	Verbenaceae	Shrub
133.	*Swietenia macrophylla* King	Meliaceae	Tree
134.	*Swietenia mahagoni* (L.) Jacq.	Meliaceae	Tree
135.	*Synedrella nodiflora (L.) Gaertn*	Asteraceae	Herb
136.	*Syngonium podophyllum* Schott	Araceae	Herb
137.	*Syzygium chavaran* (Bourd.) Gamble	Myrtaceae	Tree
138.	*Syzygium cumini* (L.) Skeels	Myrtaceae	Tree
139.	*Syzygium samarangense* (Blume) Merr. & L.M.Perry	Myrtaceae	Tree
140.	*Tabernaemontana alternifolia* L.	Apocynaceae	Tree
141.	*Tamarindus indica* L.	Leguminosae	Tree
142.	*Terminalia paniculata* Roth	Combretaceae	Tree
143.	*Terminalia arjuna* (Roxb. ex DC.) Wight & Arn.	Combretaceae	Tree
144.	*Tragia involucrata* L.	Euphorbiaceae	Herb
145.	*Tridax procumbens L.*	Asteraceae	Herb
146.	*Urena lobata L.*	Malvaceae	Shrub

Table Cont....

No.	Species	Family	Habit
147.	*Vetiveria zizanioides* (L.) Nash	Poaceae	Grass
148.	*Wattakaka volubilis* (L. f.) Stapf	Apocynaceae	Shrub
149.	*Wedelia chinensis* (Osbeck) Merr.	Asteraceae	Herb
150.	*Zingiber zerumbet* (L.) Roscoe ex Sm.	Zingiberaceae	Herb
151.	*Ziziphus oenopolia (L.) Mill. (L.) Mill.*	Rhamnaceae	Shrub
152.	*Ziziphus rugosa* Lam.	Rhamnaceae	Tree

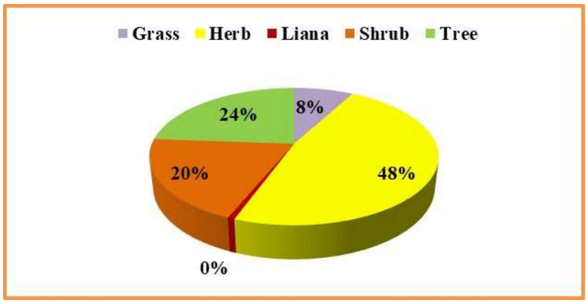

Fig. 2: Vegetation profile of Vamanapuram River Basin.

Fig. 3: Floristic composition.

crucial tool for understanding species' ecological significance across different vegetation types, a methodology aligned with the findings of Vincy et al. (2015). The analytical framework involved computing both the relative frequency and relative density of all species observed across the six panchayaths. It is noteworthy that P6 exhibited notably high relative frequency, while P5 emerged with the highest relative density, shedding light on the distinctive ecological dynamics of these regions (Table 2).

Many tree species stood out with impressively high Importance Values (IVs) when we focused on their botanical exemplars. Notably, *Macaranga peltata*, *Ficus hispida*, and *Swietenia macrophylla* exhibited the most robust IVs within this category (Table 3). Their impressive Relative Importance Value Index (RIVI) scores further underscored their ecological prominence, with *Macaranga peltata* leading the way with a score of 10.68, followed closely by *Ficus hispida* (10.57) and *Swietenia macrophylla* (8.31) (Table 3).

Table 2: Herbs, grass, shrubs, and trees of six panchayaths.

	F	D	A	RF	RD
P1	764	25.96	190.97	329.26	99.98
P2	633.32	21.66	196.39	284.87	100.03
P3	612.57	19.13	172.67	257.69	99.25
P4	541.72	18.07	177.89	236.36	99.94
P5	652.25	22.09	316.01	227.48	100.04
P6	637.51	22.94	186.83	337.83	100.02

Table 3: IVI and RIVI for tree species.

Tree species	GBH	TBA	IVI	RIVI
Acacia auriculiformis Benth.	279.46	6.12	1.92	0.64
Adenanthera pavonina L.	1139.82	102.02	6.21	2.07
Albizia chinensis (Osbeck) Merr.	172.7	2.34	5.31	1.77
Alstonia scholaris (L.) R. Br.	1227.74	118.33	13.82	4.61
Anacardium occidentale L.	1073.88	90.53	4.3	1.43
Annona reticulata L.	266.9	5.59	2.63	0.88
Areca catechu L.	1067.6	89.47	2.77	0.92
Artocarpus heterophyllus Lam.	3111.74	760.11	16.46	5.49
Artocarpus hirsutus Lam.	361.1	10.24	4.27	1.42
Averrhoa bilimbi L.	69.08	0.37	2.5	0.83
Azadirachta indica A.Juss.	78.5	0.48	9.1	3.03
Bridelia retusa (L.) A.Juss.	109.9	0.95	7.68	2.56
Carica papaya L.	204.1	3.27	1.09	0.36
Caryota urens L.	2885.66	653.67	16.11	5.37
Ceiba pentandra (L.) Gaertn.	1099	94.81	2.83	0.94
Cinnamomum verum J.Presl	335.98	8.86	1.34	0.45
Cocos nucifera L.	960.84	72.47	4.94	1.65
Couroupita guianensis Aubl.	439.6	15.17	3.13	1.04
Ficus hispida L.f.	1318.8	136.53	31.71	10.57
Ficus racemosa L.	376.8	11.15	7.96	2.65
Hevea brasiliensis (Willd. ex A.Juss.) Müll.Arg.	7096.4	3953.17	15.34	5.11
Macaranga peltata (Roxb.) Muell.-Arg.	4314.36	1461.18	32.05	10.68
Mangifera indica L.	1943.66	296.56	7.33	2.44
Phyllanthus emblica L.	471	17.41	1.61	0.54
Psidium guajava L.	282.6	6.27	2.63	0.88
Swietenia macrophylla King	6744.72	3571.06	24.93	8.31
Swietenia mahagoni (L.) Jacq.	4804.2	1811.81	15.74	5.25
Syzygium chavaran (Bourd.) Gamble	78.5	0.48	2.23	0.74
Syzygium cumini (L.) Skeels	408.2	13.08	1.49	0.5
Syzygium samarangense (Blume) Merr. & L.M.Perry	47.1	0.17	0.78	0.26
Tabernaemontana alternifolia L.	134.706	1.42	11.38	3.79
Tamarindus indica L.	1296.82	132.02	4.61	1.54
Terminalia arjuna (Roxb. ex DC.) Wight & Arn.	3501.1	962.23	9.73	3.24
Terminalia paniculata Roth	3579.6	1005.86	8.36	2.79
Ziziphus rugosa Lam.	36.424	0.104	6.14	2.05

Intriguing patterns of family-level Importance Value (FIV) emerged as well, shedding light on the collective ecological significance of plant families within the basin. Moraceae emerged as a standout with a notably high FIV of 60.4, followed by Meliaceae (49.77), Malvaceae (43.67), and Euphorbiaceae (47.39) (Fig. 4). These findings accentuate the invaluable role played by these families in shaping the basin's unique ecological fabric.

The Importance of Value Index calculations, encapsulating a species' ecological relevance within this ecosystem, holds profound implications for species conservation and management strategies. Those species manifesting lower

Table 4: ANOVA of F, D, A.

	F	p-value
P1	74.17	< 0.00001
P2	74.76	
P3	117.19	
P4	95.7	
P5	62.43	
P6	52.95	

IVI values warrant heightened attention and protective measures, an imperative underscored by Kacholi (2013). Furthermore, our meticulous analysis, as supported by one-way ANOVA results (Table 4), has brought to light significant differences among the six panchayaths in terms of species frequency, density, and abundance. These variations underscore the intricacies of the basin's ecological tapestry and further underscore the need for tailored conservation and management strategies to safeguard its biodiversity.

Species Diversity, Concentration of Dominance and Evenness

The Shannon-Wiener diversity index values exhibited a range from 3.42 to 3.78 across the studied panchayaths (Table 5). Notably, Panchayaths 5 (P5) and 1 (P1) recorded the highest diversity index values. It is noteworthy that these values align with the diversity index range reported for tropical forests in India, as documented by Singh et al. (1984), which spans from 0.83 to 4.1. This convergence underscores the tropical forest character of the Vamanapuram River Basin. However, it is essential to emphasize that the quantification of diversity based solely on species richness or density provides only a partial view of the intricate diversity patterns, which can vary depending on the measurement method, as elucidated by Gotelli & Colwell (2001).

Moving on to Simpson's index of diversity, the values ranged from 0.96 (P6) to 0.97 (P1-P5), while Simpson's reciprocal index ranged from 25 (P6) to 33.33 (P1-P5). The concentration of dominance (Cd) showed variation, ranging from 0.03 (P1-P4) to 0.05 (P6) (Table 5). This range of Cd values observed in the present study aligns well with the reported range for tropical forests, as documented by Knight (1975), with an average Cd value of 0.06. Further, Cd levels in India's tropical forests have been reported to vary from 0.21 to 0.92, consistent with the findings of Parthasarathy et al. (1992) and Visalakshi (1995).

Moreover, the analysis encompassed additional diversity indices, each shedding light on distinct facets of ecological richness. The Menhinick's Diversity Index spanned from 2.22 (P6) to 2.93 (P5), the Margalef Richness Index ranged from 8.08 (P6) to 10.43 (P5), and the Gini Coefficient exhibited variation from 0.31 (P4) to 0.49 (P2). The Berger-Parker Dominance Index spanned from 0.05 (P14) to 0.15 (P6), while the Buzas and Gibson's Index ranged from 0.06 (P2, P3, P5) to 0.07 (P1, P4, and P6). Furthermore, the Fisher's alpha diversity index showcased a range from 14.09 (P6) to 20.21 (P5), and the Pielou's Evenness Index displayed a variation from 0.86 (P2) to 0.94 (P4) (Table 5).

The concentration of dominance exhibited noteworthy correlations, with Simpson's index (0.88) and Berger-Parker Dominance Index (0.96), as revealed by the correlation matrix computed for the diversity indices. Additionally, Menhinick's Diversity Index and Margalef Richness Index exhibited a robust association (0.9), with both demonstrating a strong correlation with Fisher's Alpha Diversity Index (0.96 and 0.99, respectively) (Table 6).

Similarity Indices

The complexities of similarity indices were investigated as part of a comprehensive study to better understand how different panchayaths interact with different plants (Kiran

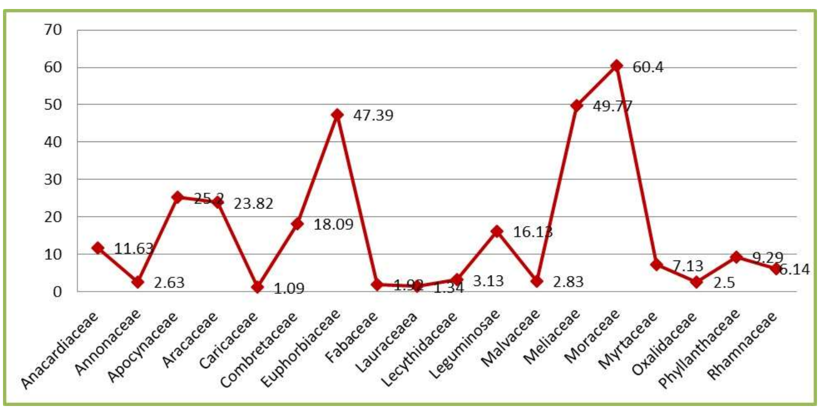

Fig. 4: FIV of families of tree species.

Table 5: Alpha diversity.

	P1	P2	P3	P4	P5	P6
Simpson's index	0.03	0.03	0.03	0.03	0.03	0.04
Simpson's index of diversity	0.97	0.97	0.97	0.97	0.97	0.96
Simpson's reciprocal index	33.33	33.33	33.33	33.33	33.33	25
Concentration of dominance	0.03	0.03	0.03	0.03	0.04	0.05
Heterogeneity	1.004	0.97	0.97	0.99	1.004	1.019
Menhinick's Diversity Index	2.28	2.33	2.66	2.6	2.93	2.22
Margalef Richness Index	8.8	8.32	9.14	8.73	10.43	8.08
Gini Coefficient	0.46	0.49	0.42	0.31	0.38	0.46
Berger-Parker Dominance Index	0.05	0.08	0.06	0.06	0.12	0.15
Buzas & Gibson's Index	0.07	0.06	0.06	0.07	0.06	0.07
Fisher's alpha diversity index	15.41	14.77	17.16	16.27	20.21	14.09
Shannon-Wiener index (H)	3.78	3.42	3.66	3.75	3.78	3.45
Pielou's Evenness Index	0.93	0.86	0.91	0.94	0.9	0.87

Table 6: Correlation of diversity indices.

	D	SDI	1/D	Cd	H	DMn	MRI	Gc	d	S	S□	H'	E
D	1	-1	-1	0.88	0.64	0.51-	0.49-	0.3	0.78	0.45	0.5-	0.56-	-0.49
SDI		1	1	-0.88	-0.64	0.51	0.49	-0.3	-0.78	0.45-	0.5	0.56	0.49
1/D			1	-0.88	-0.64	0.51	0.49	-0.3	-0.78	0.45-	0.5	0.56	0.49
Cd				1	0.76	0.12-	0.5-	0.14	0.96	0.22	-0.06	0.35-	-0.49
H					1	0.18-	0.03	-0.04	0.62	0.63	-0.04	0.15	0.04
DMn						1	0.9	-0.66	-0.02	-0.55	0.96	0.59	0.32
MRI							1	-0.44	0.03	0.5-	0.99	0.69	0.3
Gc								1	0.17	-0.17	-0.53	-0.64	-0.68
d									1	0	0.03	-0.44	-0.64
S										1	-0.53	0.13	0.4
S□											1	0.66	0.31
H'												1	0.89
E													1

et al. 2015). The concept of beta-diversity, hinging on the number of shared species between two assemblages, unveiled distinct patterns of plant species distribution. It was reported that P1 had 58 species of plants, whereas P2 had 54. Surprisingly, P1 and P2 shared a total of 28 plant species. However, P2 harbored 26 unique plant species not found in P1, while P1 held 30 distinct plant species absent in P2.

The landscapes of P5 and P6 featured 66 and 52 plant species, respectively. Remarkably, P5 and P6 exhibited a shared roster of 30 plant species, attaining a Sorensen similarity index of 50.86%. These findings underscored the unique ecological dynamics within the basin, as certain panchayaths showcased a higher degree of plant species overlap. However, it is crucial to note that only specific comparisons yielded Sorensen's similarity indices above the 50% threshold. These comparisons, encompassing P1 and P2, P1 and P5, P1 and P6, and P5 and P6, unveiled values exceeding 50% for plant species similarity, providing valuable insights into the basin's ecological affinities.

Table 7: Similarity indices.

Coefficient of Jaccard, S%						Coefficient of Sorensen, K%					
	P2	P3	P4	P5	P6		P2	P3	P4	P5	P6
P1	20	11.45	16.91	20	21.98	P1	50	25.86	40.71	50	56.36
P2	0	13.84	18.05	18.37	18.46	P2	0	32.14	44.04	45	45.28
P3		0	1308	13.89	13.39	P3		0	30.09	32.26	30.91
P4			0	16.55	13.71	P4			0	39.67	31.78
P5				0	20.27	P5				0	50.85

In contrast, none of the panchayaths exhibited values above 50% in terms of the Jaccard similarity index for plant species. Notably, P1 and P6 showed the highest value of 21.98%, closely followed by P5 and P6, with 20.27%. Conversely, P1 and P3 exhibited the lowest similarity, with a figure of 11.4%. P1, housing 58 plant species, showcased a 31-species overlap with P6, which held 52 species. Furthermore, P1 listed 27 plant species unobserved in P6, while P6 featured 21 species yet to be discovered in P1.

Table 7 presents a comprehensive overview of Sorensen's similarity indices across the six panchayaths. Beta diversity assessments, aligning with the methodology proposed by Ariyo (2007) and Ariyo et al. (2013), unveiled a range of Sorensen's similarity indices, ranging from 56.36% to 25.86%. Notably, P1 and P6 exhibited the highest similarity indices at 56.36%, followed by P5 and P6, P1 and P2, and P1 and P5, all hovering around the 50% mark. Conversely, P4 and P5, P3 and P5, P3 and P4, and P3 and P6 displayed lower similarity indices of 39.67%, 32.26%, 30.09%, and 30.91%, respectively. The comparison between P1 and P3 yielded the lowest similarity index at 25.86%. This striking variation in similarity indices underlines the unique ecological contexts of these panchayaths.

Dissimilarity Indices

Specifically, panchayaths P1 and P3 exhibited a pronounced dissimilarity index of 74.14%, marking a stark departure from the similarity indices observed earlier in Table 8. The dissimilarity indices for panchayath pairs, such as P2 and P3, P3 and P5, P4 and P5, and P3 and P6, showcased values ranging from 67.86% to 60.33%. P1 and P4, meanwhile, exhibited a dissimilarity score of 59.29%, while P1 and P6 registered the lowest dissimilarity value at 43.64%. These dissimilarity indices highlight the diversity of plant communities within the basin, reflecting the varying compositions of plant species.

To contextualize these findings, it is worth noting that different plant communities, based on their degree of similarity, can be amalgamated to form associations of distinct plant species. Researchers such as Chao et al. (2006, 2008) and Muller-Dumbois & Ellenberg (1974) have classified groups with less than 65% similarity as distinct entities. This variability in similarity indices is indicative of the fluctuating competitive capacities of seedlings, contingent upon the ever-changing prospects for regeneration, which in turn are influenced by the fluctuating floristic and structural compositions from one community to another (Barker & Kirkpatrick 1994). The numerous edaphic and microclimatic factors that diverge across different tropical forest types exert significant impacts on recruitment, growth, and survival, as elucidated by Augspurger (1984). A higher similarity index value, conversely, signifies relatively homogenous environmental conditions, while a lower value signifies pronounced variability, according to Ekta (2012).

The UPGMA algorithm was employed to construct a dendrogram that aids in hierarchical clustering to unravel the complex patterns of similarity and dissimilarity (Odum 1969). This dendrogram not only enables the analysis of the degree of similarity between VRB sites in percentage but also reveals the natural groupings of species across different sites. The dendrogram vividly portrays that locations within the same groupings exhibit significantly greater similarity than those in dissimilar groups. It further highlights the organic clustering and relatedness of P4 and P6, as well as P1 and P3. These dendrogram-based insights provide a visual representation of the degree of similarity among various VRB locations, as showcased in Fig. 5.

Statistical Analysis of Beta Diversity

Table 8: Dissimilarity Indices.

	P2	P3	P4	P5	P6
P1	50	74.14	59.29	50	43.64
P2	0	67.86	55.96	55	54.72
P3		0	69.91	67.74	60.09
P4			0	60.33	68.22
P5				0	49.15
P6					0

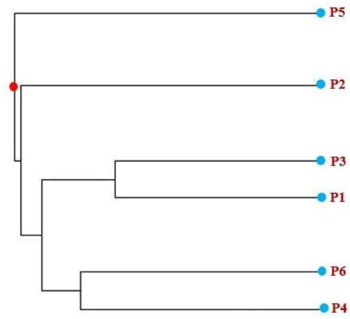

Fig. 5: Dendrogram.

Statistical analysis of beta diversity showed higher dissimilarity indices ($\sum X^2$ = 189350.65, σ = 108.17) concerning Jaccard ($\sum X^2$ = 507.47, σ = 8.23) and Sorensen similarity indices ($\sum X^2$ = 4853.68, σ = 14.71) (Table 9). One Way ANOVA analysis showed a significant difference in beta diversity (F = 10.76, p = 0.003) (Table 10).

CONCLUSION

The Vamanapuram River Basin (VRB) is home to 152 plant species from 50 different botanical families, revealing its rich biodiversity and intricate ecological dynamics. The basin is home to 13 species of Poaceae, 12 species of Leguminosae, 10 species of Araceae, and 9 species of Asteraceae. The vegetation profile includes 74 herbs, 30 shrubs, 12 grasses, 1 liana, and 35 towering trees, displaying a dynamic mix of plant forms and ecological niches. Wetland characteristics and periodic disturbances of floodplains influence this diversity, promoting the proliferation of Poaceae. Many key plant species were found to be ecologically dominant, including *Macaranga peltata*, *Ficus hispida*, and *Swietenia macrophylla*. Diversity indices, including Shannon-Wiener, show a high degree of diversity in P5 and P1. Conserving and managing VRB's biodiversity and ecological dynamics is highly important, highlighting the need for customized conservation and management strategies. Having a better understanding of VRB's unique flora and how ecosystem-based conservation and management are crucial to the region's sustainability.

Table 9: Statistical analysis of beta diversity.

	Jaccard	Sorensen	Dissimilarity	Total
$\sum X$	31.86	150.44	886.05	1068.35
Mean	5.31	25.07	147.68	59.35
$\sum X^2$	507.47	4853.68	189350.65	194711.8
Std.Dev.	8.23	14.71	108.17	87.88

Table 10: One Way ANOVA of beta diversity.

Source	*SS*	*df*	*MS*	*F*	p-value
Between-treatments	71379.24	2	35689.62	F = 10.76	0.003
Within-treatments	59923.25	15	3994.88		
Error	33164.61	10	3316.46		

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