RESEARCH ARTICLE

SABRAO Journal
of Breeding and Genetics
53 (3) 403-416, 2021

SPECIES DIVERSITY AND ENVIRONMENTAL EFFECTS ON BAMBOO (Bambusoideae) IN ESTUARIES ALONG THE EAST COAST OF SUMATRA

FITMAWATI[1]*, M. IKHSAN[1], H. KURNIAWAN[1], Z. YUNDIKA[1], B. WAHYUDA[1], S. PRANATA[2], S.N. KHOLIFAH[1], N. SOFIYANTI[1], N.N. WAHIBAH[1], KHAIRIJON[1] and A. ADNAN[3]

[1]Department of Biology, Faculty of Mathematics and Natural Sciences, University of Riau, Kampus Binawidya Jl. HR. Soebrantas Km 12.5 Pekanbaru 28293, Riau, Indonesia
[2]Ecology Division, Generasi Biologi Indonesia (Genbinesia) Foundation, Jl. Swadaya Barat No. 4, Gresik 61171, East Java, Indonesia
[3]Department of Statistic, Faculty of Mathematics and Natural Sciences, University of Riau, Kampus Binawidya Jl. HR. Soebrantas Km 12.5 Pekanbaru 28293, Riau, Indonesia
*Corresponding author email: fitmawati2008@yahoo.com
Email addresses of coauthors: maulana.ikhsan1592@student.unri.ac.id, hkurniawan1098@gmail.com, zyundika@gmail.com, bimawahyoeda@gmail.com, syafroni28@gmail.com, srnrkholifah@gmail.com, nery_yusuf@yahoo.com, nnwahibah@gmail.com, khairijon@gmail.com, arisman.adnan@lecturer.unri.ac.id

SUMMARY

Estuaries are natural and important coastal bodies that are found in different regions of the world. They provide economically and ecologically indispensable services. However, their muddy substrate is a problem for their water and soil quality. Therefore, estuaries are difficult to develop. Ecologically, the presence of bamboo plants could be an appropriate solution to improving the hydrological system of estuaries. This study aimed to analyze the diversity of bamboo species and their relationship with existing environmental conditions during 2019 and 2020 in Indragiri Hilir Estuary, Riau, Indonesia. Follow-up analyses were carried out at the bamboo herbarium of the Botanical Laboratory, Department of Biology, Riau University, Indonesia. Three different bamboo genera, 10 species, and two cultivars were identified in the estuary. *Bambusa* was the most adaptive and abundant genus with five species, followed by genus *Gigantochloa* with four species. Only one species was recorded for genus *Dendrocalamus*. The existence of these genera was influenced by environmental factors, such as elevation, soil pH, temperature, and humidity. *Bambusa* (*galah* bamboo) was found in larger quantities in its natural habitat than in the forests. Canonical correspondence analysis showed that *Bambusa vulgaris* var. *striata* was highly influenced by soil pH, temperature and elevation. *B. vulgaris.* var. *vulgaris* showed great tolerance for several environmental stresses, including high salinity. Therefore, it was considered a eurytopic species with the highest productivity value (59.4%) and has the potential to be further developed in this estuary. Bamboo species with great diversity can be further exploited and adapted well to muddy substrates with high salinity in the Indragiri Hilir estuary area.

Keywords: Bamboo, *Bambusa, Gigantochloa, Dendrocalamus,* environmental factors, muddy substrate, salinity, Indragiri Hilir estuary

Key findings: An exceptional feature of estuary areas is dominance by a muddy substrate that makes these areas difficult to develop. Bamboo can be used as a conservation plant because of its properties that improve the hydrological system. The present results revealed that *B. vulgaris* var. *vulgaris* is a well-adapted cultivar that can be further developed in the Indragiri Hilir estuary area.

Manuscript received: April 16, 2021; Decision on manuscript: June 30, 2021; Accepted: July 27, 2021.

Communicating Editor: Dr. Aris Hairmansis

INTRODUCTION

The Indragiri Hilir estuary area is divided by large rivers and canals and thus forms a cluster of small islands. This estuary has five watersheds, i.e., Reteh Gangsal, Indragiri Tuaka, Gaung Anak Serka, Batangtumu, and Guntung Kateman, that are found along the south coast to the north coast (Regional Government Indragiri Hilir, 2015). The soil in this area is exclusively dominated by a muddy substrate that originates from sediment carried by seawater and freshwater; therefore, due to high humidity, the water in this area is less clean and smelly. Estuaries represent an ecosystem that is very vulnerable to environmental changes and that is damaged by silting, pollution, tidal waves, and even global warming, making estuary regions difficult to develop (Kawaroe, 2001; Rangkuti *et al.,* 2017). Environmental factors and the influence of seawater and freshwater also produce a typical community with a varied environment that is rich in nutrients and fertile soil (Kenish, 1990; Suyasa *et al.,* 2010).

An estuary is an area wherein nutrients from the land and sea accumulate and has high productivity (Rangkuti *et al.,* 2017). The estuary is very important for the surrounding community because it provides ecosystem services and serves the national economy. Estuary area development and management is an advanced step that must be prioritized considering the strategic role of estuaries in the ecosystem. Therefore, important aspects, especially ecological aspects, require attention for the development of such areas. Identifying plants that can grow and adapt well to muddy habitats and high salinity is important to improve water and soil quality in estuary areas. Ecologically, Poaceae, Chenopodiaceae, and Cyperaceae are typical plant families capable of living under high salinity around estuaries (Grigore and Toma, 2007; Jiang and Ding, 2008; Gonzalez and Dupont, 2009; Chen *et al.,* 2020).

Bamboo is a Poaceae species that has a wide distribution and adaptation in muddy soils and peatlands; it acts as the filter and provider of clean water in peatlands (Hamilton, 2010; Fitmawati *et al.,* 2020). Bamboo is characterized by a tight rooting system that spreads in all directions and easily absorbs water; soil that has been overgrown by bamboo clumps becomes very stable. Bamboo plants can be a solution to hydrological problems, especially in estuary areas (Mulatu and Fetene, 2013; Chen *et al.,* 2016). Furthermore, as a land conservation plant, bamboo can withstand soil erosion and absorb carbon (Zhou *et al*., 2005).

Bamboo plants have a strategic role in improving the hydrological system in the Indragiri Hilir estuary (Tardio *et al.,* 2018). This study is expected to provide a basis for the management and conservation of bamboo, as well as for the development of the Indragiri Hilir estuary. Therefore, this study was planned with the aim to analyze the interaction of bamboo species diversity with various environmental factors and to improve the ecosystem of the Indragiri Hilir Estuary, East Sumatra, Indonesia.

MATERIALS AND METHODS

Plant material and procedure

The bamboo germplasm, which comprised samples of wild and cultivated species, was studied during 2019 and 2020 at the Botanical Laboratory, Department of Biology, Faculty of Mathematics and Natural Sciences, Riau University, Indonesia. Sampling was conducted in the estuary area of Indragiri Hilir. The sampling area covers three major subdistricts, i.e., Reteh, Sungai Batang, and Kuala Indragiri, and passes through the estuary flow of the Reteh Gangsal River, Indragiri Tuaka, Gaung Anak Serka, Batangtumu, and Guntung Kateman (Figure 1).

Equipment

The equipment used in this research included a mirrorless camera (Canon), Global Positioning System for determining coordinates, a pH meter, a thermometer, a hygrometer, 70% alcohol, and bamboo samples.

Data recorded

This research was conducted by using an exploratory survey method. Each bamboo species was encountered and documented, and its coordinate points were recorded. Morphological characteristics were directly observed and recorded for each species of bamboo during sampling in the field. The identification and characterization of bamboo species were carried out on the basis of morphological observations (Widjaja, 2001a, 2001b; Widjaja *et al.*, 2005; Widjaja 1997; Rijaya and Fitmawati, 2019). The standard procedures of Bean (2013) and Wondafrash (2008) were followed for the preparation of herbarium specimens. The identified bamboo samples were stored at the herbarium at Bogoriense, Center for Biology Research, Cibinong, West Java, Indonesia.

Figure 1. Research locations in the Indragiri Hilir estuary area: Reteh, Sungai Batang, and Kuala Indragiri. Source: Google Maps.

Cluster analysis

Cluster analysis was carried out by using 58 vegetative characters that were related to bamboo shoots, culms, sheath culms, clump growth, branching, and leaves. The obtained data were analyzed by using the numerical taxonomy method. The cluster analysis was performed by using the unweighted pair-group method of arithmetic averages (Sneath and Sokal, 1973). Principal component analysis (PCA) was conducted by using the Dice coefficient in the Numerical Taxonomy and Multivariate Analysis System version 2.02 and Minitab 17.0.

Environmental factor analysis

Environmental data included wind speed, light intensity, soil pH, temperature, altitude, humidity, and soil temperature. The environmental factors that affected the survival of bamboo were analyzed by canonical correspondence analysis (CCA) with Canoco software version 4.56 for Windows. CCA is a multivariate method that is used to describe the relationship between a species and their environment (Ter-Braak and Verdonschot, 1995).

Bamboo regeneration

Regeneration percentage was determined by using the following equation (Setiawan, 1999):

Regeneration (%) = (Σshoots + Σyoung stems)/Σtotal stems in the clump

where,
Total number of stems = total number of old culms + total number of young culms + number of shoots + number of stumps in the clump.

RESULTS

Bamboo species diversity and utilization in the Indragiri Hilir estuary

The eastern coast of Sumatra Island, which includes the Indragiri Hilir estuary area, holds a high potential for flora, especially for bamboo species. This research, three genera, i.e., *Bambusa*, *Gigantochloa*, and *Dendrocalamus*, were identified. Collectively, 10 species were identified within these genera, i.e., genus *Bambusa* had five species (*Bambusa vulgaris* Schrad. Ex Wendl, *Bambusa heterostachya* [Munro] Holttum, *Bambusa multiplex* [Lour.] Raeusch. Ex Schult., *Bambusa glaucophylla* Widjaja, and *Bambusa blumeana* Schult.f.). Genus *Gigantochloa* was recorded with four species, i.e., *Gigantochloa apus* (Schult.) Kurz, *Gigantochloa hasskarliana* (Kurz) Backer, *Gigantochloa serik* Widjaja, and *Gigantochloa* sp. Only one species was recorded for genus *Dendrocalamus*, i.e., *Dendrocalamus asper* (Schult.) Backer. In addition, two cultivars of genus *Bambusa*, i.e., *B. vulgaris* var. vulgaris and *B. vulgaris* var. *striata*, were also collected in the Indragiri Hilir estuary area, which is located in three major subdistricts and included five watersheds.

These species have a wide range of adaptations to environmental conditions. This study identified a fewer number of species in the estuary area than past studies, which identified a total of 17 species of bamboo in Five Islands around Riau Province, Indonesia (Rijaya and Fitmawati, 2019; Fitmawati *et al.,* 2020). The bamboo species collected in the Indragiri Hilir estuary area have their own local names. These names should be recognized because the collected bamboo species have been adapted by the community with different functions. Generally, people use bamboo, especially species of the genera *Bambusa* and *Gigantochloa*, as poles. Local communities often use *B. heterostachya* as hooks given its appropriate size over other bamboo species. The number of genera, species, and cultivars and their use by the community can be seen in Table 1. Overall, the highest number of species was recorded for genus *Bambusa,* followed by genus *Gigantochloa* with four

Table 1. Bamboo genera, species, and cultivars obtained in the Indragiri Hilir estuary area.

Genera	Species	Cultivars	Locality Name	Utilization by the community
Bambusa	*Bambusa vulgaris* Schrad. Ex Wendl	*vulgaris*	*Bambu ampel*[ac], *Bambu karbit*[c], *Bambu pengerai*[c], *Bambu hijau*[b]	Building and decoration material, household appliances, and vegetable
		striata	*Bambu kuning*[ab], *Bambu gading*[c]	
	B. heterostachya (Munro) Holttum	-	*Bambu galah*[ac], *Bambu telang*[ac], *Bambu pengait*[bc]	Hook
	B. multiplex (Lour.) Raeusch. Ex Schult.	-	*Bambu pagar*[ac], *Bambu cina*[bc]	Decorative plant and fence
	B. glaucophylla Widjaja	-	*Bambu bunga*[ac]	-
	B. blumeana Schult.f.	-	*Bambu duri*[abc]	-
Dendrocalamus	*Dendrocalamus asper* (Schult.) Backer	-	*Bambu petung*[ab]	Building and decoration material, and household appliances
Gigantochloa	*Gigantochloa apus* (Schult.) Kurz	-	*Bambu cina*[a]	Hook
	G. hasskarliana (Kurz)Backer	-	*Bambu galah*[a], *Bambu tali*[abc]	
	G. serik Widjaja	-	*Bambu galah*[a]	
	Gigantochloa sp.	-	*Bambu galah*[a]	

Note: Reteh (a), Sungai Batang (b), Kuala Indragiri (c).

species, whereas genus *Dendrocalamus* had only one species.Genus *Bambusa* was the most common and found in all types of habitats. Past findings have showed that these two *Bambusa* cultivars are often found in the Rupat, Bengkalis, Tebing Tinggi, Rangsang, and Merbau Islands of Indonesia, which have peat soil types and structures (Fitmawati *et al.,* 2020).

Cluster analysis

Cluster analysis was conducted on 11 accessions of different bamboo species on the basis of 58 representative vegetative characters, such as young shoot (type, color, hair colors, hair numbers, auricle, sheath position, and auricle midrib), culms (type, height, diameter, thickness, nodes, basic nodes, hair numbers, hair color, color of young and old culms, length of internodes, surface, and density), branching (type, distance, and number of branches), culm sheath (easily or does not easily decay, length, width, surface, color, hair present or absent, hair color, auricle, auricle length, blade present or absent, blade length, ligule, ligule length, presence or absence of blades, blade length, type of sheath, base of culm sheath, position, length, and width), leaves (length, width, abaxial, adaxial, petiole color, auricle, bristles present or absent, height of leaf sheath auricle, blade present or absent, blade length, ligule type, ligule length, blade present or absent, and blade length). The result of cluster analysis yielded a dendrogram with two main clusters (Figure 2). The first cluster consisted of subcluster IA, which contained three species, i.e., *B. vulgaris* var. vulgaris, *B. vulgaris* var. *striata* and *Dendrocalamus asper*, and subcluster IB, which contained only *G. apus*. The second cluster, which consisted of subcluster IIA, was recorded with three species, i.e., *B. heterostachya, G. serik*, and *B. blumeana.* Subcluster IIB had four species, namely, *Gigantochloa* sp., *G. hasskarliana*, *B. multiplex*, and *B. glaucophylla*. The different bamboo species were grouped on the basis of the similarity of their vegetative characters, excluding the characters of generative organs, i.e., young shoot (hair color, sheath position, midrib position, and leaf midrib), density of culms, branching (type and number of branches), culm sheath (easily or does not easily decay and base of culm sheath), leaf length, bristles (present or absent), and blade (presence or absence of ligula).

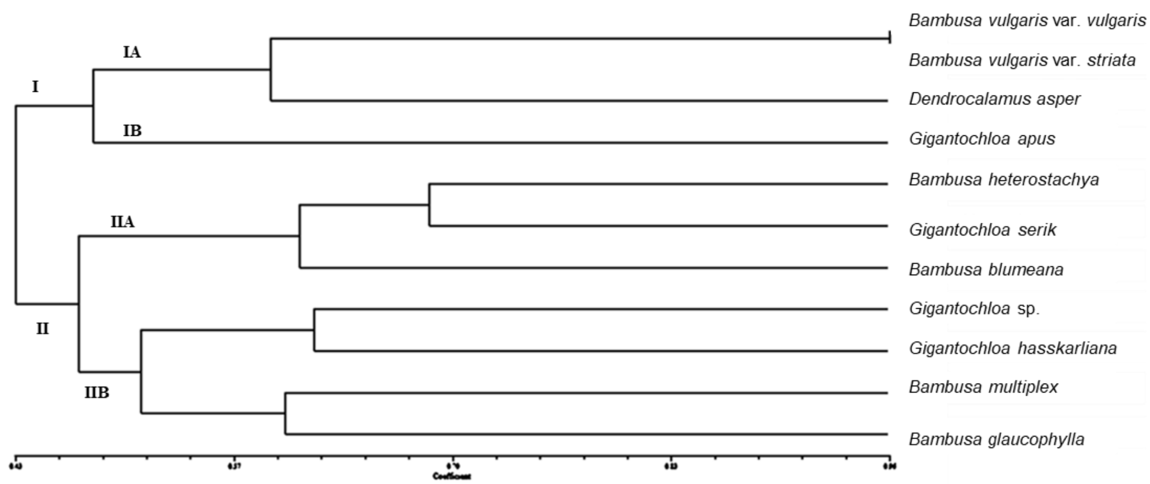

Figure 2. Dendrogram of 11 bamboo accessions from Indragiri Hilir estuary area based on morphological characters.

Species also separated from the genus *Gigantochloa* due to morphological similarities with other genera. Although this result was limited due to the absence of generative characters, similarities in vegetative characters were found between bamboo species. Species of the genus *Gigantochloa* shared similar characters. They shared as many as 14 of the 58 vegetative characters observed. This result indicated that 44 other characters separated each species. *G. apus* was assigned to subcluster IA with *B. vulgaris* var. vulgaris, *B. vulgaris* var. *striata*, and *D. asper* on the basis of similarities in character culms (height, surface, and length and width of the culm sheath). *G. serik* was classified into subcluster IIA on the basis of similarities in the characters of young shoot (type, auricle, sheath position, and auricle midrib), culms (types, thickness, basic nodes, hair number, hair color, length of internodes, and density), branching (type, distance, and number of branches), culm sheath (easily or does not easily decay, length, color, auricle, auricle length, blade present or absent, blade length, ligule, ligule length, blade length, type of sheath, position, length, and width), and leaves (width, abaxial, adaxial, petiole color, auricle, height of leaf sheath auricle, blade present or absent, blade length, ligule type, blade present or absent, and blade length). However, *Gigantochloa* sp. and *G. hasskarliana* grouped in sucluster IIB on the basis of similarities in the characters of young shoots (auricle and auricle midrib), culms (type, thickness, basic nodes, hair number, hair color, surface, and density), type of branching, culm sheath (surface, hair color, hair number, auricle, blade present or absent, blade length, ligule, ligule length, length, length, and width), leaves (length, width, abaxial, adaxial, bristles [present or absent], blade present or absent], blade length, ligule type, and ligule length). The higher the character similarity, the higher the probability that the bamboo species were placed in the same group. In previous studies, bamboo species and cultivars were grouped on the basis of morphological characteristics (Purwanto *et al.,* 2005; Fitriana *et al.,* 2018).

The cluster observations were further confirmed by PCA to determine the role of each character in the grouping (Figure 3). On the basis of PCA, quadrant I consisted of three species i.e., *B. multiplex, B. glaucophylla*, and *Gigantochloa* sp., whereas quadrant II consisted of two species, i.e., *B. vulgaris* var. vulgaris and *B. vulgaris* var. *striata*. These two varieties were grouped on the basis of the number of similarities

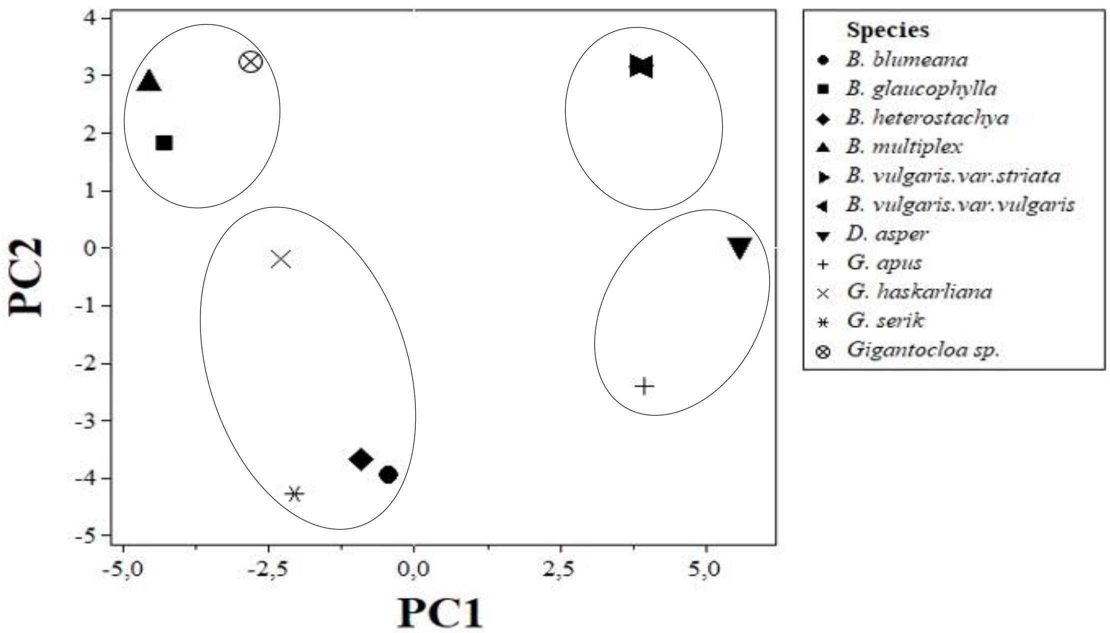

Figure 3. PCA grouping of bamboo species based on morphological characteristics.

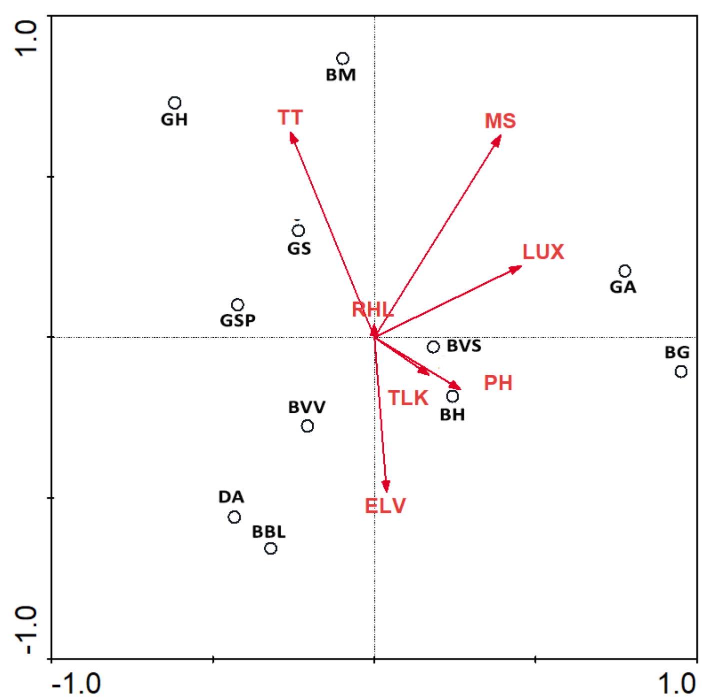

Figure 4. CCA and the relationship between environmental factors and the presence of bamboo. BVV: *Bambusa vulgaris* var. *vulgaris,* BVS: *Bambusa vulgaris* var. *striata,* BH: *Bambusa heterostachya,* BM: *Bambusa multiplex,* BG: *Bambusa glaucophylla,* GA: *Gigantochloa apus,* BBL: *Bambusa blumeana,* DA: *Dendrocalamus asper,* GS: *Gigantochloa serik,* GSP: *Gigantochloa* sp., GH: *Gigantochloa hasskarliana,* MS: wind speed, LUX: light intensity, PH: soil pH, TLK: temperature, ELV: Elevation, RHL: humidity, and TT: soil temperature.

in characters. The PCA results supported the dendogram in its grouping in the same cluster. Quadrant III consisted of two species belonging to different genera, i.e., *D. asper* and *G. apus*. Quadrant IV consisted of four species, i.e., *G. hasskarliana, G. serik, B. heterostachya*, and *B. blumeana* (Figure 3). The grouping of these species was based on culm characters (type, diameter, nodes, color of young culms, and surface), branching (distance and number of branches), culm sheath (length, surface, auricle length, blade present or absent, blade length, and ligule length), and leaves (length, abaxial and adaxial, petiole color, auricle, height of leaf sheath auricle, blade length, and ligule length). In general, the PCA results showed a stable agreement with the groupings obtained through cluster analysis. However, several species belonging to the same cluster did not occupy the same quadrant.

Relationship between species diversity and environmental factors

The existence of several species of bamboo that have been identified was influenced by several interacting environmental factors. Analyzing how environmental factors operate or function ecologically is crucial to identify the dominant factors that influence bamboo. This study, some of the physical factors, including wind speed, light intensity, soil pH, temperature, elevation, humidity, and soil temperature, were analyzed (Table 2). CCA was used to determine the relationship between environmental factors and bamboo species diversity in the estuary area under study (Figure 3). Each environmental variable that affected the presence of a species could be observed from the resulting axis. Variables close to the resulting branch axis and showing tapered angles have a relationship and role in the presence of the species (Dolezal and Srutek, 2002). Each bamboo species had a relationship with different environmental factors even though the species belonged to the same genera.

TPCA and CCA confirmed the classification of bamboo accessions on the basis of morphological characteristics and environmental factors (Figures 3 and 4). These results were also in line with clustering in the CCA that compared environmental factors. *B. multiplex* and *B. Gigantochloa* sp. were affected by humidity (RHL) and soil temperature (TT). These two environmental factors indicated that soil temperature had more influence than other factors on these two species. The *B. vulgaris* cultivars (var. *vulgaris* and var. *striata*) morphologically differed from all other cultivars in terms of their colored young shoots and adult and young culms. CCA also showed that cultivar *B. vulgaris* var. *striata* was highly influenced by soil pH, environmental temperature (TLK), and elevation (ELV), whereas *B.* cultivar *vulgaris* var. vulgaris was not influenced by environmental factors at all (Figure 4). These results could well explain and prove that this species could be adapted to various habitats. The capability to grow, survive, and adapt to different soils with high salinity levels indicated that this species had a high level of tolerance for the environment and could thus be further developed and recommended for water and land conservation.

Bamboo regeneration

The bamboo plants that were collected from the estuary environment can live in various types of habitats. This capability provides an opportunity to bamboo species for high regeneration (productivity) and a high degree of adaptation. The productivity of bamboo can be observed and determined on the basis of several parameters, including the number of stems, old stems, young stems, and emerging shoots (shoots). This research focused on the capability of bamboo species to regenerate (%). Only the productivity of 8 out of 11 species was calculated because the number of individuals encountered in the field was small, precluding the measurement of their productivity (Table 3). Bamboo regeneration is marked by the appearance

Table 2. Environmental factors that affect the survival of bamboo in estuaries.

Environmental factors	Bamboo species										
	Dendrocalamus asper (Schult.) Backer	*Gigantochloa hasskarliana* (Kurz)	*Bambusa glaucophylla* Widjaja	*Bambusa multiplex* (Lour.) Raeusch. Ex Schult.	*Bambusa blumeana* Schult.f.	*Bambusa vulgaris* var. *striata* (Lodd. ex Lindl) Gamble	*Bambusa vulgaris* var. *vulgaris*	*Bambusa heterostachya* (Munro) Holttum	*Gigantochloa apus* (Schult.) Kurz	*Gigantochloa serik* Widjaja	*Gigantochloa* sp.
Wind speed (M/S)	0–0.2	0.5–0.7	0.8–1.6	0	0.2	0.7–1.2	0.1–1.8	0.7–1	0– 0.5	1–2.2	0–1.2
Light intensity (LUX)	253– 275	2110–2280	2349 – 2540	1280–1302	1094–1397	2450 – 2550	184–342	400–602	4620–4772	653–742	1325–1465
Soil pH (pH)	1–3	5–5.2	4–5.2	1–1.4	4.2–4.5	5– 6.5	5.4–5.6	5–5.7	5–5.2	5–5.3	4.5–5
temperature (°C)	30–30.7	30–31.5	32–32.4	30.9–38.9	32–32.3	32–32.3	36–36.2	34.7–37	32.6–33.2	35–36.3	30–32.1
Elevation (asl)	9	9	3	3	5	3	4	5	3	4	5
humidity (% RH)	76.4–76.9	75–76.1	63.2 64.1	74.7–75	67.7–68.4	65–65.3	58–60	60–60.5	69.6–70	63–64.3	68–67.7
Soil temperature (°C)	25–27.2	25–26	26–27	26.8–27	25.8–26	27–28.3	24.7–26	26–27	27–27.4	26–26.7	25.3–26.2

Table 3. Bamboo productivity showing the regeneration percentage.

Species	Adult culm	Young culm	Bamboo shoots	Total culm	Regeneration (%)
Bambusa heterostachya (Munro) Holttum	236	187	7	430	45.1%
Bambusa multiplex (Lour) Raeusch Ex Schult	343	225	18	586	41.5%
Bambusa glaucophylla Widjaja	118	54	8	180	34.4%
Bambusa bluemena Schult f	180	46	16	242	25.6%
Bambusa vulgaris var. *striata* (Lodd Ex Lindl) Gamble	64	40	11	115	44.3%
Bambusa vulgaris var. *vulgaris*(Lodd Ex Lindl) Gamble	89	125	5	219	59.4%
Dendrocalamus asper (Schult) Backer	86	7	14	105	20.0%
Gigantochloa apus (Schult) Kurz	67	26	3	96	30.2 %

of bamboo shoots on the rhizome. The results revealed that the species *B. vulgaris* var. *vulgaris* (59.4%) recorded the highest percentage of regeneration, followed by *B. heterostachya* (45.1%), *B. vulgaris* var. *striata* (44.3%), and *B. multiplex* (41.5%). A low percentage of regeneration was observed for the species *D. asper* (20.0%) and *G. apus* (30.2%). Sutiyono (1992) reported that the number of shoots depends on many factors, including the bamboo species, soil fertility, rainfall, and the number of old culms and clump conditions.

DISCUSSION

Conservation activities in watershed areas begin downstream (estuary), which has a muddy substrate and where the water quality is not as clean as that in other areas. The Indragiri Hilir Estuary is an area that has conservation prospects because of its uniqueness. Three bamboo genera, 10 species, and two cultivars were identified in the Indragiri Hilir estuary area. The community in the Indragiri Hilir estuary area mainly uses the genera *Bambusa* and *Gigantochloa* mainly as *galah* (hook). *Bambusa* and *Gigantochloa* are mainly used because they have the highest economic value (Widjaja, 2001b; Rahmawati *et al.,* 2019).

Many unique species of bamboo have developed in this area, showing that they existed thousands years ago in Indonesia. This phenomenon is supported by the use of bamboo as poles by the community since ancient times from generation to generation. Bamboo species are often found in the forests of the Indragiri Hilir Estuary, indicating that they may be native to Sumatra Island. This fact differs from the past opinion that bamboo species (*Bambusa* and *Gigantochloa*) were introduced from the Malay Peninsula. However, this fact also has a biogeographical explanation. Specifically, these two landmasses merged before the ice melted approximately 14 000 years ago. The Kalimantan, Sumatra, Java, and Malay Peninsula formed a single landmass called the Sundaland (Biswas, 1973; Batchelor, 1979). Therefore, these bamboo species might have existed on two different land forms that today are separated by oceans. Another piece of evidence is the use of bamboo for various purposes, such as medicine, food, musical instruments, and traditional ceremonies and for the construction of buildings, electric poles/supports, and bridges by the coastal Malay community (Liana *et al.,* 2017; Muhtar *et al*., 2017; Nguyen *et al.,* 2017; Fitmawati *et al.,* 2020). This situation indicates that the coastal Malay community has had cultural interactions with bamboo for a long time.

In this study, several different genera were grouped into one cluster. In cluster analysis, the grouping of species was obtained on the basis of the similarity of vegetative characters with high plasticity. Culm sheath and generative characters differed across bamboo genera. These results are supported by PCA and CCA, which showed that the classification was based on morphological and environmental characteristics. Therefore, the bamboo species *B. multiplex*, *B. glaucophylla*, and *Gigantochloa* sp. were grouped in Quadrant I. These findings were analogous to the clustering in CCA based on interactions with environmental factors. *B. multiplex* and *Gigantochloa* sp. were affected by humidity and soil temperature but were more influenced by soil temperature than other factors.

B. vulgaris cultivars showed morphological differences only in terms of their colored young shoots and adult and young culms. CCA also showed that *B. vulgaris* var. *striata* was more influenced by elevation, temperature, and soil pH than other factors. However, *B. vulgaris* var. *vulgaris* was not influenced by environmental factors. The results confirmed that this species could adapt well to various habitat conditions and could be further developed and recommended for water and land conservation in the Indragiri Hilir estuary area. *B. multiplex* grows well in tributary areas with low pH, as well as in dry and humid areas (Hadjar *et al.,* 2017). *B.*

vulgaris was found in almost all the community plantation areas, and the genera *Dendrocalamus* and *Bambusa* grow well on the riverbanks with high adaptability (Huzaemah *et al.,* 2016; Fitmawati *et al.,* 2020).

D. asper and *G. apus* were in one quadrant because of their similar morphological characters. CCA revealed that these two species grouped separately. *G. apus* was influenced by light intensity, whereas species *D. asper* was considerably influenced by soil pH, temperature, and elevation. *G. hasskarliana, G. serik, B. heterostachya*, and *B. blumeana* grouped together on the basis of morphological characters. CCA demonstrated that *G. hasskarliana* and *G. serik* were also influenced by soil temperature. *B. heterostachya* was influenced by soil pH, temperature, and elevation, whereas no environmental effects were recorded by *B. blumeana*. Bamboo species are highly influenced by different environmental factors, such as elevation, which affects humidity, temperature, shade intensity, and soil pH (Tang and Fang, 2004; An *et al.,* 2015).

The environment is a combination of complex factors that interact with each other. Interactions exist not only between biotic and abiotic factors but also among biotic factors themselves. Analyzing the relationship between species diversity and environmental factors is crucial to determine the dominant factors that mainly influence bamboo plantations. Estuaries have higher productivity than freshwater and saltwater habitats. However, various physical and chemical factors are found in estuary areas, creating a stressful environment for existing organisms. Favorable surface temperatures ranging from 20 °C to 30 °C and a minimal rainfall per year of 1020 mm with the desired humidity of 80% are required for the best growth of bamboo plantations in the tropics (Richter, 2014). A suitable environment with temperatures of approximately 8.8 °C to 36 °C is required for the best growth of bamboo plants (Berlian and Rahayu, 1995; Andoko, 2003).

Generally, elevation does not significantly influence the presence of bamboo species; however, these three genera can grow in highlands, such as areas of Ciremai Mountain National Park (TNGC), Indonesia. In this area, the genera *Gigantochloa*, *Bambusa*, and *Dendrocalamus* grow at altitudes of 500–1500 and 500–1000 masl. *D. asper* and *B. vulgaris* grown mainly at the highest altitudes of 750–1500 masl and can withstand landslides (Cahyanto *et al.,* 2016). *G. apus* has good growth and adaptation to various types of environments and exhibit rapid adaptation to environmental changes (Ekayanti, 2016). Various species of bamboo are reported to grow well in lowland areas at altitudes ranging from 3 masl to 9 masl. The identified three genera of bamboo are known to be capable of growing in lowlands at altitudes ranging from 11 masl to 486 masl (Huzaemah *et al.,* 2016). *Dendrocalamus* also grows well on riverbanks. Dransfield and Widjaja (1995) reported that bamboo plantations are scattered and well adapted to environments with an altitude of 500 masl to 1500 masl. *Gigantochloa* can easily grow in high and lowlands (Hadjar *et al.,* 2017; Hastuti *et al.,* 2018) and around rivers (Widjaja *et al.,* 2004).

In addition to affecting the presence of bamboo species, environmental factors affect bamboo productivity. The regeneration of young stems and shoots is one of the parameters used to determine productivity. According to Sutiyono *et al.* (1989), young bamboo stalks or shoots appear during the rainy season in the form of a cone covered by layers of fronds. Bamboo shoots grow and develop very rapidly and reach their maximum length after 2–4 months of age. Branches begin to form after longitudinal growth ends. The regeneration percentage is the total number of shoots and young stems divided by the total number of stems in the clump. Each bamboo clump has 40–50 culms and grows an additional 10–20 culms annually (Hanim *et al.,* 2010). Old stems have the potential to be cut down for use by the community. Dead shoots that fail to develop into culms are also a determining parameter for bamboo productivity. In nature, the bamboo is the fastest growing plant, and shoots that appear and live grow into stems. The lack of bamboo shoot regeneration can be caused by many factors, including disturbance and stress caused by human activities, especially harvesting, which can have positive and negative effects on bamboo regeneration. On the one hand, harvesting can remove parts of the bamboo plant and directly stimulates productivity. On the other hand, overharvesting can cause damage and decrease the number of individual bamboos (Kleinhenz and Midmore, 2001; Sheil *et al.,* 2012). In this study, *D. asper* had the lowest productivity. According to the local community, the population of this species is shrinking due to the harvesting of young shoots for use as vegetable materials. Given that bamboo shoots have a high economic and consumptive value for the community as a vegetable, their intensive utilization results in a decrease in the number of bamboo culms.

CONCLUSIONS

Three bamboo genera, 10 species, and two *Bambusa* cultivars were found in the Indragiri Hilir estuary area. The genus *Bambusa* dominated other genera because it was least affected by environmental factors, such as altitude, temperature, and soil pH. *B. vulgaris* var. *vulgaris* was found to be the most adaptable cultivar in Indragiri Hilir estuary area given that it showed the highest regeneration capability (59.4%) and tolerance for salinity. The identified bamboo species has the potential for further development in all the habitats, especially in the estuary area.

ACKNOWLEDGEMENTS

The author would like to thank Kemenristekdikti (DRPM) contract number 763/UN.19.5.1.3/PT.01.03/2020 for providing funding for this research. Thanks are also given to Prof. Dr. Elizabeth A. Widjaja, the bamboo expert who was willing to assist in correcting the names of bamboo species, as well as to all participants of this research.

REFERENCES

An P, Li X, Zheng Y, Eneji AE, Qiman Y, Zheng M, Inanaga S (2015). Distribution of plant species and species-soil relationship in the east central Gurbantunggut Desert, China. *J. Geogr. Sci.* 25: 101-112.

Andoko A (2003). *Cultivated of bamboo sprout*. Kanisius, Yogyakarta, Indonesia.

Batchelor BC (1979). Discontinuously rising late cainozoic eustatic sea-levels, withspecial reference to Sundaland, Southeast Asia. *Neth*. *J. Geosci.* 58(1): 1-20.

Bean T (2013). *Collecting and preserving plant specimens, a manual*. State of Queensland, Departement of Science. Queensland Herbarium. Brisbane, Australia.

Berlian NVA, Rahayu E. (1995). *Types and prospects of bamboo business*. Penebar Swadaya, Jakarta, Indonesia.

Biswas B (1973). Quaternary changes in sea-level in the South China sea. *Bull. Geo. Soc. Malaysia* 6: 229-256.

Cahyanto T, Arigustin D, Efendi M (2016). Diversity of bamboo species in Mount Ciremai, West Java. *Biogenesis* 4(2):90-94.

Chen FM, Deng JC, Li XJ, Wang G, Smith ML, Shi QS (2016). Effect of laminated structure design on the mechanical properties of bamboo-wood hybrid laminated veneer lumber. *Eur. J. Wood Wood Prod.* 75(3): 439-448.

Chen Y, Huang E, Schefuß E, Mohtadi M, Steinke S, Liu J, Martínez-Mendez G, Tian J (2020). Wetland expansion on the continental shelf of the northern South China sea during deglacial sea level rise. *Quat. Sci. Rev*. 231: 106202.

Dolezal J, Srutek M (2002). Altitudinal changes in composition and structure of mountain temperate vegetation: a case study from the Western Carpathians. *Plant Ecol.* 158: 201–21.
Dransfield S, EA Widjaja (1995). *Plant resources of Southeast Asia (PROSEA) No: 7-Bamboos*. Backhuys Publishers. Leiden, Netherland.
Ekayanti NW (2016). Biodiversity of bamboo (*Bambusa* spp.) in Penglipuran tourism village, Bangli District. *J. Bakti Saraswati*. 5(2): 132-138.
Fitmawati, Saputri NA, Hartanto S, Kholifah SN, Kapli H, Sofiyanti N, Wahibah NN, Khairijon (2020). Diversity utilization of bamboo (Bambusoideae) in five islands around Riau Province, Indonesia. *SABRAO J. Breed. Genet*. 52(2): 177-190.
Fitriana RA, Yulistyarini T, Soegianto A, Ardiarini NR (2018). Relationship of bamboo germplasm collection of purwodadi botanical garden based on morphological characters. *J. Produksi Tanaman*. 5(5): 812-820.
Gonzalez C, Dupont LM (2009). Tropical salt marsh succession as sea-level indicator during heinrich events. *Quat. Sci. Rev*. 28: 939-946.
Grigore MN, Toma C (2007). Histo-anatomical strategies of Chenopodiaceae halophytes: adaptive, ecological and evolutionary implications. *WSEAS Trans. Bio. Biomed*. 12(4):204–218.
Hadjar N, Pujirahayu N, Fitriono E. (2017). Diversity of bamboo species (*Bambusa* sp.) In the Tahura Nipa-nipa area, Mangga Dua Village. *Ecogreen*. 3(1): 9-16.
Hamilton SL (2010). W220 Bamboo (*Phyllostachys* spp.). University of Tennessee, Knoxville. Available from: https://trace.tennessee.edu/utk_agexgard/90 [Accessed on-line Februari 18, 2021].
Hanim AR, Zaidom A, Abood F, Anwar UMK (2010). Adhesion and boncing characteristics of preservatives-treated bamboo (*Gigantochloa scortechinii*) laminates. *J. Appl. Sci*. 10(14): 1435-1441.
Hastuti RW, Yani AP, Ansori I (2018). Study of the diversity of bamboo species in the village of Tanjung Tersana Bengkulu Tengah. *J. Pendidik. Biol*. 2(1): 96-102.
Huzaemah, Mulyaningsih T, Aryanti E (2016). Bamboo identification in the Tiupupus River Basin, North Lombok Regency. *J. Biol. Trop.* 16(2): 23-36.
Jiang H, Ding Z (2008). A 20 Ma pollen record of East-Asian summer monsoon evolution from Guyuan, Ningxia, China. *Palaeogeogr. Palaeoclimatol. Palaeoecol.* 265: 30–38.
Kawaroe M (2001). The contribution of the mangrove ecosystem to the structure of the fish community on the North coast of Subang Regency, West Java. *J. Pesisir dan Lautan*. 3(3): 12-25.
Kenish MJ (1990). *Ecology of estuaries*. Vol II: Biological. CRC Press. Inc Boca Raton. USA.
Kleinhenz V, Midmore DJ (2001). Aspects of bamboo agronomy. *Adv. Agron*. 74: 99–145.
Liana A, Purnomo, Sumardi I, Daryono BS (2017). Ethnobotany of bamboo in Sangirese, North Celebes. *Biosaintifika J. Biol. Biol. Educ*. 9(1): 81-88.
Muhtar DF, Sinyo Y, Ahmad A (2017). Utilization of bamboo plants by the community in the North Oba sub-District of the Tidore archipelago city. *J. Saintifik*. 1(1): 37-44.
Mulatu Y, Fetene M (2013). Stand structure, growth and biomass of *Arundinaria alpina* (Highland bamboo) along topographic gradient in the Choke Mountain, Northwestern Ethiopia. *Ethiop. J. Biol. Sci.* 12(1): 1-23.
Nguyen HN, Nguyen VT, Le VL, Tran VT, Vien N (2017). *Dendrocalamus phuthoensis* (Poaceae: Bambusoideae), a new species from Phu Tho province, Vietnam. *Phytotaxa*. 296(3): 274-280.
Purwanto A, Ambarwati E, Setyaningsih F (2005). Phylogenetic of orchids based on morphological characters. *Ilmu Pertanian*. 12(1): 1-11.
Rahmawati, Baharuddin, Putranto B (2019). Potential and utilization of bamboo string (*Gigantochloa apus*) in the Leu Village of Bolo District, Bima District. *J. Perennial.* 15(1): 27-31.
Rangkuti AM, Cordova MR, Rahmawati A, Yulma, Adimu EH (2017). *Indonesian Coastal and Marine Ecosystems.* Jakarta, Indonesia: PT. Bumi Aksara.
Regional Government Indragiri Hilir (2015). *RPIJM Kabupaten Indragiri Hilir (2015 – 2021*). Kabupaten Indragiri hilir. sippa.ciptakarya.pu.go.id.
Richter M. (2014). *Temperatures in the Tropics.* In: Köhl M., Pancel L. (eds) Tropical Forestry Handbook. Springer, Berlin, Heidelberg.

Rijaya I, Fitmawati (2019). Type of bamboo (Bambusoideae) on Bengkalis Island, Riau Province, Indonesia. *Floribunda*. 6: 41-52.

Setiawan H (1999). Assessment of community pressure on national parks (study the case of collecting bamboo in Meru Betiri National Park). [*Undergraduate Paper*]. Bogor Agricultural Institute. Bogor.

Sheil D, Ducey M, Ssali F, Ngubwagye JM, Van-Heist M, Ezuma P (2012). Bamboo for people, mountain gorillas, and golden monkeys: evaluating harvest and conservation trade-offs and synergies in the Virunga Volcanoes. *For. Eco. Manag*. 267: 163–171.

Sutiyono (1992). Growth rate of clumps of four types of *Gigantochloa* bamboo from stem cuttings. *Buletin Penelitian Hutan*. 552: 51-58.

Sutiyono, Durahim, Sukardi I (1989). Five species of bamboo youth ability. *Buletin Penelitian Hutan*. 513: 47–57.

Suyasa NI, Nurhudah M, Rahardjo S (2010). *Ekologi perairan*. STP Press. Jakarta.

Tang ZY, Fang JY (2004). A review on the elevational patterns of plant species diversity. *Biodiv. Sci*. 12: 20–28.

Tardio G, Mickovski SB, Rauch HP, Fernandes JP, Acharya MS (2018). *The use of bamboo forerosion control and slope stabilization: Soil bioengineering works.* Chapter 7. Bamboo: current and future prospects. DOI 10.5772/intechopen.75626.

Ter-Braak CJF, Verdonschot PFM (1995). Canonical correspondence analysis and ralated multivariate methods in aquatic ecology. *Aquatic Sci.* 57: 255-289.

Widjaja EA (2001b). *Identification of bamboo species on Sunda Kecil archipelago*. Puslitbang Biologi-LIPI. Bogor, Indonesia.

Widjaja EA (1997). New taxa in Indonesia bamboos. *Reinwardtia.* 11: 57-152.

Widjaja EA (2001a). *Identification of bamboo species on Java.* Puslitbang Biologi-LIPI. Bogor, Indonesia.

Widjaja EA (2004). Endemic species of bamboo and their conservation in Indonesia. Prosiding Seminar Nasional Biologi XV.

Widjaja EA, Astuti IP, Arinasa IBK, Sumantera IW (2005). *Identikit bamboo on Bali.* Puslitbang Biologi-LIPI. Bogor, Indonesia.

Wondafrash M (2008). *National herbarium of Ethiopia*. Department Biology, Addis Ababa University, Indonesia.

Zhou BZ, Fu MY, Xie JZ, Yang XS, Li ZC (2005). Ecological functions of bamboo forest: research and application. *J. For. Res.* 16: 143–147.