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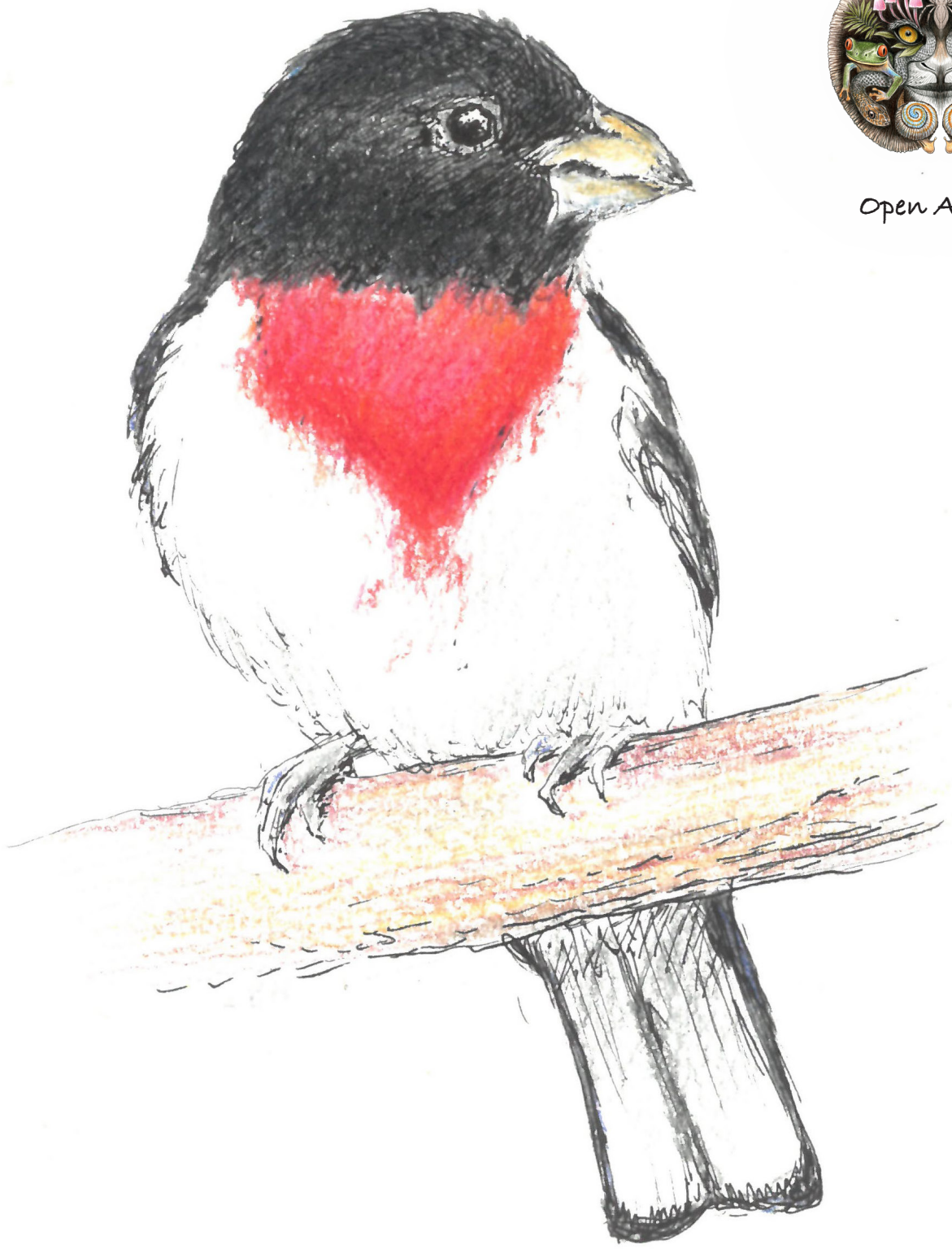

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Cover: Rose-breasted Grosbeak *Pheucticus ludovicianus*, pen & ink with colour pencil. © Lucille Betti-Nash.

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ARTICLE

Floristic diversity of mangroves and mangrove associate species of Kali River Estuary, Karwar, Karnataka, India

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Abstract: This study assessed the mangrove flora of the Kali River estuary, Uttara Kannada district, Karnataka. Fourteen true mangrove species belonging to eight families and 11 genera were documented from four locations: Devbagh, Mavinhole, Kalimatha Island, and Halgejoog. The mangrove species show a discontinuous distribution pattern in the Kali River estuary. The highest IVI in true mangroves was recorded for *Avicennia officinalis* at Devbagh, *Acanthus ilicifolius* at Mavinhole, *Sonneratia caseolaris* (after *Oryza coarctata*) at Kalimatha Island, and *S. caseolaris* (after *Derris trifoliata*) at Halgejoog. Of the four sites, Devbagh has the highest Shannon-Wiener diversity index, and with regard to species composition, Devbagh and Kalimatha Island are the most similar sites. Kalimatha island has the most well-preserved mangrove community.

Keywords: Floristic diversity, Kalimatha Island, Kali mangroves, phytosociology, vegetation analysis.

Abbreviations: A/F Ratio—Abundance to Frequency Ratio | GBH—Girth at Breast Height | IVI—Importance Value Index | L1—Location 1: Devbagh | L2—Location 2: Mavinhole | L3—Location 3: Kalimatha Island | L4—Location 4: Halgejoog.

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Author contributions: AGH—conducted fieldwork, led primary research, drafted and revised the manuscript. DDB—conducted field work, supervision, identified the species, reviewed and edited original draft. PKV—conducted supervision, reviewed and edited tables.

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INTRODUCTION

Mangroves are unique plant communities found in sheltered shores, estuarial inter-tidal zones, tidal creeks, backwaters, lagoons, mudflats, and marshes of the tropical and sub-tropical areas of the world. Mainly found in areas between latitude 24° N and 38° S (India State of Forest Report 2019), evergreen trees and shrubs chiefly make up the vegetational components of the mangrove ecosystem. They have adapted to grow in hostile conditions such as high salinity, recurring inundation by tidal saltwater, high temperature & wind speeds, and anaerobic soils. Mangrove species can be obligate halophytes, euryhalines, or stenohalines.

Mangroves provide a broad range of ecosystem services, including protecting coastline against erosion, storms and cyclones, serving as a natural carbon sink, and providing breeding grounds and nurseries for fish and prawns. This fragile ecosystem is in a seriously threatened state due to natural and anthropogenic causes. Standing at the brink of degradation, the mangroves are in need of urgent protecting and safeguarding. It is of grave importance that all the components of every ecosystem on earth, along with its interactions, are preserved. This conservation of the health of the ecosystems is imperative, not only for the sake of nature itself but also to ensure the survival of the present life and of the generations to come. This is because the human race heavily depends on the services (all the four types – provisioning, regulating, supporting, and cultural services) that the ecosystem so freely provides.

A global plan has to be made and executed in order to conserve not only a few species, but the whole mangrove ecosystem. Global mangrove mappings and biodiversity documentations are crucial for they define the mangrove limits, show an estimation of the carbon stores (Ximenes 2015), serve as an essential source of information about the biodiversity of the area and its biomass and describe the ecosystem as a whole. These mappings can also sometimes be used to determine the extent of the degradation or alteration of the mangrove communities. They serve as a guide for conservation efforts and hence policymaking for the same.

Chandran et al. (2012) studied the mangroves of Gangavali, Aghanashini estuaries, and Sharavathi-Badgani estuarine complex. Ramachandra et. al. (2013) estimated the total economic value of the ecosystem benefits provided by the mangroves of Venktapur, Sharavathi, Aghanishini, Gangavali, and Kali River estuaries. The study shows how the estuarine ecosystems contribute to the sustenance of the Uttara Kannada district's economy. The present study aims to understand the vegetation structure and estimate the floral diversity of the mangrove forests of the Kali River estuary at Karwar, Uttara Kannada district, Karnataka.

MATERIALS AND METHODS

Study Area

The current study was undertaken in the mangrove forests belonging to Karwar's Kali River estuary (74.1876°N, 14.8836°E) in Uttara Kannada district, Karnataka. Four locations were chosen to represent the floral diversity in the mangrove species varying with the salinity of the Kalli River estuary: Devbagh, Mavinhole, Kalimatha Island, and Halgejoog (Image 1). Except for the Kalimatha Island, which belongs to the Karwar Range of the Karwar Sub-Division, all the locations belong to the Gopshitta Range of Karwar Sub-Division, Canara Circle of the Karnataka State Forest Department.

1. Devbagh: located at the creek mouth (14.8476^0N and 74.1211^0E), at the junction of the creek and the river Kali. This water is 'euhaline' (salinity levels > 30.0ppt). The mangrove cover in the area is 40.07 ha of the total 102 ha belonging to the Devbagh region.

2. Mavinhole: located in a creek of the river Kali (14.8677^0N and 74.1219^0E), at 2.5 km from the mouth of the river. The water is 'polyhaline' (with salinity levels in the range of 18.0–30.0 ppt). The mangroves occupy 23.8 ha of the total 30 ha belonging to the Mavinhole region.

3. Kalimatha Island: located 3.2 km away from the river-mouth (14.8420^0N and 74.1428^0E), the water around the island is 'polyhaline' (with salinity levels in the range of 18.0–30.0 ppt). There is a patch of coconut trees and other cultivable plants at the center and at the periphery of this 8.5 ha island sits a 7 ha mangrove belt.

4. Halgejoog: located 10.5 km away from the mouth of the river (14.8818^0N and 74.1974^0E), the river water here is 'mesohaline' (with salinity levels in the range of 5.0–18.0 ppt). The mangroves here occupy an area of 91.13 ha.

Sampling and data collection

Nested quadrat method was used to gather primary data from the chosen study area. The quadrats sizes for trees, shrubs, and herbs were 31.62 × 31.62 m (approx. 0.1 ha), 3 × 3 m, and 1 × 1 m, respectively. On the confirmation of the presence of the mangroves in the area and their accessibility, random plots were selected for the study. Species accumulation curves

Image 1. Map showing the location of the four study areas.

were plotted, and 5 quadrats were sampled at each of the four locations.

The true mangrove and the mangrove associate species were identified and enumerated in all the chosen plots. The girth of all trees (> 15 cm) was measured at a height of 1.37 m above the ground level (GBH). The plots for shrubs and herbs were nested inside the plot for trees.

The phytosociology and the diversity indices for true mangroves and the associate mangroves were then estimated using this data.

The field data was gathered in various sessions in March 2021, during the low tides.

Species Identification

The plant specimens of true mangroves and mangrove associates were collected for identification purposes. Standard books and research papers on mangroves (Banerjee et al. 1989; Rao & Suresh 2001; Chandran et al. 2012) were consulted for the verification of the names of the species after their photographs were taken.

Species Composition and Importance Value

The plant species at the study plots of each location were identified and enumerated. The data collected from the field was used to analyze the distribution pattern of mangroves and their population structure by establishing a quantitative relationship among the plant species.

Relative frequency, relative density, relative dominance, abundance, abundance to frequency ratio, and Importance Value Index (IVI) were calculated in the application 'Microsoft Excel 2019', using the standard phytosociological methods (Curtis & McIntosh 1951). IVI was calculated as the sum of relative frequency, relative dominance, and relative density (Vijayan et al. 2015),

$$\text{Frequency (\%)} = \frac{\text{Number of quadrats in which a species occurs}}{\text{The total number of quadrats sampled}} \times 100 \quad \text{(Eq. 1)}$$

$$\text{Density} = \text{Number of individuals / ha} \quad \text{(Eq. 2)}$$

$$\text{Dominance} = \frac{GBH}{4\pi} \quad \text{(Eq. 3)}$$

$$\text{Abundance} = \frac{\text{Total number of individuals of a species}}{\text{Total number of quadrats in which the species occurs}} \quad \text{(Eq. 4)}$$

$$\text{Abundance/ Frequency (A/F) Ratio} = \frac{\text{Abundance of a species}}{\text{Frequency (in \%) of the species}} \quad \text{(Eq. 5)}$$

$$\text{Relative Frequency (\%)} = \frac{\text{Frequency of a species}}{\text{Frequency of all species}} \times 100 \quad \text{(Eq. 6)}$$

$$\text{Relative Frequency (\%)} = \frac{\text{Total number of individuals of a species}}{\text{Total number of individuals of all species}} \times 100 \quad \text{(Eq. 7)}$$

$$\text{Relative Dominance (\%)} = \frac{\text{The dominance of a species}}{\text{The dominance of all species}} \times 100 \quad \text{(Eq. 8)}$$

$$\text{IVI} = \text{Relative Frequency} + \text{Relative Density} + \text{Relative Dominance} \quad \text{(Eq. 9)}$$

Table 1. Occurrence of true mangroves and mangrove associates at the four locations.

Mangroves			Locations			
Family	Species	Life form	L – I	L – II	L – III	L – IV
True Mangroves						
Acanthaceae	*Acanthus ilicifolius* L.	S	+	+	+	+
	Avicennia marina (Forssk.) Vierh.	T	+	+	+	-
	Avicennia officinalis L.	T	+	+	+	-
Combretaceae	*Lumnitzera racemosa* Willd.	T	+	+	-	-
Euphorbiaceae	*Excoecaria agallocha* L.	T	+	+	+	+
Lythraceae	*Sonneratia alba* Sm.	T	+	-	+	-
	Sonneratia caseolaris Engl.	T	+	-	+	+
Poaceae	*Oryza coarctata* Roxb.	H	-	-	+	+
Primulaceae	*Aegiceras corniculatum* (L.) Blanco	S	-	+	+	-
Pteridaceae	*Acrostichum aureum* L.	H	-	+	-	+
Rhizophoraceae	*Bruguiera cylindrica* Blume	T	-	-	+	-
	Kandelia candel Druce	T	-	+	+	+
	Rhizophora apiculata Blume	T	-	+	+	+
Rhizophoraceae	*Rhizophora mucronata* Poir.	T	-	+	+	-
Mangrove Associates						
Bignoniaceae	*Dolichandrone spathacea* (L.f.) Baillon ex Schumann	T	-	-	-	+
Convolvulaceae	*Ipomoea pes-caprae* (L.) R.Br.	C	+	-	-	+
Fabaceae	*Acacia auriculiformis* A.Cunn. ex Benth.	T	-	+	-	-
	Caesalpinia crista L.	C	+	+	+	+
	Derris trifoliata Lour.	C	+	+	+	+
Lamiaceae	*Premna corymbosa* Rottler & Willd.	S	-	+	-	-
	Volkameria inermis L.	S	+	+	+	-
Lauraceae	*Cassytha filiformis* L.	C	+	+	+	+
Malvaceae	*Thespesia populnea* Sol. ex Corrêa	T	+	-	+	-

+—Presence | -—Absence | S—Shrub | T—Tree | H—Herb | C—Creeper/Climber

Species Diversity

Two of the three main components of diversity—α-diversity and β-diversity were calculated. For α-diversity, three measures of diversity – evenness, richness, and heterogeneity were calculated to analyse the diversity in the chosen locations based on the data collected. Cluster analysis was carried out to calculate β-diversity.

To determine the species evenness, Pielou's equitability index (J) and Buzas-Gibson's evenness index (E) were calculated; for species richness, Margalef's index (d) was calculated; for species diversity or heterogeneity, Shannon-Weiner index (H') and Simpson's diversity index (1-D) were calculated. These were calculated using the software 'PAST (PAleontological STatistics) Version 4.03' (Hammer et al. 2001). Further, the similarity in the species composition among the four locations was compared by the method of cluster analysis on the presence/absence transform data, using the software 'BioDiversity Professional Version 2.0'.

RESULTS

Species Composition

A total of 14 true mangrove species from eight families and 11 genera, and nine mangrove associate species belonging to six families and nine genera were found in the quadrats chosen for the present study.

Other true mangrove (*Bruguiera gymnorhiza* (L.) Lam. (Family: Rhizophoraceae)) and mangrove associate species (*Ixora concinna* R.Br. ex Hook.f. (Family: Rubiaceae), *Casuarina equisetifolia* L. (Family: Casuarinaceae), *Sesuvium portulacastrum* (L.) L. (Family: Aizoaceae), *Salvadora persica* L. (Family: Salvadoraceae), *Pongamia pinnata* (L.) Pierre (Family: Fabaceae), *Terminalia catappa* L. (Family: Combretaceae)) were also observed in the vicinity, but outside of the study plots.

The highest number of species (true mangroves and mangrove associates) of the four locations was observed at the Kalimatha Island (Location 3), with 17 species—12 true mangroves and five mangrove associates, followed by Mavinhole (Location 2), with 16 species—10 true mangroves and six mangrove associates. At Devbagh (Location 1), 13 species—seven true mangroves and six mangrove associates were observed, while at Halgejoog (Location 4), it was 12 species—seven true mangroves and five mangrove associates.

Acanthus ilicifolius and *Excoecaria agallocha* occurred at all the four locations, *Avicennia marina* and *Avicennia officinalis* occurred at locations 1, 2, and 3;

Table 2. Phytosociological characters of mangroves at Devbagh.

Species	Frequency (%)	Relative frequency (%)	Density	Relative density (%)	Dominance	Relative dominance (%)	Abundance	A/F ratio	IVI
Acanthus ilicifolius	40	5.71	40	1.34	5.74	0.007	10	0.25	7.06
Acrostichum aureum	0	0	0	0	0	0	0	0	0
Aegiceras corniculatum	0	0	0	0	0	0	0	0	0
Avicennia marina	40	5.71	84	2.82	6781.19	8.26	21	0.52	16.80
Avicennia officinalis	100	14.29	360	12.08	26126.16	31.82	36	0.36	58.19
Bruguiera cylindrica	0	0	0	0	0	0	0	0	0
Excoecaria agallocha	80	11.43	112	3.76	3657.38	4.46	14	0.18	19.64
Kandelia candel	0	0	0	0	0	0	0	0	0
Lumnitzera racemosa	40	5.71	6	0.20	206.90	0.25	1.5	0.04	6.17
Oryza coarctata	0	0	0	0	0	0	0	0	0
Rhizophora apiculata	0	0	0	0	0	0	0	0	0
Rhizophora mucronata	0	0	0	0	0	0	0	0	0
Sonneratia alba	40	5.71	166	5.57	17330.78	21.11	41.5	1.04	32.40
Sonneratia caseolaris	100	14.29	366	12.28	24677.61	30.06	36.6	0.37	56.63
Acacia auriculiformis	0	0	0	0	0	0	0	0	0
Caesalpinia crista	40	5.71	340	11.41	646.23	0.79	85	2.12	17.91
Cassytha filiformis	40	5.71	24	0.81	1.51	0.002	6	0.15	6.52
Derris trifoliata	40	5.71	52	1.74	264.65	0.32	13	0.32	7.78
Dolichandrone spathacea	0	0	0	0	0	0	0	0	0
Ipomoea pes-caprae	40	5.71	110	3.69	43.20	0.05	27.5	0.69	9.46
Premna corymbosa	0	0	0	0	0	0	0	0	0
Thespesia populnea	60	8.57	40	1.34	1536.00	1.87	6.67	0.11	11.78
Volkameria inermis	40	5.71	1280	42.95	814.87	0.99	320	8	49.66
Total	700	100	2980	100	82092.23	100	618.77		300

Sonneratia caseolaris occurred at locations 1, 3, and 4; *Kandelia candel* and *Rhizophora apiculata* were found at locations 2, 3, and 4; *Lumnitzera racemosa* was observed at locations 1 and 2; *Sonneratia alba* occurred at locations 1 and 3; *Rhizophora mucronata* was found at locations 2 and 3, while *Bruguiera cylindrica* was observed only at location 3. *Caesalpinia crista*, *Cassytha filiformis*, and *Derris trifoliata* were the most widespread mangrove associates. They were found distributed at all the four locations (Table 1).

The floral composition that was observed at the four locations is as follows:

Location 1 – Devbagh: *A. officinalis* and *S. caseolaris* were present in all the sample plots and were observed to have good growth. *A. ilicifolius, A. marina*, *L. racemosa*, and *S. alba* were found only in two sample plots; *S. alba* was found in plenty in the samples studied near the sea. The shrubby vegetation was sparse at best. This could probably be due to the lack of huge areas of deposited sediments that do not float away with the water because of the daily low- and high-tide phenomena. Vast expanses of mangroves were destroyed due to the inundation caused by heavy floods that occurred in 2019.

Location 2 – Mavinhole: *R. mucronata* occurred in all the sample plots at the location. There was a good amount of shrubby vegetation in some plots.

Location 3 – Kalimatha Island: *Oryza coarctata* was observed in newly forming mudflats in some plots (and in the adjacent areas) at the location. In some plots, a very good growth of *S. alba* was observed, and so was the case of *S. caseolaris* in some other plots. A good amount of species richness was observed at the location.

Location 4 – Halgejoog: *K. candel* and *S. caseolaris* were found in all the study stations of the location; but the plots were mostly dominated by shrubby and ground vegetation. A large number of mangrove associates were also observed adjacent to the study plots.

Table 3. Phytosociological characters of mangroves at Mavinhole.

Species	Frequency (%)	Relative frequency (%)	Density	Relative density (%)	Dominance	Relative dominance (%)	Abundance	A/F ratio	IVI
Acanthus ilicifolius	80	9.30	9746	74.37	1256.41	0.80	1218.5	15.23	84.47
Acrostichum aureum	40	4.65	44	0.34	6.22	0.004	11	0.28	4.99
Aegiceras corniculatum	60	6.98	1832	13.98	54331.54	34.52	305.33	5.09	55.48
Avicennia marina	40	4.65	62	0.47	4600.45	2.92	15.5	0.39	8.05
Avicennia officinalis	40	4.65	6	0.05	820.28	0.52	1.5	0.04	5.22
Bruguiera cylindrica	0	0	0	0	0	0	0	0	0
Excoecaria agallocha	60	6.98	238	1.82	7620.12	4.84	39.67	0.66	13.63
Kandelia candel	60	6.98	330	2.52	72111.05	45.82	55	0.92	55.31
Lumnitzera racemosa	40	4.65	10	0.08	602.88	0.38	2.5	0.06	5.11
Oryza coarctata	0	0	0	0	0	0	0	0	0
Rhizophora apiculata	40	4.65	126	0.96	3193.13	2.03	31.5	0.79	7.64
Rhizophora mucronata	100	11.63	318	2.43	10860.88	6.90	31.8	0.32	20.96
Sonneratia alba	0	0	0	0	0	0	0	0	0
Sonneratia caseolaris	0	0	0	0	0	0	0	0	0
Acacia auriculiformis	40	4.65	24	0.18	1294.01	0.82	6	0.15	5.66
Caesalpinia crista	60	6.98	76	0.58	171.91	0.11	12.67	0.21	7.67
Cassytha filiformis	40	4.65	28	0.21	2.75	0.002	7	0.18	4.87
Derris trifoliata	60	6.98	62	0.47	298.26	0.19	10.33	0.17	7.64
Dolichandrone spathacea	0	0	0	0	0	0	0	0	0
Ipomoea pes-caprae	0	0	0	0	0	0	0	0	0
Premna corymbosa	40	4.65	16	0.12	99.47	0.06	4	0.1	4.84
Thespesia populnea	0	0	0	0	0	0	0	0	0
Volkameria inermis	60	6.98	186	1.42	118.41	0.08	31	0.52	8.47
Total	860	100	13104	100	157387.77	100	1783.05		300

Vegetation Structure and Importance Value

Location 1 – Devbagh: Frequency (%) was the highest for *S. caseolaris* and *A. officinalis* (100%); density was the highest for *S. caseolaris* (a total of 366 stems in the study plots, i.e., 732 stems/ha and a relative density of 12.28%) and *Volkameria inermis* (1560 stems/ha and a relative density of 42.95%). Relative dominance was the highest for *A. officinalis* (31.82%). Abundance and A/F ratio were the highest for *S. alba* (abundance—41.5 | A/F ratio—1.05) and *V. inermis* (abundance—320 | A/F ratio 8). *A. officinalis* had the highest Importance Value Index—58.19 (Table 2).

Location 2 – Mavinhole: Frequency (%) was the highest for *R. mucronata* (100%); density was the highest for *A. ilicifolius* (a total of 9746 stems in the study plots, i.e., 19492 stems/ha and a relative density of 74.37%), *Aegiceras corniculatum* (3764 stems/ha and a relative density of 13.98%), *K. candel* (660 stems/ha and a relative density of 2.52%), and *R. mucronata* (636 stems/ha and a relative density of 2.43%). Relative dominance was the highest for *K. candel* (45.82%) and *A. corniculatum* (34.52%). Abundance was the highest for *A. ilicifolius* (abundance—1218.5) and *E. agallocha* (abundance—39.67). A/F ratio was the highest for *A. ilicifolius* (15.93) and *K. candel* (0.92). *A. ilicifolius* had the highest Importance Value Index—84.47 (Table 3).

Location 3 – Kalimatha Island: Frequency (%) was the highest for *A. corniculatum, A. officinalis, B. cylindrica,* and *R. apiculata* (80%); density was the highest for *S. caseolaris* (a total of 454 stems in the study plots, i.e., 908 stems/ha and a relative density of 9.33%) after *O. coarctata* (a grass species with a total of 5520 stems/ha and a relative density of 56.70%). Relative dominance was the highest for *S. caseolaris* (41.38%). Abundance and A/F ratio were the highest for *O. coarctata* (abundance—460, A/F ratio—7.67) and *S. caseolaris* (abundance—75.67, A/F ratio—1.26). *S. caseolaris* had the highest Importance Value Index—56.96 at location

Table 4. Phytosociological characters of mangroves at Kalimatha Island.

Species	Frequency (%)	Relative frequency (%)	Density	Relative density (%)	Dominance	Relative dominance (%)	Abundance	A/F ratio	IVI
Acanthus ilicifolius	60	6.25	260	5.34	41.38	0.03	43.33	0.72	11.62
Acrostichum aureum	0	0	0	0	0	0	0	0	0
Aegiceras corniculatum	80	8.33	172	3.53	4613.58	3.59	21.5	0.27	15.46
Avicennia marina	40	4.17	12	0.25	2429.26	1.89	3	0.08	6.31
Avicennia officinalis	80	8.33	188	3.86	42784.91	33.32	23.5	0.29	45.52
Bruguiera cylindrica	80	8.33	136	2.79	4645.89	3.62	17	0.21	14.75
Excoecaria agallocha	60	6.25	54	1.11	1612.88	1.26	9	0.15	8.62
Kandelia candel	40	4.17	70	1.44	2195.54	1.71	17.5	0.44	7.32
Lumnitzera racemosa	0	0	0	0	0	0	0	0	0
Oryza coarctata	60	6.25	2760	56.70	1083.85	0.844	460	7.67	63.79
Rhizophora apiculata	80	8.33	38	0.78	915.38	0.71	4.75	0.06	9.83
Rhizophora mucronata	60	6.25	96	1.97	2652.00	2.07	16	0.27	10.29
Sonneratia alba	40	4.17	148	3.04	10811.63	8.42	37	0.92	15.66
Sonneratia caseolaris	60	6.25	454	9.33	53129.58	41.38	75.67	1.26	56.96
Acacia auriculiformis	0	0	0	0	0	0	0	0	0
Caesalpinia crista	40	4.17	46	0.94	122.11	0.095	11.5	0.29	5.20
Cassytha filiformis	40	4.17	16	0.33	1.01	0.001	4	0.1	4.50
Derris trifoliata	60	6.25	42	0.86	225.79	0.18	7	0.12	7.29
Dolichandrone spathacea	0	0	0	0	0	0	0	0	0
Ipomoea pes-caprae	0	0	0	0	0	0	0	0	0
Premna corymbosa	0	0	0	0	0	0	0	0	0
Thespesia populnea	40	4.17	16	0.33	900.18	0.70	4	0.1	5.20
Volkameria inermis	40	4.17	360	7.36	229.18	0.18	90	2.25	11.74
Total	960	100	4868	100	128394.16	100	844.75		300

3 (Kalimatha Island), after *O. coarctata* (63.79) (**Table 4**).

Location 4 – Halgejoog: Frequency (%) was the highest for *A. ilicifolius, Acrostichum aureum, K. candel*, and *S. caseolaris* (100%); density was the highest for *A. aureum* (a mangrove fern). Relative dominance was the highest for *S. caseolaris* (48.27%). Abundance was the highest for *A. aureum* (506) and *S. caseolaris* (9.6). A/F ratio was the highest for *O. coarctata* (11.62) and *R. apiculata* (0.12). *D. trifoliata* had the highest Importance Value Index—67.25, followed by S. caseolaris (61.11) (Table 5).

Species Diversity

α-diversity

Species richness, species evenness, and species heterogeneity were calculated for the four locations using various diversity indices (Table 6).

According to Margalef's index (d), the Kalimatha Island (location 3) had the highest species richness (with a Margalef's index value of 2.052) of the four locations. The Margalef's index values were 1.642, 1.706, 2.052, and 1.233 for locations 1, 2, 3, and 4, respectively.

Both the indices to calculate species evenness—Pielou's evenness index (J) and Buzas-Gibson's evenness (E) measure indicate to Devbagh (location 1) having the highest species evenness (with Pielou's index value of 0.7282 and Buzas-Gibson's index value of 0.498) of all the four locations. Pielou's index of species richness gives a measure of the degree of community structuring, and ranges from 0–1. A higher value indicates a lesser variation of the species abundance within a community, and this means that all the species occur in relatively similar proportions.

Pielou's index values were 0.7282, 0.3609, 0.602, and 0.6525 for the locations 1, 2, 3, and 4, respectively. Buzas-Gibson's index values were 0.498, 0.17, 0.3238, and 0.4217 for the locations 1, 2, 3, and 4, respectively.

For the calculation of species heterogeneity of

Table 5. Phytosociological characters of mangroves at Halgejoog.

Species	Frequency (in)	Relative frequency (%)	Density	Relative density (%)	Dominance	Relative dominance (%)	Abundance	A/F ratio	IVI
Acanthus ilicifolius	100	12.20	3240	21.57	623.95	1.51	324	3.24	35.27
Acrostichum aureum	100	12.20	5060	33.68	715.34	1.73	506	5.06	47.61
Aegiceras corniculatum	0	0	0	0	0	0	0	0	0
Avicennia marina	0	0	0	0	0	0	0	0	0
Avicennia officinalis	0	0	0	0	0	0	0	0	0
Bruguiera cylindrica	0	0	0	0	0	0	0	0	0
Excoecaria agallocha	60	7.32	12	0.08	467.36	1.13	2	0.03	8.53
Kandelia candel	100	12.20	24	0.16	954.85	2.31	2.4	0.02	14.67
Lumnitzera racemosa	0	0	0	0	0	0	0	0	0
Oryza coarctata	40	4.88	1860	12.38	730.42	1.77	465	11.62	19.03
Rhizophora apiculata	40	4.88	20	0.13	454.78	1.10	5	0.12	6.11
Rhizophora mucronata	0	0	0	0	0	0	0	0	0
Sonneratia alba	0	0	0	0	0	0	0	0	0
Sonneratia caseolaris	100	12.20	96	0.64	19937.82	48.27	9.6	0.1	61.11
Acacia auriculiformis	0	0	0	0	0	0	0	0	0
Caesalpinia crista	80	9.76	1060	7.06	1665.04	4.03	132.5	1.66	20.84
Cassytha filiformis	40	4.88	46	0.31	2.89	0.007	11.5	0.29	5.19
Derris trifoliata	80	9.76	3380	22.50	14454.55	35.00	422.5	5.28	67.25
Dolichandrone spathacea	40	4.88	24	0.16	1218.73	2.95	6	0.15	7.99
Ipomoea pes-caprae	40	4.88	200	1.33	78.54	0.19	50	1.25	6.40
Premna corymbosa	0	0	0	0	0	0	0	0	0
Thespesia populnea	0	0	0	0	0	0	0	0	0
Volkameria inermis	0	0	0	0	0	0	0	0	0
Total	820	100	15022	100	41304.27	100	1936.5		300

Table 6. Diversity indices of the four locations.

Diversity indices	Location 1	Location 2	Location 3	Location 4
(i) Species richness				
Margalef's index (d)	1.642	1.706	2.052	1.233
(ii) Species evenness				
Pielou's index (J)	0.7282	0.3609	0.602	0.6525
Buzas-Gibson's index (E)	0.498	0.17	0.3238	0.4217
(iii) Species diversity				
Shannon-Wiener's index (H')	1.868	1.001	1.706	1.621
Simpson's index (1-D)	0.7654	0.428	0.6561	0.7688

the study sites, Shannon-Wiener's diversity index (H') and Simpson's diversity index (1 - D) were calculated. Shannon-Wiener's diversity index values were 1.868, 1.001, 1.706, and 1.621 for location 1, 2, 3, and 4, respectively. Simpson's diversity index values were 0.7654, 0.428, 0.6561, and 0.7688 for locations 1, 2, 3, and 4, respectively. According to Shannon-Wiener's diversity index, Devbagh (location 1) had the highest species heterogeneity or diversity (with the index value of 1.868) of the four locations. But the Simpson's diversity index values of the four locations showed that location 4 (Halgejoog) was the most diverse one, with an index value of 0.7688, while Devbagh had the index value of 0.7654.

Shannon-Wiener's diversity index is a Type I index, i.e., it is most sensitive to the changes in the rare species of the community sample, while Simpson's diversity index is a Type II index, which means that it is most sensitive to the changes in the more abundant species of the community sample (Peet 1974).

The calculated diversity indices indicate to Devbagh having the highest diversity of the four locations with the diversity being sensitive to the less-abundant species of the community sample, and Halgejoog having

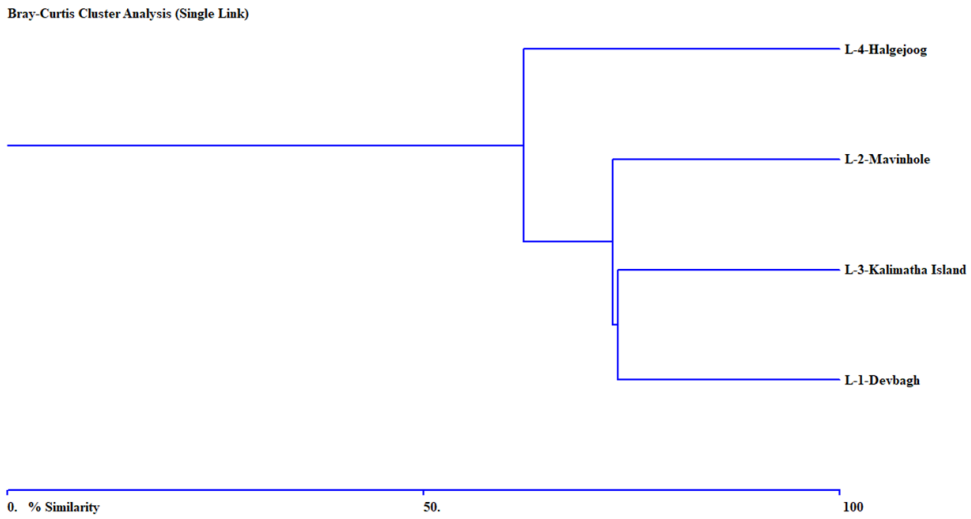

Figure 1. Dendrogram of the species composition at the four locations based on presence/absence transform data by way of single-link Bray-Curtis cluster analysis.

the highest diversity with the diversity being sensitive to the common or more abundant species at the location. This would imply that Devbagh was more diverse due to the presence of less-abundant species, while Halgejoog was more diverse due to the dominance of the common species at the location. This can be supported by the fact that the index values of both measures – species richness and species evenness, of Devbagh are higher as compared to those of Halgejoog. The index value for Margalef's species richness of Halgejoog (1.233) is much lesser than that of Devbagh (1.642), while there is a lesser difference between the index values of the measure of species evenness of the two locations – the Pielou's species evenness index value of Devbagh is 0.7282, and that of Halgejoog is 0.6525. Similarly, the Buzas-Gibson's species evenness index value of Devbagh is 0.498, while that of Halgejoog is 0.4217. This means that the species abundance at both Devbagh and Halgejoog was almost similar, but Devbagh was more species-rich, i.e., there were more less-abundant species at Devbagh than there were at Halgejoog.

β-diversity

Based on the presence/absence transform data of the species, the similarity index was calculated, and the dendrogram (Figure 1) briefs it based on the Bray-Curtis Cluster Analysis (Single-Link).

Locations 1 (Devbagh) and 3 (Kalimatha Island) were most similar to each other (73.33% similarity), while location 2 (Mavinhole) is 72.73% similar to this cluster. Location 4 (Halgejoog) matched the least with the rest of the locations, with a similarity of 62.07%.

DISCUSSIONS

Of the four locations studied, Kalimatha Island had the highest number of species (17)—12 true mangroves and five mangrove associates. Devbagh had the highest species evenness of the four locations and is also the most diverse concerning the less-abundant species, and second-most diverse when common species are emphasized. Halgejoog had the highest species diversity from Simpson's diversity indices (0.7688), i.e., diversity with respect to common species. Kalimatha Island and Devbagh are the most similar locations regarding the species composition. Tree density was the highest at Mavinhole (2,505 trees/ha).

Although plantation activities have been taken up at all the four locations, the study shows that, out of Devbagh, Mavinhole, Kalimatha Island, and Halgejoog, Kalimatha Island has the best-preserved mangrove community as it has the highest number of true mangroves (12) and the least number of mangrove associates (five). Halgejoog is located well inland compared to the other three sites and shows mostly shrubby vegetation, despite having seven true mangrove and five mangrove associate species. Devbagh, located at the mouth of the river, has the maximum number of mangrove associate (six) and the least number of true mangroves species (seven), which seems to be so because of frequent floods and long-term inundations. Non-native species like *Acacia auriculiformis* was observed in the study plots at Mavinhole, which could hamper the growth of native biodiversity of the area. Anthropogenic interference – both positive (like plantation activities, and other

measures for conservation) and negative (pollution, and fishing), was observed at all the sites.

The Karwar mangrove forests can be classified as scattered patches since the mangrove species, at all the sites, showed a discontinuous distribution pattern.

The studied mangrove forests create a very fragile ecosystem as they depend on unique ecological conditions like salinity, depth of water, specific substrate, and any alteration triggers to these conditions may lead to invasion of other associate species resulting in risks to the true mangrove species in the future.

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