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"TRUE" MEASURE OF LITHOPHYTES DIVERSITY ACROSS MICROCLIMATE

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ABSTRACT – Microclimate is an important factor in the establishment of lithophytes found along river headwaters. Microclimate, as influenced by air temperature and humidity, is a major influence on lithophyte diversity. This study measures lithophyte diversity along a longitudinal gradient of river headwaters using different measures of diversity. Microclimate and lithophyte diversity are described along eight (8) sampling sites extending 400 m longitudinally from the upper to lower reaches of the headwater. Plants were identified using available and relevant taxonomic literature. The population counts of identified lithophytes were analyzed to obtain different measures of diversity. A total of 20 lithophytes species belonging to nine (9) families were identified as: 10 species for Polypodiaceae; 2 for each Orchidaceae and Liliaceae; and 1 for each Amaryllidaceae, Begoniaceae, Caprifoliaceae, Crassulaceae, Piperaceae and Sellaginellaceae. Lithophytes from upper reaches were more diverse than the lithophytes located in the lower reaches. Chronological ranking between species richness *(Sr)*, and Shannon entropy *(H')* and Gini-Simpson *(HGS)* diversity indices revealed inconsistencies. *H'* and *HGS* have the same ranking with their equivalent effective number of species (N_qH' and N_qHGS). There is a significant relationship between microclimate and lithophytes diversity with high humidity and low temperature providing suitable environment for their growth and diversity. Confidence interval difference *(CID)* of N_qH' and N_qHGS are narrower, compared to *Sr, H'* and *HGS*. Effective number of species and their function was found to be a true measure of diversity, making interpretations increasingly relevant and ultimately more valid.

Keywords: diversity, microclimate, lithophytes

INTRODUCTION

Species diversity will vary across broad biomes as a consequence of both localized and environmental effects (Cowling et al, 1996). As a generalization, however, there is a strong relationship between diversity and climate (Abdel Khalik et al., 2013; Gigauri et al., 2013; Mukhia et al., 2011; Loreau et al., 2001; Allen et al., 1991; Solbrig, 1991; Peet and Christensen, 1988; Tilman, 1988; Margules et al., 1987; Huston, 1979; Connel, 1978; Peet, 1978; Peet, 1974; Auclair and Goff, 1971).) Measures of diversity are frequently used to detect changes in the environment due to climate change. As a result, diversity measures establish a certain degree of interdependence between diversity and microclimate. Contrary to the common belief, standard generalized measures such as Species richness, Shannon entropy and Gini-Simpson indices are not diversities. These measures do not actually capture the intuitive notion of diversity, and should be distinguished from measures of diversity (Jost, 2009).

Gradients in microclimate are common, particularly in forest edges (Chen et al., 1995; Matlack, 1993). Streams create a local environment as influenced by air temperature and humidity. Changes in microclimate have been repeatedly hypothesized to result in varying responses of many plant species (Stewart and Mallik, 2006; Honnay et al., 2002; Murcia, 1995) contributing to the distinction of plant assemblages. In general, relative humidity gradients appear to extend laterally than those of

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air temperature (Anderson et al., 2007; Rykken et al., 2007; Welsh et al., 2005; Meleason and Quinn, 2004; Hagan and Whitmann, 2000; Danehy and Kirpes, 2000; Dong et al., 1998; Brosofske et al., 1997). A few studies had characterized plant assemblages or composition for watershed, zero order basins and 1st- to 6th-order streams. Waters et al. (2011) found plant assemblages in watershed area to have association with relative humidity. Sheridan and Spies (2005) and Pabst and Spies (1999; 1998) reported a comparable pattern in zero order basins and 1st- to 6th-order streams, respectively.

Species-based diversity measures have been instrumental in understanding fundamental ecological properties of communities. They are the subjects of recent reviews for their general application (Koleff et al., 2003; Magurran, 2004). Although, many diversity indices have been proposed (Ricotta, 2005), development of new measures still continues (Hill, 1973; Guiasu and Guiasu, 2012; 2010; Jost, 2010). Aspects of species diversity can be measured in a number of ways. The simplest measure of diversity is species richness. In its ideal form, species richness consists of a complete catalogue of all species within a taxa occurring in the area under consideration. Species richness measures tend to be based on samples. (Pearce & Moran, 1994). Obviously, this ignores how many individuals each species have (Magurran, 2004). The best-known measures of biodiversity that simplify information on species richness and relative abundance into a single index, are the Gini-Simpson index *HGS* and the Shannon entropy *H'* (Guiasu and Guiasu, 2012). Shannon index weighs each species exactly according to its frequencies. More value is given to the presence of each species than to the abundance of each species. Due to its logarithmic nature, the Shannon index is sensitive to uncommon plant species and less sensitive to very common species (Krebs, 1989; Peet, 1974). The Gini-Simpson's index pays more attention to the most common species (Peet, 1974) since it involves the sum of the squares of the frequencies, and the square of a very small frequency is a very small number. So rare species hardly contribute to the sum (Jost, 2008).

According to Jost (2007) and Hardy and Jost (2008), many of biologists' standard forms of reasoning about diversity are only valid when applied to the N_q (numbers equivalents or effective number of species). N_q is the number of equally common species required to give a particular value of an index. Although, species richness is one measure of diversity, which in its own is a number equivalent (Jost, 2010), nonetheless it pays no attention to frequencies (Jost, 2008). Diversity indices should be converted to their N_q before interpreting them as diversities to avoid misinterpretation of nonlinearity (Jost, 2006). In this way, complexity measures will occur as a linear scale. This gives a set of common behaviors and properties that can be easily interpreted in comparing diversities of different communities (Jost, 2010). However, Hoffmann and Hoffmann (2008) assert that virtually all commonly used measures of "diversity" can be used depending on the mathematical needs of the application. They propose to call them all "diversities".

For this application, research has been conducted to scrutinize the performance of different measures that precisely calculates species diversity of lithophytes along the headwater of Guinzadan in Bauko, Mt. Province. This study is the first to make use of different measures of diversity. In addition, the status of lithophytes as a group is not entirely clear because of relatively few publications on the group. This paper studies patterns of lithophytes diversity *vis-à-vis* underlying microclimate conditions, particularly air temperature and relative humidity, ,that could yield relationships at a realistic scale. The overall evaluation of lithophytes diversity and its relationship to microclimate conditions, therefore allows a rigorous reasoning, thus provoking further discussion on the issue of diversity measures.

METHODOLOGY

Study area

The study area is the rocky stream located along the headwater of Guinzadan in Bauko, Mt. Province *(Figure 1).* The landscape is dominated by gently sloping terrain with an elevation of 1,300 m to 1,700 m of a slope complex mainly of limestone and sandstone composites. The mountainous area has a temperate "warm" climate. This ecoregion experiences two pronounced seasons, i.e. the dry season, which starts from October and peaks towards March and April and the rainy season from May to October. The type of soil found in this area is mostly clayish red.

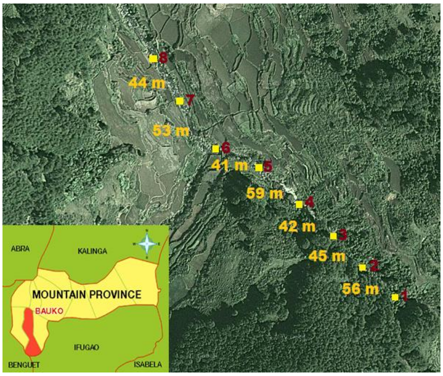

Figure 1. *Location of eight sampling sites on the headwater of Guinzadan, Bauko, Mt. Province.*

Collection of Data

Field exploration of the river headwater was done. Eight sampling sites consisting of a 3m x 3m transect were chosen and established along a 400 m transect designated longitudinally from the upper portion of the reach in a forest to the lower portion beside a broad-acre of ricefield. The distances between sites were 56 m, 45 m, 42 m, 59 m, 41 m, 53 m and 44 m *(Figure. 1)*. At each site, air temperature and relative humidity were measured quasi-simultaneously in the morning using a pyschrometer. Data for microclimates were recorded for January 2012 *(Table 1)*. Correspondingly, lithophytes were collected and photographed in situ. Morphological characteristics were studied and identified using keys and descriptions from relevant and available taxonomic literatures. Voucher specimens were deposited at the Natural Sciences Research Unit, of Saint Louis University (SLU) in Baguio City.

Table 1. Basic data for the studied sampling sites

Site	Latitude	Longitude	Ta (°C)	Hum (%)
1	16°57'14.32" N	120°52'31.36" E	16.5	87.23
2	16°57'15.47" N	120°52'29.86" E	16.5	85.88
3	16°57'16.66" N	120°52'28.87" E	16.6	82.46
4	16°57'17.99" N	120°52'26.67" E	16.5	83.71
5	16°57'18.95" N	120°52'25.65" E	16.7	81.47
6	16°57'19.78" N	120°52'23.50" E	16.8	76.59
7	16°57'21.25" N	120°52'22.39" E	16.9	79.95
8	16°57'22.47" N	120°52'21.57" E	16.8	81.12

Measures of Species Diversity

Species richness and two indices of species diversity, the Shannon-Wiener index and the Gini-Simpson index, were calculated for each sampling site. These latter indices were converted to effective number of species, which can be interpreted as the number of equally common species needed to produce the same heterogeneity as was observed in the sample. Conversions of common indices to N_q effective number of species were calculated in terms of *pi*. Different measures were used to evaluate whether or not these measures gave desirable analysis for diversity. Measures of diversity were derived using the following equation:

Species richness ***(Sr)*** $= \sum_{i=1}^{S} p_i^0$

Shannon entropy ***(H')*** $= -\sum_{i=1}^{S} p_i \ln p_i$

Gini-Simpson index ***(HGS)*** $= 1 - \sum_{i=1}^{S} p_i^2$

N*q* of Shannon entropy ***(NqH)*** $= exp(-\sum_{i=1}^{S} p_i \ln p_i)$

N*q* of Gini-Simpson index ***(NqHGS)*** $= 1/\sum_{i=1}^{S} p_i^2$

Statistical Analysis

Pearson's product moment correlation coefficients were calculated to reveal patterns of relationship between different measures of species diversity of lithophytes and microclimate conditions, particularly air temperature and humidity. Fischer transformation was also carried out to normalize the distribution and stabilize the variance and its application in calculating the confidence interval based from the correlation coefficients. Confidence intervals *(CI)* were calculated at a confidence level of 95%. This provided a range of plausible values for the different measures of diversity. Confidence interval differences *(CID)* were calculated by subtracting the upper limit *CI* with its corresponding lower limit. This shows that the narrower the interval, the more precise the measure of diversity.

RESULTS AND DISCUSSION

Lithophytes Characteristics and Distribution

Twenty lithophytes species belonging to nine (9) families were identified in the study sites. These are: Polypodiaceae, the richest family with ten species; Orchidaceae and Liliaceae with two species each; and one single species each for Amaryllidaceae, Begoniaceae, Caprifoliaceae, Crassulaceae, Piperaceae and Sellaginellaceae, Differences from the collected lithophytes were observed for the different sites. These species grew on bare rock or in rock crevices, either in shady areas or exposed surfaces, or sometimes in vertical walls along the stream, but always on well-drained soils. Rocky areas are unfavorable habitat for these species due to lack of water (Sharma, 2008). Rock faces commonly exhibited small-scale zonation, and are dominated by Polypodiaceae, succulent types such as Piperaceae; Crassulaceae and Caprifoliaceae; and with an increasing understory of flowering plants such as Begoniaceae and Liliaceae species. The prominence of Polypodiaceae may be due in part to the efficiency of spores' dispersal. In the same way, lithophytes are geophytes with underground storage organs, namely creeping rhizomes (i.e. Polypodiaceae, Begoniaceae, Sellaginellaceae) and pseudobulbs or tubers (i.e. Caprifoliaceae, Crassulaceae, Orchidaceae), which are easily found in colonized rocks or boulders. These species are mostly succulent with roots occupying fissures into the rock (i.e. Amaryllidaceae, Liliaceae Piperaceae). In this context, these characters or in combination resulted in successful establishment of lithophytes.

Distribution of lithophytes species varied markedly over the different study sites. The change in the distribution and abundance of the principal lithophytes reflected their ecological requirements or tolerance. Six species, namely *Acrostichum aureum, Hypodematium crenatum, Dendrochilum cobbianum, Hostas plantaginea, Mianthemium canadense* were common along the sampling sites. *Weldenia candida*. *A. aureum, D. cobbianum* and *W. candida* were commonly found on exposed-inclined surfaces of rocks. *D. cobbianum* was mostly associated with *A. aureum.* This species had thickened-stems to form pseudobulbs that function as storage containers for nutrients and large amounts of water, giving it some resistance to excessive heat. *H. plantaginea, a succulent species, and M. canadense, with underground tubers,* preferred shaded sections but were also found in open sunny areas.

On the other hand, some species were separately observed on the study sites. Three species were found to occur only on the most upper reaches, namely *Adiantum pedatum*, *Asplenium lucidum* and *Begonia olsoniae.* Stems and leaves of *A. pedatum* and *A. lucidum* are fully hard but grow in semi or partially shaded sites. *B. olsoniae*, encountered in the field surveys, were herbs with rock-crevice creeping rhizomes. They are unbranched or weakly branched with distinct erect aerial stems that are always found flowering. It is also interesting to note here that *Begonia* is confined or restricted on sheltered depressions of rocks found on the forest floor along the streams, and never collected from other sites.

Lower portion of the stream consisted of large-scale clearings where lithophytes species have adapted shade tolerance strategies and are small in relation to its abundance. Four species were found on these sites, namely *Davallia mariesii*, *Nephrolepsis exaltata, Crinum asiaticum* and *Cotyledon orbiculata*. . The species *D. mariesii* and *N. exaltata* are extremely tolerant to drought. Succulent *C. orbiculata* and hardy *C. asiaticum* prefer exposed sunny sites. The habitat develops in open areas exposed throughout the day to sunlight. This environment is generally unfavorable to the occurrence of these species especially in the dry season. Nevertheless, it may encourage speciation supporting the occurrence of *Crinum asiaticum* and *Cotyledon orbiculata.* It is interesting that these species were recorded from this kind of habitat.

Four species occurred from the upper to the middle reaches. These include *Ceterach officinarium, Pteris wallichiana, Phragmipedium caudatum*, *Peperomia obtusifolia* and *Selaginella lepidophylla*. The species *C. officinarium* and *P. wallichiana* usually have long creeping rhizomes with numerous clinging roots for extension in adhering to the rock surfaces or in rock crevices. *P. caudatum* and *Peperomia obtusifolia* have succulent characteristics, and thus need moisture. . However, *P. caudatum* prefers semi-shaded sites and *Peperomia obtusifolia* grows in full sun sites. On exposed bare rocks, *S. lepidophylla* curled their fronds inwards to prevent transpiration. Two more species were found on the middle reaches, namely *Asplenium bulbiferum* and *Polypodium musifolium.* Similar morphological adaptation, especially with slender creeping rhizomes were observed, in the f Polypodiaceae family.

Measures of Lithophytes Species Diversity

Lithophytes from the upper reaches exhibited higher measures of diversity, compared to the lower reaches of the headwater *(Table 2).* Higher species diversity indicate a more complex and healthier community because greater variety of species allows for more species interactions. Site 1 was recorded to be the most diverse having the highest species richness *(Sr),* greater index *(H’ and HGS)* and effective number of species (N_qH' and N_qHGS). Site 6 was the lowest in lithophytes diversity. However, further ranking of the different measures revealed discrepancies especially between *Sr* and indices or effective numbers of species. The ranking of diversity measures for the different sites ,from the highest to the lowest are: *Sr* – sites 1, 2, 4, 3, 7, 8, 6; *H’* – sites 1, 3, 2, 4, 5, 8, 7, 6; *HGS* – sites 1, 2, 4, 3, 5, 8, 7, 6; *NqH'* – sites 1, 3, 2, 4, 5, 8, 7, 6; and *NqHGS* – sites 1, 2,4, 3, 5, 8, 7, 6. The *H'* and *NqH'* follow the same ranking, similarly with *HGS* and *NqHGS*. When *Sr* was used in combination with indices *(H'* and *HGS),* or even with effective number of species *(NqH'* and *NqHGS), it* may lead to invalid conclusions especially when comparing diversities of the different sites. This contradicts the claims of Reich et al (2001) and Sullivan et al (1998) that in operational trials it is more effective and scientifically accepted to use a combination of indices or measures to assess plant diversity.

Table 2. Different measures of lithophytes diversity

Site	Sr	H'	GS	N*q*H'	N*qH*GS
1	14	2.498	0.91	12.16	11.11
2	12	2.372	0.898	10.72	9.846
3	11	2.398	0.889	11	9.031
4	12	2.31	0.891	10.08	9.143
5	11	2.186	0.869	8.904	7.62
6	8	1.745	0.776	5.728	4.47
7	10	2.04	0.845	7.691	6.444
8	9	2.081	0.864	8.014	7.327

Sr: *Species richness,* ***H’:*** *Shannon entropy Index,* ***HGS:*** *Gini-Simpson’s Index,* ***NqH’:*** *Effective number of Shannon’s Index,* ***NqHGS:*** *Effective number of Gini-Simpson’s Index*

Air temperature correlates negatively with humidity. It can also be seen from the above linear functions that air temperature and humidity were strongly correlated with the different measures of species diversity *(Table 3).* This supports the basis that climate is considered an important factor affecting the composition and diversity of plants (Pauli et al., 2004). However, these measures other than effective number of species vary in reference to microclimate conditions. For instance, humidity is highly but positively correlated with all the different measures of lithophytes diversity ($p=<0.01$). On the other hand, air temperature is more significantly and negatively correlated with measures using N_qH' and N_qHGS ($p=<0.01$), *when* compared to generalized measures such as *Sr, H’* and *HGS* ($p=<0.05$). This may simply reflect that mismatches occur when generalized measures are equated with diversity. These differences of the standard generalized measures may be the result of particular mathematical properties, which are inconsistent with their forms of inferences (Jost, 2009).

Table 3. Pearson's correlations between microclimate conditions and different measures of species diversity.

	Hum	*Sr*	*H'*	*GS*	N_qH'	N_qHGS
Ta	-.839**	-.824*	-.821*	-.744*	-.849**	-.860**
Hum		.937**	.939**	.932**	.941**	.984**

(**=p<0.01, *=p <0.05)

Ta: *Air temperature;* ***Hum:*** *Humidity;* ***Sr:*** *Species richness,* ***H':*** *Shannon's Index,* ***HGS:*** *Gini-Simpson's Index, NqH'****:*** *Effective number of Shannon's Index,* N_q***HGS:*** *Effective number of Gini-Simpson's Index*

Effective numbers of species were compared with diversity *(Table 4)*. The confidence interval difference *(CID)* of N_qH' and N_qHGS in reference to air temperature and humidity were less when compared to *Sr, H'* and *HGS*. The former had a *CID* of 0.612 and 0.579 and the latter with 0.287 and 0.085, respectively. The problem illustrated in the preceding observed correlations within generalized measures *(Sr, H' and HGS)* denote that humidity is the most significant *(p=<0.01)* factor related to diversity of lithophytes and less of temperature *(p=<0.05)*. However, based on the calculated correlations on effective number of species (N_qH' and N_qHGS), humidity and temperature set out that both are the most significant *(p=<0.01)* factors. Hence, effective number of species merely established or incrementally shifts certain measures of relationships between microclimate and diversity on more realistic scales.

High humidity and lower temperature provide a suitable environment for lithophyte diversity. Using N_qH' and N_qHGS as a true measure of diversity, humidity and air temperature are inextricably linked to the growth and establishment of these rock species *(Table 3)*. According to Solbrig (1991), one of the reasons for high diversity of plants is related with climate. Microclimate conditions may underlie response of lithophytes diversity near streams. Near-surface water tables common to riparian areas indirectly influence microclimate by supporting development of vegetation and supplying moisture for transpiration from foliage (Chen et al., 1995; Matlack, 1993; Olson et al., 2007, Swanson et al., 1988; Salo et al., 1986). It is also well known that riparian vegetation regulates temperature regimes (Naiman and Decamps, 1990). Low temperature with a high humid climate moistened rock account for the recording of lithophytes species localized in this kind of habitat.

Table 4: Fischer Transformation of Pearson's r at 95% Confidence Interval (CI).

Diversity Measures	*Ta r*		*Hum r*		*CID*	
	Lower	*Upper*	*Lower*	*Upper*	*Ta r*	*Hum r*
Sr	-0.967	-0.285	0.684	0.988	0.682	0.304
H'	-0.966	-0.277	0.693	0.989	0.689	0.296
GS	-0.950	-0.083	0.663	0.987	0.867	0.324
N_qH'	-0.972	-0.360	0.702	0.989	0.612	0.287
N_qHGS	-0.974	-0.395	0.912	0.997	0.579	0.085

CID: *Confidence Interval Difference,* ***Ta r:*** *Pearson's correlation of air temperature with diversity measures,* ***Hum r:*** *Pearson's correlation of humidity with diversity measures*

CONCLUSION

Headwater of Guinzadan inBauko Mt. Province is rich in lithophyte diversity. Twenty lithophytes species belonging to nine families, namely, Polypodiaceae with ten species; Orchidaceae and Liliaceae with two species each; and Amaryllidaceae, Begoniaceae, Caprifoliaceae, Crassulaceae, Piperaceae and Sellaginellaceae were identified from eight transect sites in the study area. Microclimate conditions account for the variation in the distribution of lithophytes from the upper to the lower reaches. Air temperature and humidity have influence on the diversity of lithophytes. Varying standard generalized measures of diversity that were applied to lithophyte diversity in this study showed inconsistencies. Effective number of species and its function was found to be a true measure of diversity, making interpretations increasingly relevant and ultimately more valid.

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STATEMENT OF AUTHORSHIP

The first author conducted the literature search, prepared the conceptual framework, identified thematic points, and undertook the writing. The second and third authors initiated the concept, identified some issues, and reviewed the paper.

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