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WATER CHEMISTRY AND THE DISTRIBUTION OF PODOSTEMACEAE IN GHANA

G. K. Ameka, K. A. A. de Graft-Johnson and J. K. Adomako
*(G. K. A. and J. K. A.: Department of Botany, University of Ghana, Legon, Ghana;
K. A. A. de G-J.: CSIR-Water Research Institute,
P. O. Box M.32, Accra, Ghana)*

Abstract

The physico-chemical parameters of several rivers in southern Ghana were determined during the dry season. Other environmental features, e.g. canopy cover, rock substrate type, etc. of each site sampled were also recorded. Four Podostemaceae species were recorded in 10 of the rivers sampled. The distribution of the Podostemaceae appeared to relate to availability of rock substrate, open canopy and some level of plant nutrients, e.g. phosphates and nitrates in the water. Further data must be collected at the sites where Podostemaceae grow in the tropics, particularly in Africa, to enable a better understanding of the contribution of river chemistry and other environmental parameters to the distribution of the Podostemaceae.

Résumé

Ameka, G. K., de Graft-Johnson, K. A. A. & Adomako, J. K.: *La chimie d' eau et la distribution de podostemaceae au Ghana.* Les paramètres physico-chimiques de plusieurs rivières au sud du Ghana étaient déterminés pendant la saison sèche. D'autres caractéristiques environnementales, par ex. l'abri de canopée, le type de substrat dans les rochers, etc., de chaque site prélevé était aussi noté. Quatre espèces de Podostemaceae étaient notées dans les 10 de rivières prélevées. La distribution de Podostemaceae semble être liée à la disponibité de substrat dans les rochers, à la canopée ouverte, et à un certain niveau de substance nutritive végétale, par ex. les phosphates et les nitrates dans l'eau. Des données supplémentaires doivent être recueillies aux sites ou les Podostemaceae particulièrement en Afrique, pour permettre une meilleure compréhension de la contribution de la chimie de rivière et d' autres paramètres environnementales à la distribution de Podostemaceae.

Introduction

There are 407 genera of aquatic vascular plants worldwide (Cook, 1999) of which about 50 belong to the Podostemaceae (Ameka, 2000; Ameka *et al*., 2002). The Podostemaceae, or river-weeds, are the largest family of submerged aquatic flowering plants (Philbrick & Novelo, 1995). The plants grow tenaciously attached to rocks, stones, or other solid substrata including roots and wood in harsh conditions of the rapid river habitat, waterfalls and cataracts that are unusual for angiosperms except for example, the Hydrostachyaceae. The Podostemaceae occur usually, in the tropics and subtropics, reaching from north and south America, Africa (Egypt to South Africa, Senegal to Ethiopia) including Madagascar, India and Sri Lanka, China to Java and Australia (Lister, 1903; Willis, 1915; Cook, 1996; Ameka, 2000). Few species are found in temperate climates. *Podostemum ceratophyllum* Michx. is found in temperate North America (Graham & Wood, 1975) and species of *Cladopus* Möller and *Hydrobryum* Endl. are found in Japan (Imamura, 1927; Kadono & Usui, 1995).

Members of the Podostemaceae family are

rheophytes. The plants grow vegetatively and usually submerged during the rainy season. During the dry season when the water level recedes, the plants are exposed and flowering and fruiting occur. Several members of the Podostemaceae are annuals and some others are perennials. The family is unique in having a high degree of endemism (Graham & Wood, 1975) with many species and some genera known only from a single river or from small geographical areas (Cook, 1996). *Angolaea fluitans* Wedd. is known only from the Quanza river in Angola (Baker & Wright, 1909; Cook, 1996). Four species of *Stonesia* are restricted to a small district in Guinea and Sierra Leone (Taylor, 1954; Cook, 1996). Some species are, however, widely distributed. *Podostemum ceratophyllum,* for instance, occurs in a wide geographical area in north to south America (Graham & Wood, 1975), and *Tristicha trifaria* is found in central to south America, Africa and Madagascar, and the Mascarine Islands (Cook, 1996).

There is renewed interest in the study of the Podostemaceae in recent years. Many of the published works, however, are in the areas of taxonomy and morphology including developmental morphology. Very little work has been done on how water chemistry and other environmental factors affect the Podostemaceae. In this paper, data on water chemistry and other environmental variables at the habitat of three Podostemaceae species in Ghana are presented, and how the variables affect their distribution are examined. The species are *Ledermanniella bowlingii* (J. B. Hall) C. Cusset, *Saxicolella amicorum* (J. B. Hall), and *Tristicha trifaria* (Bory *ex* Willd) Sprengel.

Experimental

Twenty-six rivers, at 30 sites, in southern Ghana (Table 1) were surveyed for Podostemaceae. Each river site was visited once during the dry season, November 1999-March 2000, when the impact of pollution was most severe and Podostemaceae were in their reproductive phase. The geographical co-ordinates (longitude and latitude) of the sites were determined using a Global Positioning System, Garmin GPS 45, set to read in degrees and minutes. The forest type was identified based on the classification of Hall & Swaine (1981) and its status, i.e. forest reserve, non-forest reserve, resource reserve, etc. was recorded using data from the Wildlife Department of the Ministry of Lands and Forestry, Accra, and the work of Hall & Swaine (1981).

Percentage tree canopy cover of the site was estimated by comparing canopy cover in the adjacent forest to that over the river at the sampling site. The canopy cover in the adjacent forest was closed in which the tree crowns touch and interlock with each other. In an open canopy a gap is created between the tree crowns which do not touch or interlock. The percentage canopy cover was scored as follows: 50-100 per cent as closed canopy, 25-50 per cent as partially opened canopy, and 0 – 25 per cent as open canopy.

The river catchment characteristics were also determined using geological survey maps drawn by the Ghana Survey Department (Anon., 1973), particularly area of catchment of river and area of catchment within forest reserves. A particular point in the river was the sampling site of water for chemical analyses. This point was used as reference in determining the catchment area of the rivers. Substrate type and Podostemaceae species present at the site of water sample collection were also recorded.

River water samples were collected during the survey of rivers for Podostemaceae for analyses during the dry season. During the dry season (November-March) the river recedes and the flow is sluggish. At each site, the water was collected from a spot where there was free flowing water. The water samples were collected in 250 ml pre-washed and labelled polypropylene bottles. The samples, other than those for determination of *p*H and electrical conductivity, were stored on ice and transported to the laboratory, where they were kept in a refrigerator at 4 ^{o}C, and analysed.

TABLE 1

Rivers in southern Ghana surveyed for Podostemaceae and the sampling sites at the respective localities. (Longitude and latitude values of the sampling sites were obtained from a GPS (Garmin GPS 45) set to read in degrees and minutes)

River	*Locality*	*Sampling site*	
Afia	Antwi Kwa	01^{o} 25.3’ W	05^{o} 27.3’ N
Agumatsa	Wli	00^{o} 35.5' E	07^{o} 06.9’ N
Akrum 1	Begoro	00^{o} 18.0’ W	06^{o} 20.0’ N
Akrum 2	Dominase	00^{0} 12.0’ W	06^{0} 29.0’ N
Ankasa	Ankasa	02^{o} 39.1’ W	05^{o} 13.5’ N
Asuboni	Kwahu Nteso	00^{0} 35.5’ W	06^{0} 45.0’ N
Asuohyiame	Banso	02^{0} 17.0’ W	05^{0} 11.3’ N
Atronsu	Awaso	02^{0} 13.0’ W	06^{0} 16.0’ N
Awa	Awaso	02^{0} 17.0’ W	06^{0} 16.0’ N
Bia	Tipokrom	02^{0} 84.8’ W	06^{0} 73.1’ N
Birim	Bunso	00^{0} 15.0’ W	06^{0} 30.0’ N
Densu	Obuasi-Potrase	00^{0} 30.0’ W	06^{0} 08.0’ N
Disue 1	Yankoman	02^{o} 47.5’ W	05^{o} 50.4’ N
Disue 2	Achimfo	02^{o} 71.6’ W	05^{o} 77.8’ N
Draw	Banso	02^{o} 16.3’ W	05^{o} 10.3’ N
Jeba	Adubrim	02^{o} 20.0’ W	05^{o} 05.3’ N
Jimi	Akrofuom	01^{o} 39.3’ W	06^{o} 07.0’ N
Kakum	Asuansi	01^{o} 15.1’ W	05^{o} 19.0’ N
Nwhini 1	Akropong	02^{o} 17.3’ W	05^{o} 05.0’ N
Nwhini 2	Adubrim	02^{o} 20.3’ W	05^{o} 06.3’ N
Oben	Sagyimase	00^{0} 32.0’ W	06^{0} 16.0’ N
Obuo	Twifo Adubrim	01^{o} 33.0’ W	05^{o} 31.0’ N
Pawnpawn	Huhunya	00^{o} 12.9’ W	06^{o} 11.3’ N
Pusupusu	Asiakwa	00^{o} 32.0’ W	06^{o} 15.0’ N
Subiri kokoo 1	Asaa	01^{o} 28.3’ W	05^{o} 23.0’ N
Subiri kokoo 2	Akotosu	01^{o} 29.0’ W	05^{o} 22.3’ N
Supon	Sagyimase	00^{o} 34.0’ W	06^{o} 18.0’ N
Tano	Ntotroso	02^{o} 30.8’ W	07^{o} 02.9’ N
Tsatsadu	Alavanyo	00^{o} 26.0’ E	07^{o} 04.0’ N
Wankobiri	Kyirepong	00^{o} 32.0’ W	06^{o} 16.0’ N

The hydrogen ion concentration (*p*H) and electrical conductivity were measured in the field using a Jenway 3071 *p*H meter and Jenway 4071 conductivity meter, respectively. Twelve other parameters of the water were measured. The standard relevant methods for these determinations were followed, and, unless otherwise stated, the methods were as described in APHA-AAA-WWA-WPCF (1989), and used in routine analyses in the research laboratory of the Water Research Institute in Accra. The methods are as follows: orthophosphate (PO_4-P) by reaction with molybdate (Mackereth, Heron & Talling, 1978; Chloride (Cl^-) by silver nitrate titration with potassium dichromate; sulphate (SO^{2-}_4) by turbidimetric using barium chloride; silica (SiO_4) by molybdosilicate method; calcium (Ca^{2+}) and total hardness by titration with ethylenediamine tetraacetic acid (EDTA); ammonia-nitrogen (NH_3-N) by indophenol blue method (FAO, 1975); nitrate-nitrogen (NO_3-N) by hydrazine reduction, followed by diazotizing to form an azo dye; turbidity by nephelometric method; total suspended solids determined as nonfilterable residue dried at 105 ^{0}C and total dissolved solids as filterable residue dried at 108 ^{0}C. Magnesium (Mg^{2+} wascalculated as Mg = total hardness - Ca^{2+})

Results and discussion

Characteristics of river sites sampled for Podostemaceae

The geographical positions and localities of river sites sampled are shown in Table 1. Twenty-six rivers at 30 localities were sampled for Podostemaceae. Characteristic features of the sites are presented in Table 2. Riverbed substrate of the rivers was sandy, coarse sand, gravel or rock. The Podostemaceae were found growing only in rivers with rocky substrate. Four Podostemaceae species were found in 10 rivers at 12 sites (Table 2). The catchment area of the rivers varied from as low as about 3 km^2 to a height of about 2600 km^2.

Nearly a third of the rivers have their catchment areas under full forest cover. The other rivers have partly forested catchment areas. Fifty per cent of all rivers sampled have part or all of their catchment areas in forest reserves. The forest types in which the rivers occur can be put into five categories: upland evergreen, wet evergreen, moist evergreen, moist semi-deciduous and dry semi-deciduous. Seventeen per cent of the rivers were found in upland evergreen, 23 per cent in wet evergreen and 20 per cent each in the remaining forest types. The canopy cover was closed in 33 per cent of the rivers, partially closed in 27 per cent and opened in 40 per cent of them.

In order to examine the effect of environmental variables, other than water chemistry, on the distribution of Podostemaceae in the rivers, an ordination principal component analysis of environmental variables of the rivers was carried out. Non-numerical data in Table 2 was coded before being used for the PCA, which resulted in Fig. 1. The coding was as follows: forest reserves were coded as 1= Kakum, 2 = Pra Suhien, etc.; forest type was coded as 1 = wet evergreen, 2 = moist evergreen, etc.; canopy cover was coded as 1 = closed, 2 = partially closed and 3 = opened; substrate of riverbed was coded as 1 = rock, 2 = gravel, 3 = sand; and Podostemaceae species were coded as 1 = *Ledermanniella bowlingii*, 2 = *Saxicolella amicorum*, 3 = *Saxicolella submersa* and 4 = *Tristicha trifaria*.

It appears that the occurrence of Podostemaceae in the rivers sampled is related to availability of rock substrate and open forest canopy cover. This is shown by the principal component analysis in Fig. 1, which is based on data in Table 2, in which river sites with open canopy (75–100% open) are in one group (GP I). In the second group (GP II) are sites with partially opened canopies (50–75% open), and the third group (GP III) are those with closed canopies (≤ 50%). All the sites in GP I have rock substrata, and, except for Tsatsadu river, are inhabited by at least one Podostemaceae species. GP II and GP III sites have a variety of substrata ranging from sand, gravel, pebble to rock, and do not have Podostemaceae.

Chemistry of rivers which were surveyed for Podostemaceae

Twenty-six rivers in southern Ghana were surveyed for Podostemaceae. River water samples were taken from 21 of these rivers at 25 localities (Table 3) during the dry season (November- March), when the impact of pollution was most severe and Podostemaceae were in their reproductive phase, and analysed. All rivers in which Podostemaceae was found were included

TABLE 2
Characteristics of catchment areas and rivers which were sampled for Podostemaceae in southern Ghana

River	*Substrate of riverbed*	*Catchment area (km²)*	*% Forest cover*	*Forest reserve*	*Forest type*	*Canopy cover*	*Podostemaceae species*
Afia	Sand/rock	39.2	50.5	Kakum	MS	Closed	-
Agumatsa	Rock	89.0	100.0	-	DS	Opened	*Saxicolella*
Akrum 1	Rock	121.0	32.0	-	DS	Opened	
Akrum 2	Rock	439.9	12.8	-	DS	Opened	*T. trifaria*
Ankasa	Rock	89.4	81.0	Ankasa	WE	Opened	*S. amicorum*
Asuboni	Rock	171.8	6.0	-	DS	Opened	*L. bowlingii*
Asuohyaime	Gravel	2.7	100.0	Draw	WE	Closed	-
Atonsu	Gravel	1.5	100.0	-	MS	Closed	-
Awa	Gravel	6.5	100.0	-	MS	Partial	-
Bia	Rock	2436.0	21.0	Subin	MS	Partial	-
Birim	Gravel	100.0	32.0	-	MS	Opened	-
Densu	Rock	14.7	80.4	Atewa	UE	Partial	-
Disue 1	Rock	754.9	29.9	-	ME	Partial	*T. trifaria*
Disue 2	Gravel	656.6	34.4	-	ME	Partial	-
Draw	Rock	90.2	68.3	Draw	WE	Partial	*T. trifaria*
Jeba	Sand	3.0	70.1	Ebi Shbelt	WE	Closed	-
Jemi	Gravel	267.9	10.1	-	MS	Opened	-
Kakum	Rock	155.5	34.6	-	DS	Opened	*T. trifaria*
Nwhini 1	Rock	395.4	36.1	-	WE	Partial	*S. amicorum*
Nwhini 2	Rock	334.2	40.6	-	WE	Opened	*T. trifaria*
Oben	Rock	3.1	100.0	Atewa	UE	Closed	-
Obuo	Rock	297.6	36.9	-	ME	Opened	*T. trifaria*
Pawnpawn	Rock	35.0	100.0	Boti Falls	DS	Opened	*T. trifaria*
Pusupusu	Rock	10.5	100.0	Atewa	UE	Closed	-
Subiri 1	Sandy	27.8	1.0	-	ME	Partial	-
Subiri 2	Sandy	38.7	9.0	Pra Suhien	ME	Closed	-
Supon	Gravel	8.5	100.0	Atewa	UE	Closed	-
Tano	Rock	2648.0	15.0	Bosumkese	MS	Closed	-
Tsatsadu	Rock	15.0	1.0	-	DS	Opened	-
Wankobiri	Gravel	12.3	100.0	Atewa	UE	Closed	-

in the analysis. The results obtained are shown in Table 3.

The *p*H of the rivers surveyed ranged from slightly acidic to near neutral (*p*H 5.2 - 7.2). The *p*H of the rivers fell well within the range reported for Ghanaian and other W. African rivers by Biney (1985), John (1986) and Ameka (1987). Turbidity ranged from 3 to 74 NTU. Most of the rivers with Podostemaceae had low turbidity ranging from 3 to 15 NTU; e.g. Agumatsa river had turbidity of 3 NTU. In freshwaters, turbidity affects adequate illumination of submerged plants, thus, high

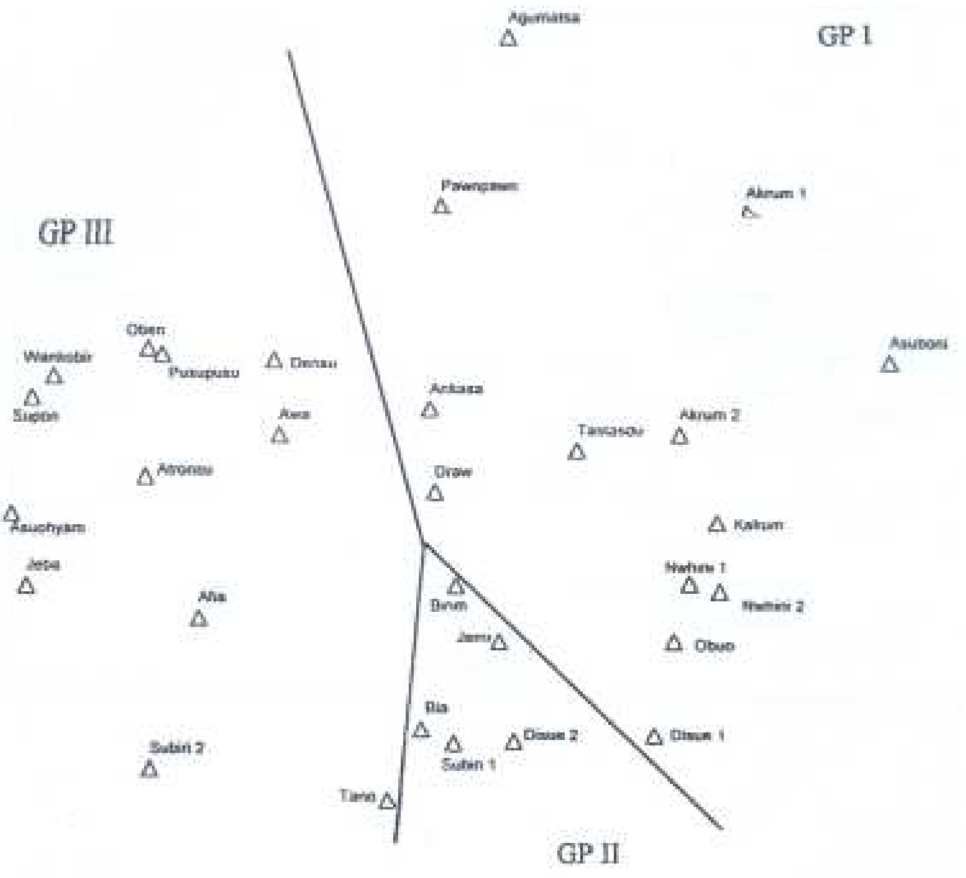

Fig.1. Ordination (principal component analysis) of environmental variables of 26 rivers surveyed for Podostemaceae in southern Ghana

turbidity will affect illumination of Podostemaceae. However, for rivers with high turbidity in which Podostemaceae occur, the plants are usually exposed and not submerged during the dry season when turbidity was measured. It is possible that lower turbidity will be recorded during the wet season because of dilution in such rivers. All rivers in which Podostemaceae was found growing had low total suspended solids of 0-9 mg l^{-1}, which suited the species growing in them, as the attachment of seeds and seedlings to the substrata would not be disturbed by deposits of particles or silt on the surface of the substrata.

Apart from phosphates there were detectable levels of all the nutrients measured in all the rivers surveyed. Phosphates were not detected in two rivers, Afia river and Subin river. The values obtained for rivers with Podostemaceae were similar to those reported for Mexican rivers with Podostemaceae by Quiroz *et al*. (1997). The values in Table 3 for rivers, which did not have Podostemaceae, fell within the range of values for rivers with Podostemaceae in Ghana. The principal component analysis (Fig. 2) shows that separation of the rivers (based upon water

TABLE 3

Dry season water chemistry of 21 rivers at 25 sites (localities), 1997 and 1998

Rivers	p*H*	*Calcium (mg l⁻¹)*	*Silica (mg l⁻¹)*	*Turbidity (NTU)*	*Magnesium (mg l⁻¹)*	*Chloride (mg l⁻¹)*	*Phosphate (mg l⁻¹)*	*Ammonia-nitrogen (mg l⁻¹)*	*Nitrate-nitrogen (mg l⁻¹)*	*Sulphate (mg l⁻¹)*	*Conductivity (µS cm⁻¹)*	*Total hardness (mg l⁻¹)*	*Total suspended solids (mg l⁻¹)*	*Total dissolved solids (mg l⁻¹)*
Afia	6.60	7.2	22.8	20	4.13	20.0	0.000	0.490	1.040	7.0	99.0	28	11	49.4
Agumatsa	6.80	7.2	15.4	3	3.12	12.0	0.042	0.081	0.280	8.4	58.8	20	1	14.8
Akrum 1	6.84	6.0	16.7	14	2.20	1.5	0.769	0.210	1.830	22.8	44.4	15	4	22.4
Akrum 2	6.67	4.0	17.1	14	2.19	12.5	0.656	0.385	1.150	2.7	38.4	10	2	19.2
Ankasa	6.61	3.2	16.1	12	3.40	15.0	0.146	0.250	0.664	5.0	53.6	12	6	26.7
Asuboni	7.20	11.5	9.3	6	3.77	24.0	0.024	0.210	0.414	6.4	53.6	27	4	35.5
Asuohyia	6.98	5.6	21.5	42	2.45	17.0	0.302	0.850	0.540	7.2	76.5	16	5	38.2
Bia	7.21	12.0	22.7	31	4.39	25.0	0.299	1.100	0.425	4.3	163.9	30	10	81.8
Birim	7.15	11.0	9.6	37	4.92	17.5	0.096	0.526	0.109	15.3	112.8	31	42	55.2
Disue 1	7.16	10.0	17.5	31	2.73	17.0	0.035	0.573	3.390	6.3	70.4	25	9	35.1
Disue 2	7.08	8.0	20.1	35	2.88	17.5	0.004	0.499	1.570	6.3	71.5	20	14	35.7
Draw	6.83	4.0	20.8	25	2.48	20.0	0.164	0.580	0.188	4.3	91.6	14	6	45.7
Jeba	6.59	6.4	23.8	76	2.68	18.0	0.182	3.350	0.528	6.6	103.6	18	29	51.6
Kakum	6.50	12.0	27.8	74	8.41	37.0	0.524	2.000	0.238	15.5	194.8	42	8	97.3
Nhwini 1	6.83	6.4	16.0	11	2.63	18.0	0.070	0.110	0.376	3.8	87.4	18	0	43.6
Nhwini 2	6.83	4.0	13.0	15	2.53	16.0	0.128	0.350	0.186	3.0	80.7	18	6	40.2
Oben	5.20	2.4	4.7	6	2.60	16.0	0.075	0.106	0.866	3.2	31.7	6	9	15.7
Obuo	6.60	5.6	25.5	12	5.44	19.0	0.152	0.350	0.612	1.5	116.7	28	7	58.2
Pawnpawn	7.16	8.6	8.6	9	5.46	15.9	0.050	0.170	0.310	5.6	53.6	31	1	36.0
Pusupusu	7.23	6.0	7.7	5	2.75	14.4	0.422	0.472	0.049	5.9	50.5	19	10	25.6
Subiri 1	6.60	6.4	17.0	24	2.63	22.0	0.000	0.350	0.454	5.5	85.4	16	2	42.6
Subiri 2	6.60	7.2	18.5	26	2.55	23.5	0.000	0.980	0.830	8.7	93.9	24	7	46.9
Supon	5.30	2.4	5.8	6	0.49	16.0	0.045	0.124	1.205	3.6	39.8	14	11	19.8
Tano	7.44	16.0	15.4	19	5.12	20.0	0.079	0.308	1.810	1.8	83.5	40	9	41.7
Wankobiri	5.96	6.0	9.6	2	2.92	14.1	0.512	0.554	0.044	5.4	18.6	18	3	9.3

chemistry) into those with Podostemaceae and those without Podostemaceae were not achieved. This demonstrates that the presence of Podostemaceae in a particular river is not necessarily related to the water chemistry. Other environmental factors such as availability of rock substrata and open forest canopy, etc. may be more important, as shown earlier in the text.

A number of interesting features may also be noted in Fig. 2. The first axis is related to rainfall and soil fertility as indicated by the forest types. The most extreme sample site on axis 1 is from Kakum river and it is from moist semi-deciduous forest. Other sample sites from the moist semi-deciduous forest types are in the lower left of Fig. 2. These sample sites are from low rainfall areas. Sample sites to the right in Fig. 2 are from high rainfall areas (in wet evergreen, moist evergreen and upland evergreen forest types). Low rates of rainfall mean that most of the water entering the rivers is by slow deep seepage from the soil profile, while in high rainfall areas it is largely by surface flow. Thus, rivers in low rainfall areas are relatively concentrated compared to those in high rainfall areas. The exceptions are Akrum, Asuboni, Pawnpawn and Agumatsa rivers from low rainfall (dry semi-deciduous forest type) areas. The catchments of these rivers are on Voltaian sandstone on which develops infertile soil, yielding waters similar in nutrient content to high rainfall areas.

The three sample sites in the extreme right of Fig. 2 are rivers draining the Atewa Range Forest Reserve, a bauxite-capped hill bearing one of the few areas of upland evergreen forest in Ghana. Bauxitic soils are the oldest in the country and have undergone the longest period of weathering so that even silica has been leached, leaving

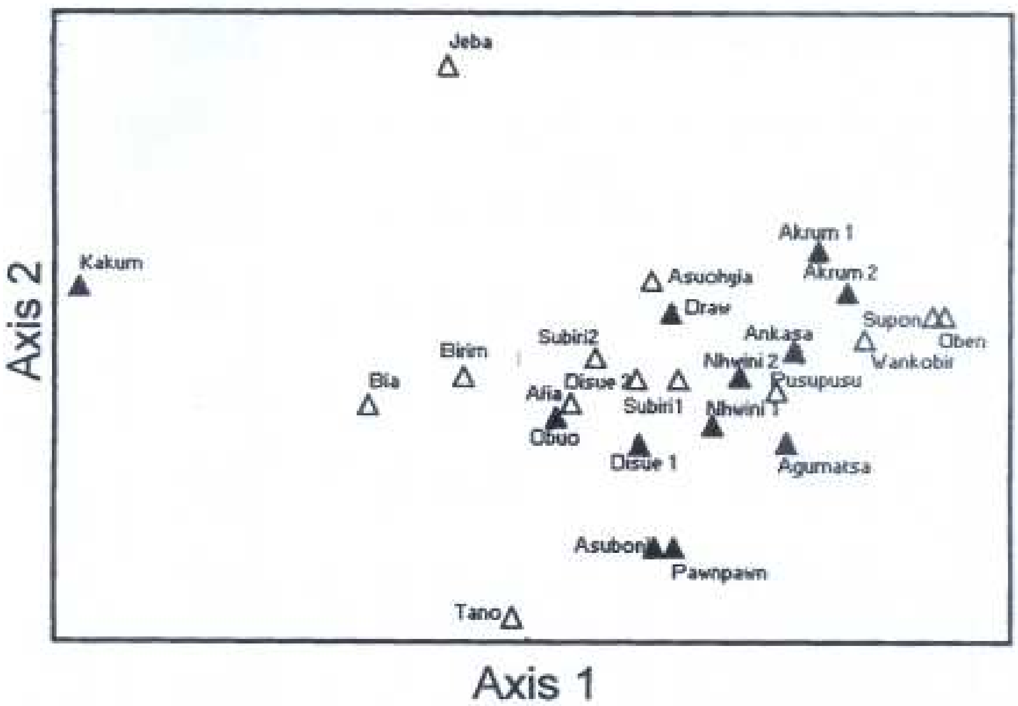

Fig. 2. Principal component analysis of 14 water quality variables of samples taken from rivers with Podostemaceae (▲) and without Podostemaceae (△) in dry season (low water) in southern Ghana

sesquioxides of iron and aluminium. The reduced temperatures, higher cloud cover and increased rainfall relative to the surrounding lowlands lead to reduced decomposition rates in soil and higher carbon and nitrogen.

Conclusion

Three Podostemaceae species were collected from 10 of 26 rivers sampled during the study. The plants were growing only in rivers with rocky riverbeds and in places with open forest canopy cover. The water chemistry of the 10 rivers showed that they have conditions suitable for the growth of submerged aquatic plants which include low turbidity and total suspended solids. It appears that the amount of rainfall and the underlying rock type in the catchment areas influence water chemistry of the rivers. Rivers in low rainfall areas are relatively concentrated compared to those in high rainfall areas. Exceptions are rivers whose catchments are on Voltaian sandstones. Such rivers are similar to rivers from high rainfall areas. Among the environmental variables measured rocky riverbed and open forest canopy appear to be more important in the distribution of the Podostemaceae than water chemistry.

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