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PATTERNS OF MORPHOMETRIC VARIABILITY IN *DENDROCALAMUS HAMILTONII* MUNRO POPULATIONS ACROSS EAST KHASI HILLS, NORTHEAST INDIA

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ABSTRACT

A study was undertaken in *Dendrocalamus hamiltonii* to assess variability and structure in seven commercially important morphological parameters in 120 sampled clumps across six populations in east Khasi Hills. Statistically significant variations were found in six parameters viz., culm length, culm diameter at breast height (dbh), culm internode length, number of nodes, culm wall thickness and culm lumen diameter. A high negative and significant (p = 0.01) correlation between culm internode length and culm wall thickness was observed. Principal components analysis of populations based on morphological parameters differentiated Khasi populations from the lone population in Naga Hills. This variation between the two regions could be explained by the parameters culm wall thickness and internode length. No clear population structure was detected in the Khasi Hills populations, where some degree of overlapping among populations was observed indicating continuous variation in the observed morphological parameters.

***Key words*:** Morphological parameters, *Dendrocalamus hamiltonii*, Clump improvement, Morphometric variability.

Introduction

With 18 genera and over one hundred species, bamboo is one of India's most important forest resources. Bamboos of diverse kinds provide food, shelter and raw material for numerous other uses for a good part of its population, and are vital to the rural economy of the country. *Dendrocalamus hamiltonii*, known as Kako bah in Assam, is one of India's five most important bamboos and by far the commonest of the Himalayan *Dendrocalamus* species. The species is distributed along the entire Himalayan range especially along the outer hill ranges, such as Siwaliks and Mahabharat Lekh (Stapleton, 1994). This natural resource is widely exploited by the communities in the north-eastern part of India primarily for edible shoots. The species holds number one position in terms of its contribution (1859 ton/year, 32.7% of total shoot production) to the total edible bamboo shoot production in northeast India (Bhatt *et al.*, 2004). Besides its use as edible shoot, its culms are used in numerous other purposes. Also, the species playes an ecological role as a soil binder, restricting erosion on hill slopes.

In the northeastern part of India *D. hamiltonii* is under threat from three major forces viz., (i) shifting cultivation where the land is clear-felled of all vegetation for growing agricultural crops, (ii) unscientific harvesting and clear-felling of clumps by contractors supplying culms to paper mills, (iii) land conversion to alternate uses. The continuing presence of these destructive forces is likely to have adverse effects on the genetic diversity and structuring in *D. hamiltonii*. Despite being one of the most economically important natural bamboo resources of India, *D. hamiltonii* has generally been neglected in in-depth studies, a contributing factor being poor integration of the limited knowledge in the species that does exist.

The process of plant domestication involves continuous selection and breeding. Because of the inherent problem of flowering in bamboos, selection is the usual strategy adopted for productivity improvement. Knowledge of the existing natural variation in morphological variables is therefore important in the process of domestication of natural bamboos. As clump selection for productivity improvement in bamboos is based on morphological parameters and for the fact that *D. hamiltonii* is an undomesticated natural resource, a study was undertaken in the Khasi Hills of India to assess variability in some commercially important parameters and their structure in *D. hamiltonii* natural populations.

Material and Methods

Study area

The northeastern region of India consists of eight states rich in forest resources. Five countries border this region of India: Nepal, Bhutan, China, Bangladesh and

Significant variations were found in culm length, culm diameter, culm internode length, number of nodes, etc. in 6 population of *Dendrocalamus hamiltonii* in east khasi hills.

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Myanmar. This study was carried out in and around the Nongkhyllem Forest Reserve (25.92408°N, 91.82360°E) in the East Khasi Hills (Ri Bhoi district) in Meghalaya state and in the Disoi Valley Forest Reserve (26.59206°N, 94.34148°E) in the Naga hills bordering Assam state. The approximate locations of the investigated populations are depicted in Fig. 1.

The climate of the study area is warm perhumid with mean annual temperature ranging from 17 to 23°C. Shillong, located on the Shillong plateau, has a mean annual temperature of 17°C while the corresponding figure for Brynihat, located on the north slopes of the East Khasi Hills, is 23°C. East Khasi Hills receive rain both from the northeast and the southwest monsoons. The study area is located on the northern slope, which receives less rain than the southern slope, on which are regarded as two rainiest places in the world (Cherrapunjee: 11,016 mm per annum; Mawsynram: 14,672 mm per annum). The mean annual rainfall recorded at Brynihat is 1306 mm, emphasizing the south-north contrast in the rainfall. The rainy season is from May to September, with the most intense rain received during July.

The soil of the Khasi hills as a whole derives from gneissic rocks and cretaceous formations. The study area is occupied by metamorphic rocks of great age, of quartzite and gneiss with a little of mica. Overlying the gneiss are cretaceous beds of sandstone with conglomerates (Joseph, 1982). A soil survey carried out in the region by the National Bureau of Soil Survey and Land Use Planning (NBSS & LUP, Calcutta) classified the soils into subgroups of regosols, cambisols and nitosols (Bhaskar *et al.*, 2000). The vegetation of the region varies from mixed evergreen to semi-evergreen type, with more deciduous components seen towards the north. Forests outside the Nongkhyllem reserve have been subjected to varying degrees of disturbance owing to the traditional practice of jhum cultivation. The common trees in the region are *Acrocarpus fraxinifolius* Wight & Arn., *Alstonia scholaris* (L.) R. Br., *Anthocephalus cadamba* (Roxb.) Miq., *Artocarpus chaplasha* Roxb., *Bischofia javanica* Blume., *Bombax ceiba* L., *Mallotus philippensis* (Lam.) Müll. Arg., *Mesua ferrea* L., *Schima wallichii* Choisy, *Shorea robusta* Gaertn. and *Toona ciliata* M. Roem. There are pure stands of bamboo in places, and bamboos are also interspersed in dense forest where there are canopy gaps. The common bamboos of the region are *Dendrocalamus hamiltonii* Munro and *Bambusa tulda* Roxb.

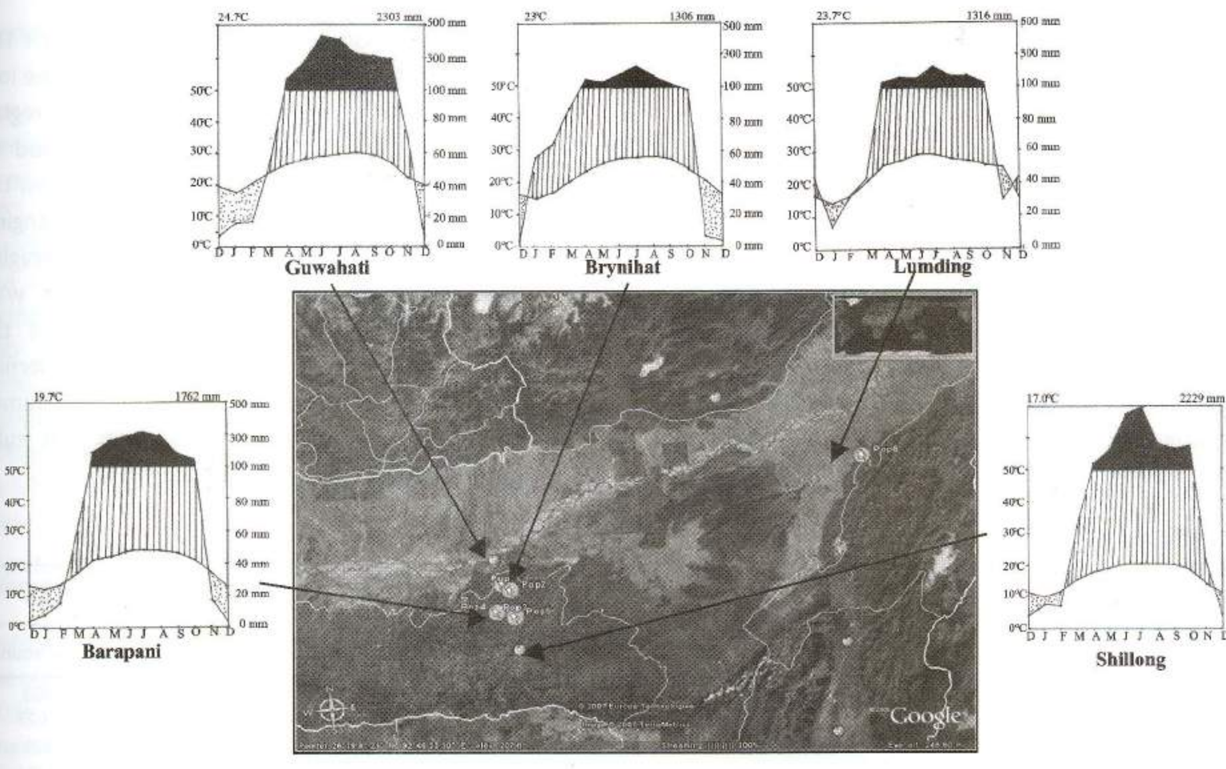

Fig1: Satellite photograph showing the approximate geographic location of the studied *Dendrocalamus hamiltonii* populations in the Khasi and Naga Hills, in the northeastern region of India. The populations are coded as Pop1 (Umtru), Pop2 (Umling), Pop3 (Umnget), Pop4 (Audit point), Pop5 (Uman dairy) and Pop6 (Disoi valley). Climatic diagrams indicate prevailing climate at the study location. The diagrams are based on meteorological data from 1995 to 2004 of the nearest meteorological stations located at Guwahati, Brynihat, Barapani, Shillong and Lumding.

Sampling of populations and clumps

Five populations (located between Guwahati and Shillong at Umtru, Umling, Umnget, Audit point, Umran dairy), located at different altitudes and with an minimum and maximum separation distances of 2.5 and 25.0 Kms., were chosen for assessing variability and structure in morphological characters. Simultaneously, an outlier population located in another region at Disoi valley in the Naga Hills bordering Assam was chosen to see if it differed morphologically from the Khasi populations. Twenty adult clumps were sampled from each population. Owing to the difficulty in assessing clump age, clump similarity was defined in size terms. Undisturbed clumps with a diameter in the range 2.0–4.0 m, at least 10 m from the nearest neighbouring clump, were sampled. Seven commercially important morphological parameters were recorded: culm length, culm dbh, culm internode length, number of nodes, nodes per metre, culm wall thickness, culm lumen diameter.

Recording of morphological parameters

Dendrocalamus hamiltonii clumps are not exactly circular so two diameters, one along the direction of longest spread and a second at right angle to the first were measured. Both the measurements were recorded at 1.37 m above ground level between the outer walls of peripheral culms and expressed in metres. Clump diameter was taken as the average of the two measurements. In order to study comparable clumps at different locations this variable was used as an indication of age and clumps of similar diameter were sampled. Each sampled *Dendrocalamus hamiltonii* clump was divided into four quadrants: NE, SE, SW, NW. One mature culm aged three years or above (age judged by dull green colour of culm and complete absence of culm sheaths from nodes) was sampled randomly ("representative" culms) from those in each quadrant for measuring the parameters culm dbh and culm internode length. The representative culm for the south-east quadrant was harvested flush with the ground for measuring variables culm length, number of nodes, culm wall thickness and lumen diameter.

- **Culm length:** The harvested culm was measured from base to the tip and expressed in metres.
- **Culm dbh :** The diameters of each four representative culm was measured 1.37 m above ground (dbh) with a Vernier calliper and expressed in cm. The mean culm dbh for the clump was taken as the average of the four measurements.
- **Culm internode length :** The fifth internode from the ground level (collar region) was identified on the representative culms and measured using a metric tape. Mean internode length for the clump was taken as the average of the four measurements and expressed in cm.
- **Number of nodes :** The nodes on the harvested representative culm, including the ones on the slender apical region of culm, were counted to arrive at the total number of nodes.
- **Nodes per metre :** The number of nodes on the harvested part of the representative culm was counted and divided by the length as an estimate of nodes per metre.
- **Culm wall thickness and lumen diameter :** The harvested representative culm was cut at the mid point of the fifth internode from the collar region (culm base). A Vernier calliper was used to measure the wall thickness at two points on the cut surface, on lines intersecting at right angles. Culm wall thickness was arrived at by averaging the two measurements. From the wall measurement positions the diameter of the internodal cavity was measured using a Vernier calliper and the average taken as the lumen diameter. Both culm wall thickness and culm lumen diameter were expressed in mm.

Table 1: Summary statistics for the recorded variables in *Dendrocalamus hamiltonii.*

Quantitative variable	Number of observations	Minimum	Maximum	Mean	Std. Deviation	95 % confidence interval for mean	
						Lower bound	Upper bound
Clump diameter (m)	120	2.10	4.00	2.874	0.524	2.778	2.969
Culm length (m)	120	11.00	34.60	18.908	3.977	18.189	19.627
Culm dbh (cm)	120	4.45	10.84	7.160	1.443	6.899	7.421
Culm internode length (cm)	120	15.30	38.30	26.878	5.010	25.973	27.784
Number of nodes (N)	120	29.00	70.00	51.410	9.358	49.72	53.10
Nodes per meter	120	1.82	3.85	2.755	0.386	2.685	2.825
Culm wall thickness (mm)	120	6.83	26.42	15.669	4.203	14.909	16.428
Culm lumen diameter (mm)	120	18.23	83.47	41.951	12.004	39.781	44.121

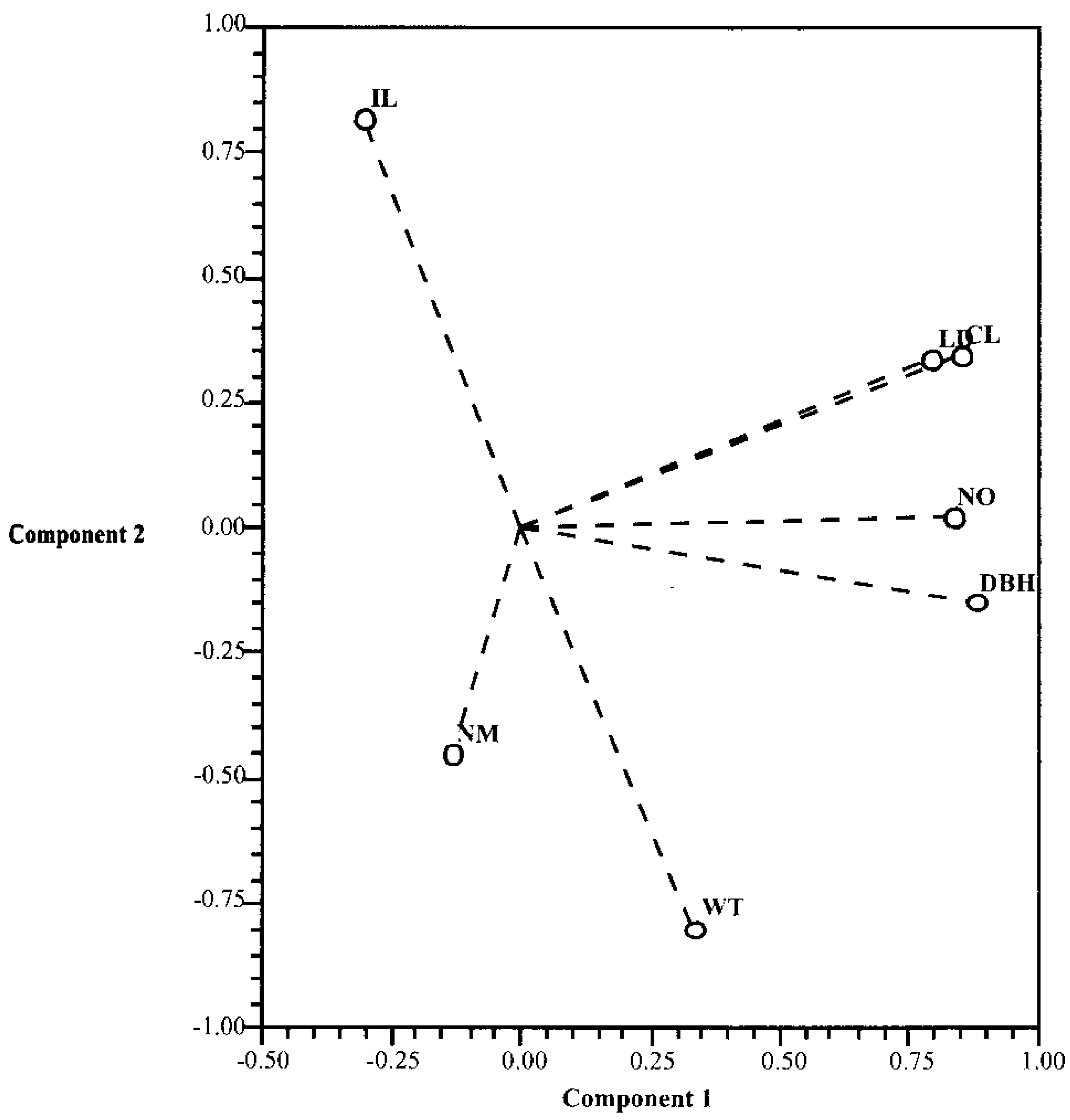

Fig. 2: Scatter plot of the first and second principal components calculated from the correlation matrix (7 120) of seven morphological variables and 120 *D. hamiltonii* samples. The variables are coded as: CL – culm length; LD – culm lumen diameter, NO – number of nodes; DBH – culm diameter at breast height; IL – culm internode length; WT – culm wall thickness; NM – nodes per meter.

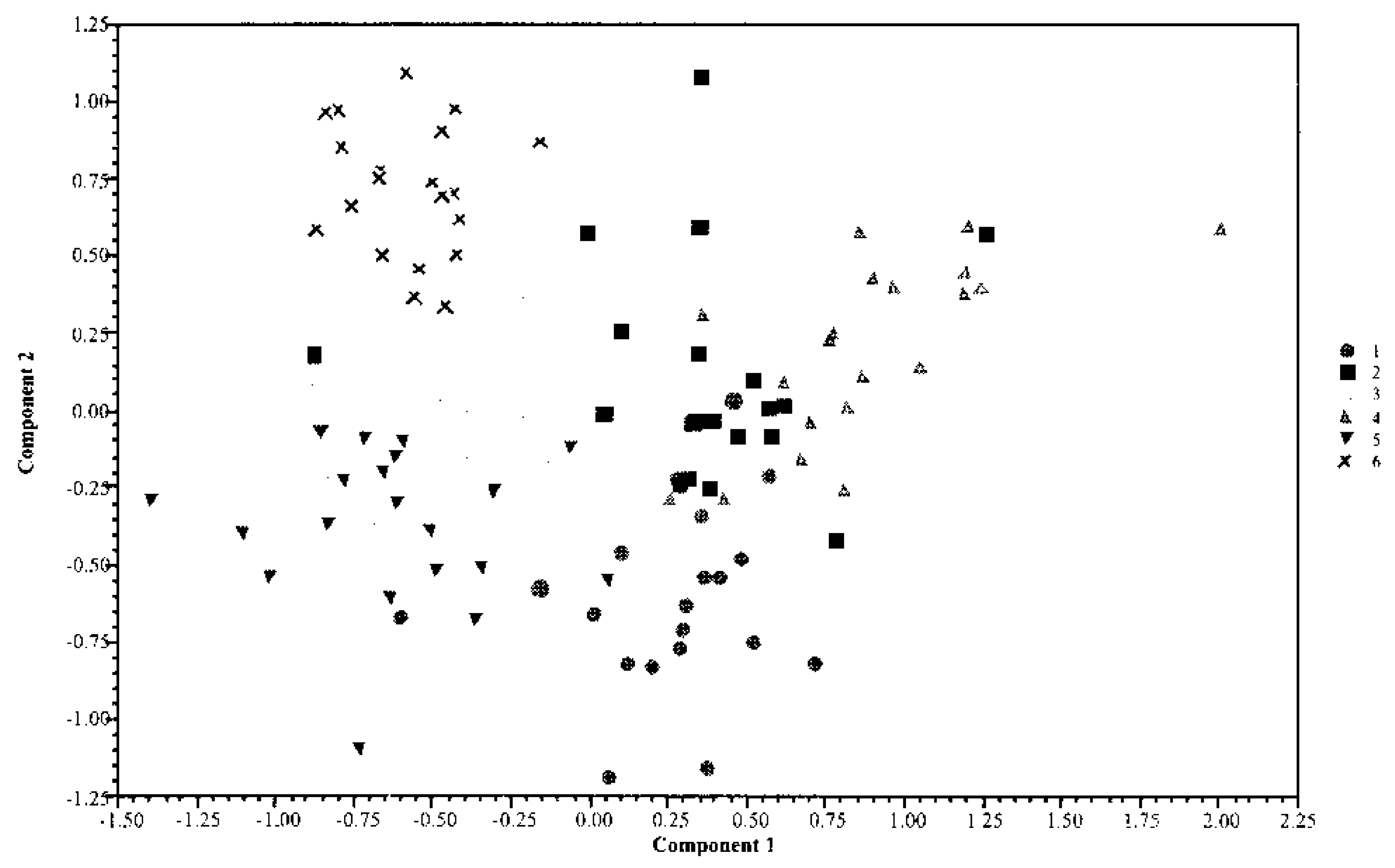

Fig. 3: Scatter plot of the first and second principal components calculated from the correlation matrix (7 120) of seven morphological variables and 120 *D. hamiltonii* samples. The symbols refer to the populations to which the samples belong. The populations are coded as: circle (1) – Umtru; square (2) – Umling; star (3) – Umnget; upright triangle (4) – Audit point; inverted triangle (5) – Umran dairy; cross (6) – Disoi valley.

Statistical analysis

Initially, seven variables were summarized using summary statistics: mean, standard deviation and 95% confidence interval for mean. The assumptions of normality and homogeneity of variance were tested in SPSS using the Shapiro-Wilk and Levene statistic. Variables showing non-normal distribution (culm length and internode length) were transformed (ln) before further analysis. Analysis of variance (ANOVA), Tukey's HSD *post-hoc* tests and correlation analyses were performed in SPSS version 14. Principal components analysis was performed in NTSYSpc 2.11X (Rohlf, 2000) to investigate possible underlying factors explaining the variability among populations in the recorded parameters.

Results and Discussion

The variations observed in recorded morphological parameters are summarized in Table 1. The analysis of variance revealed significant variation ($p \leq 0.01$), among the populations in six parameters viz., culm length, culm dbh, culm internode length, number of nodes, culm wall thickness and culm lumen diameter (Table 2). The derived variable 'nodes per meter' was found non-significant. The within population variation was significant ($p \leq 0.05$) for two variables: culm internode length and culm lumen diameter. For other variables it was non-significant. The Tukey's HSD *post-hoc* tests grouped the populations into three to four homogeneous subsets that differed significantly from each other.

Correlation studies revealed significant linear relationships between pairs of many variables (Table 3). High positive and significant ($p = 0.01$) correlations were found among variables culm length, culm dbh, number of nodes and culm lumen diameter. In contrast, a very high negative and significant ($p = 0.01$) correlation was observed between culm internode length and culm wall thickness. Other notable associations include a positive correlation between culm dbh and culm wall thickness, and a negative correlation between culm dbh and culm internode length. Principal components analysis extracted three principal components (factors) having eigenvalues greater than one (Table 4). These three components together accounted for 85.1% of total variation in the populations. The variables culm length, culm dbh, number of nodes, and culm lumen diameter had high loadings on the first component. Culm wall thickness and internode length had high loadings on the second component. Nodes per meter showed a high loading on the third component. Fig. 2 depicts the clustering of variables in the component plot with respect to the first two components. The clustering of variables confirms the high positive correlations among culm length, culm lumen diameter, number of nodes and culm dbh, and high negative correlation between culm internode length and culm wall thickness. Principal components analysis of the populations based on 120 clumps revealed overlapping of clumps belonging to the five populations in the Khasi region indicating continuous variation in the observed morphological parameters (Fig. 3), with the Disoi valley clumps in a separate group.

Discussion

The present study revealed wide variability in some of the culm morphological parameters recorded in natural populations of *Dendrocalamus hamiltonii* in the Khasi and Naga Hills of India. For four variables (culm length, culm dbh, number of nodes and culm lumen diameter) the mean maximum value was observed for Audit point and the mean minimum for Umran dairy. The mean maximum value for internode length was observed for Disoi valley and the mean minimum for Umtru. Whereas, the mean maximum for culm wall thickness was observed for Umtru and the mean minimum for Disoi valley.

Analysis of variance revealed statistically significant variation among the populations in six parameters *viz.* culm length, culm dbh, culm internode length, number of nodes, culm wall thickness and culm lumen diameter. Subsequent post-hoc analysis grouped the populations into three to four homogeneous subsets that differed significantly from each other. However, the composition of subsets differed with variables. Kochhar *et al.* (1988) had reported a marginal variation between two *D. hamiltonii* populations, located at North Siang and North Lakhimpur in northeast India, in four variables (culm diameter, internode length, wall thickness and lumen diameter).

Correlation studies and principal components analysis of the variables revealed significant positive relationships among culm length, culm dbh, number of nodes and culm lumen diameter, and significant negative relationships between culm internode length and culm wall thickness. This suggests that a few variables could be used in clump selection process but could be chosen so as to have desired impact on additional variables. Similar association among variables was reported by Banik and Das (1996) for some bamboo species of Bangladesh. In general, they found that culms of thick walled bamboos (*Dendrocalamus giganteus, Bambusa balcooa, B. polymorpha* and *B. vulgaris*) were taller with wide diameter, whereas opposite was the case for thin walled bamboos (*Melocanna baccifera* and *Neohouzeaua dullooa*).

Principal components analysis of populations based on all recorded variables, revealed significant structure between the Khasi and Naga populations. This regional structure between Naga and Khasi populations could be explained by the variables culm wall thickness and internode length that showed high loadings on the second component. Longer internodes and thin walls characterize Naga Hills population. However, no clear differentiation of the Khasi Hills populations was emerged and there was much intermixing within the scatters. Genetic analysis of the studied populations

Table 2: Analysis of variance showing significance of variation among and within populations in the seven observed morphometric quantitative variables in *Dendrocalamus hamiltonii*.

Quantitative variable	Source of variation	df	F
Culm length	Between population	5	18.601**
	Within population	19	0.872^{NS}
	Residual	95	(0.025)
Culm dbh	Between population	5	52.156**
	Within population	19	1.116^{NS}
	Residual	95	(0.658)
Culm internode length	Between population	5	37.186**
	Within population	19	1.734*
	Residual	95	(0.013)
Number of nodes	Between population	5	18.793**
	Within population	19	0.770^{NS}
	Residual	95	(51.184)
Nodes per meter	Between population	5	1.400^{NS}
	Within population	19	0.901^{NS}
	Residual	95	(0.149)
Culm wall thickness	Between population	5	43.473**
	Within population	19	0.727^{NS}
	Residual	95	(6.446)
Culm lumen diameter	Between population	5	33.029**
	Within population	19	1.862*
	Residual	95	(58.024)

* p 0.05, ** 0.01, NS - non-significance

Table 3: Pearson's pair-wise correlation coefficients for the seven variables in *Dendrocalamus hamiltonii*. Correlation analysis performed on 120 observations in each variable.

Variables	Culm length	Culm dbh	Culm internode length	Number of nodes	Nodes per meter	Culm wall thickness	Culm lumen diameter
Culm lumen diameter	.622**	.681**	.043	.583**	-.144	-.057	1
Culm wall thickness	.071	.397**	-.659**	.143	.049	1	
Nodes per meter	-.442**	-.032	-.134	.245**	1		
Number of nodes	.753**	.622**	-.124	1			
Culm internode length	-.015	-.298**	1				
Culm dbh	.578**	1					
Culm length	1						

** Correlation is significant at the 0.01 level (2-tailed).

Table 4: Percentage variance explained by the principal components extracted in an analysis of correlation matrix (120 7) in *D. hamiltonii*.

Component	Eigen values	% of variance	Cumulative %
1	3.026	43.2	43.2
2	1.774	25.3	68.5
3	1.156	16.5	85.1

(data not presented) using Amplified Fragment Length Polymorphism markers revealed similar patterns of structuring - weak structure (ϕ_{PT} = 0.037) among Khasi Hills populations, whereas, prominent structure (ϕ_{PT} = 0.122) between Naga and Khasi Hills populations (Pattanaik, 2008). These findings have implications for bamboo improvement programmes based on clump selection.

In sampling natural populations, Ward (1974) made a distinction between the biological population composed of all individuals and the measurable population consisting a subset of individuals. Although the biological population may normally contain seedlings, stunted or broken plants, and diseased individuals, these are not thought of as representative or characteristic. In quantitative sampling from natural populations subjectivity enters at another point also. The measurable population must be defined *i.e.* limits of variability must be set beyond which individuals, though unquestionably part of biological population, are disregarded for the purposes of sampling. In the present study the sampling of biological populations was limited to Khasi Hills and Naga Hills. The measurable populations were defined by setting a clump diameter limit of 2-4 m and a minimum distance of 10 m between two nearest neighbouring clumps. Considering the wide spatial distribution of *D. hamiltonii*, ideally more biological populations should have been sampled representing *D. hamiltonii*'s natural range. However, a combination of factors like poor accessibility and resource constraints limited the sampling of biological populations over a spatial scale of 2.5 to 25.0 Kms. in Khasi Hills, with a distant outlying population from Naga Hills. Therefore, any interpretation of the variability estimates produced in the present investigation, which relate to the measurable populations rather than the species as a whole, need to be taken into account.

Conclusion

Population studies in *Dendrocalamus hamiltonii* revealed wide variability in phenotypic characters. Statistically significant variation was observed among the studied populations in six morphological variables *viz.* culm length, culm dbh, culm internode length, number of nodes, culm wall thickness and culm lumen diameter. These variables could be grouped into two components in the principal components analysis. Four variables *viz.* culm length, culm dbh, number of nodes and culm lumen diameter, which were positively correlated, received high loadings on the first principal component. Whereas, the variables culm internode length and culm wall thickness, which were negatively correlated, received high loadings on the second principal component. The PCA of populations based on morphological parameters separated the Naga Hills population from those of the Khasi Hills on the second principal component, and suggests that the variables internode length and culm wall thickness are responsible for the observed differences among these two regions. The observed variation among the Khasi Hills populations was due to the variables culm length, culm dbh, number of nodes and culm lumen diameter which had high loading on the first principal component. However, no clear differentiation of the Khasi Hills populations emerged and there was much intermixing within the scatters. These findings have implications for bamboo improvement programmes based on clump selection. For instance, depending on the objective, a few variables could be used in the selection process, but could be chosen so as to also have desirable implications for additional variables.

उत्तर-पूर्वी भारत की पूर्वी खासी पहाड़ियों के उस पार *डेंड्रोकेलेमस हेमिल्टोनाई* मुनरों की आबादी में मोर्फोमेट्रिक वैविध्य के प्रतिमान

एस. पटनायक तथा जॉन.बी. हाल

सारांश

पूर्वी खासी पहाड़ियों के उस पार 120 नमूना समूहों की छः आबादियों में वैविध्य और संरचना का आकलन करने के लिए *डेंड्रोकेलेमस हेमिल्टोनाई* पर अध्ययन किया गया। छः प्राचलों में सांख्यकीय रूप से महत्वपूर्ण वैविध्य पाये गये यथा: नाल की लम्बाई, छाती की ऊँचाई पर नाल का व्यास, नाल की अन्त: गांठ की लम्बाई, गांठों की संख्या, नाल भीति की मोटाई तथा नाल ल्यूमेन व्यास। नाल अंत:गांठ की लम्बाई तथा नालभीति की मोटाई में उच्च नकारात्मक और महत्वपूर्ण (पी=0.01) सह-संबंध पाया गया। आकृति विज्ञानीय प्राचलों के आधार पर खासी आबादी का नागा पहाड़ियों की एकल आबादी से विश्लेषण किया गया। दोनों क्षेत्रों में नालभीति की मोटाई और अन्त: गांठ लम्बाई के वैविध्य का वर्णन किया गया। खासी पहाड़ियों की आबादी में स्पष्ट संरचना का पता नहीं चला। जबकि कुछ हद तक आबादी की अतिव्याप्ति पाई गई, जिससे आकृति विज्ञानीय प्राचलों में निरंतर वैविध्य का संकेत मिला।

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