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Probabilistic Classification of Tree and Shrub Vegetation on Phytogeographic System

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Abstract: The phytogeographical system for vegetation classification split the vegetation in first level types: Forest and Grasslands. The Forest type can be recognized in tropical rain forest and seasonal, depending on the environmental conditions. This determines the occurrence of deciduous species in big or small quantity. And the grasslands are Savannah in majority. This work proposed probabilistic methods to classify these vegetation types based on priori occurrence of species. The test was carried out with forest inventory data using ten vegetation fragments in farm of Embrapa and Cascata's park, in Sete Lagoas city, Minas Gerais, Brazil. The distribution of species with occurrence in different types was adapted to set theory and Bayes theorem. This way it is possible calculate to belonging of species on vegetation types. The results were compared with usual classification. The main contribution of probabilistic methods was the increase the information to classify tree and shrub vegetation inventoried. It is especially recommended for transition regions between vegetation types.

Key words: Sets theory, Bayes, Savannah, forest, transition.

1. Introduction

The main creators of classification systems of flora were Martius, Humbolt, Schimper, the last one known as the father of phytogeography. In Europe, Mueller-Ellenberg Dombois made proposals to classify phytophysiognomic patterns. The principles vary from floristic to physiognomy, or a combination of both. Through naturalists, with the discovery of new continents in the sixteenth century, new physiognomy standards were known, with large increase of taxa due to tropical regions with greater biodiversity [1].

The establishment of the Brazilian flora is due to the contributions of the Amazon "hileia", of Africa, of the Andes and of Australia, in different geological eras. Among the species that came from Amazon forest are Anadenanthera colubrina, Copaifera langsdorfil, Scheflera, Ipê amarelo, Jatobá, *Myracroduon urundeuva*, *Tapirira guianensis*, *Protium heptaphyllum*. The genus *Caesalpinia*, family Fabaceae, is of African origin. Some families are indicators of the biome, such as Cactaceae, endemic to Savannah-steppe, probably originated in the Andean region, and Caryocaraceae, *Caryocar* genus, endemic to Savana [1].

But phytogeographical classification is not yet considered sufficient due to the scale and the terminology of diversity, the complexity due to the interaction climate-plant-soil-fauna and geological formations, which form complex ecosystems. Thus, some survey results may not fit in the present classifications. An example is the typology "Evergreen Seasonal Forest" newly inserted in the classification system [1].

In Brazil, the adaptations to the classification system began with Martius, in 1824, followed by Gonzaga de Campos, in 1926, with a physiognomy-structural principle. And Sampaio, in 1940, and Santos, in 1943,

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the later being known as the precursor of system classification adopted by Radam Brasil in 1970 [2]. Rizzini, in 1963, interpreted the biomes as Caatinga, the Pantanal, Restinga complexes, etc., and, finally, Veloso, Góes-Filho in 1982, Rangel Filho and Lima in 1991, and the Manual of Brazilian Vegetation of IBGE, in 1992, consolidated the current classification system [1].

The Savana Brazilian biome is subject to seasonal continental tropical climate and is generally found on highly weathered and deep soils (mostly Oxisols and Psamments), with high levels of exchangeable aluminum, and it is an edaphic climax vegetation.

The Seasonal Forests are also conditioned by climatic seasonality, which can be tropical, defined by rainfall, with a rainy season and one dry season, or subtropical, determined by a period of lower temperatures [3-5]. It is usually on Oxisols or Ultisols, and may occur interspersed with savannah formations. Their species are constituted mostly by phanerophytes with drought protected leaf buds by suqamae (cataphylls or hair) with adult sclerophillous leaves or deciduous membranes [1].

The standard for establishing a seasonal forest type considers the proportion of individuals of deciduous species. If are found less than 20% of individual trees of deciduous species, the forest type is classified as “broadleaf”; if it is between 20% and 50%, the forest is classified as “seasonal semi-deciduous” [1]; and if the number of individuals is greater than 50%, the typology is “seasonal deciduous”. In case of tropical rain forests the percentage it is also lower than 20%, with differentiation defined by climatic factors, mainly precipitation.

In addition to deciduousness and edaphic component, the presence of some genera and endemic species to help at classification. Whereas, the Floristics is an essential principle of the classification systems, and that there are species that are endemic of certain typologies, the occurrence of species helps in understanding the ecosystem under study, besides physiognomic and physiological information, such as the presence of deciduous species, canopy size, and trunk features among others.

It can be assumed that species are grouped into subsets environment, each with affinity edaphoclimatic combinations and there is a transition zone corresponding to the intersecting areas, and endemic areas that correspond to mutually exclusive areas, for species that occurs only in a typology.

One way to represent the distribution of species in typologies that are subsets determined by a combination of climate, soil, topography and hydrology, is by means of set theory, and Bayes theorem of conditional probability [6]. Thus, the methodology proposed in this study aims to add probabilistic information belonging to a particular ecosystem forest to a particular typologie, based on a priori occurence of individuals of floristic survey, which enables complementary or revise the conventional classification.

2. Material and Methods

The study area is located in Sete Lagoas city, Minas Gerais state. It was obtained inventory data of fourteen areas in forests and Savannah. The twelve areas are forests in experimental farm, one area is forest in Cascata park [7] and one area is Savannah in experimental farm [8].

A collection of botanical material in forest sites and of the Cascata park was sent to the Herbarium of Epamig (Herbarium Code: PAMG), identified by APGIII system [9] and the collection of botanical material from the Savannah inventory was sent to the Laboratory of Dendrology-UFVJM.

The Köppen climate classification for Sete Lagoas is Cwa [10], indicating climate of Savannah with dry winter and rainy summer. The average annual temperature is 21.1 °C and a temperature range of around 6 °C. The average annual precipitation is 1,384 mm and a potential evapotranspiration annual average of approximately 1,444 mm [11].

2.1 Conventional Classification of Forest Typology

For the classification of rainforests and seasonal forests, it used the criterion of the proportion of individuals of deciduous in relation to all individuals wich species to classify the forest. If the ratio is less than 20%, the type will be Rain, between 20 and 50%, the type will be Semideciduous, if greater than 50%, the type will be Deciduous. In the area concerned only the riparian Matas and gallery are areas of seasonal forest always green. The characterization of Savannah was based on existing mappings based on physiognomic parameters and taking into account soil characteristics, Oxisol (LVd), typical of Savannah [1, 12].

2.2 Set Theory

In order to compare with the conventional method which classifies according to the deciduousness, two probabilistic methods have been proposed, based on a priori occurrence of the species. Both used the Set Theory of sets, one considering events with overlapping sample spaces, and another considering mutually exclusive events, applying Bayes' theorem.

2.3 Intersection of Sets

In order apply the probabilistic method with intersection sets, it was considered the occurrence of the species in the typologies of the forest and Savannah, and the ones associated with proximity to water bodies (always green forest). The transition between events has been established assuming moisture gradient between types, except the Savannah, which is considered the edaphic climax. The events of occurring species are:

A = (Savannah),

B = (Deciduous seasonal forest),

C = (Semideciduous seasonal forest),

D = (Tropical rain forest),

E = (Seasonal forest always green),

S-ABCDE = (Species with unidentified occurrences),

sample space, S = (A, B, C, D, E, S-ABCDE),

With the following partitions (mutually exclusive events or subsets in this space):

A, AB, ABC, ABCD, ABCDE, ABCE, ABD, ABDE, ABE, AC, ACD, ACDE, ACE, AD, ADE, AE, B, BC, BCD, BCDE, BCE, BD, BDE, BE, C, CD, CDE, CE, D, DE, E, S-ABCDE, which correspond to possible occurrences of each species, including failure to identify its occurrence. For forest sites in Table 1, the species and occurrences are presented.

As an example, looking at the data of site 11, in Table 1, of the 77 individuals inventoried, 20 are endemic of the Savannah, 1 occurs at Savannah and deciduous forest, and so on, and, finally, records were not found in the literature about 11 individuals.

The sets representing typologies were placed in Fig. 1, with the joint occurrence on Table 1. For example, if a species is endemic to Savannah, is located in the exclusive subspace of A.

One can deduce that

$$p(A \cup B \cup C \cup D \cup E) = p(A) + p(B) + p(C) + p(D) + p(E) \\ -p(A \cap B) - p(B \cap C) - p(C \cap D) - p(D \cap E) - p(E \cap A) \\ +p(A \cap B \cap C \cap D \cap E)$$

But to get the probability of the forest site 11 be of Savannah, one would need to isolate p(A) in this expression, what would not solve the problem, because the authors would not have the other probabilities p(B), p(C), p(D), p(E) ...

The solution to obtain the probability of A is the sum of the exclusive subspaces of Figure 1 with the data in

Table 1 Data of occurrence of inventoried species in site 11 by exclusive subspace.

Occurrence	Num ind.
A	20
AB	1
ABCDE	13
ABCE	3
AC	11
AE	4
B	1
BCD	3
CE	9
E	1
S-ABCDE	11
S	77

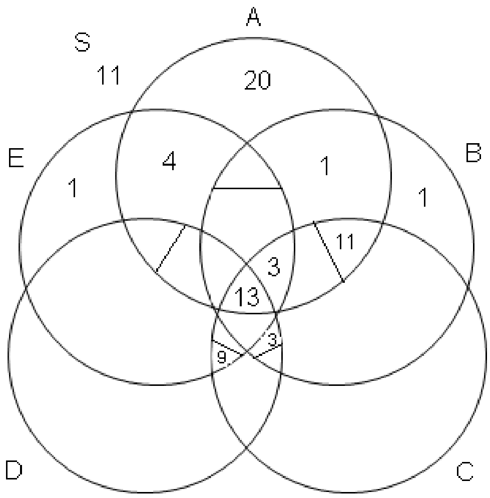


Fig. 1 Partition of sample space between forests and Savannah, filled with data of Table 1. Partition with "-----" delimits the hollow area of the intermediate circle, example: AC = 11 (hollowed B).

Table 2. Thus it is possible to obtain

$$p(A) = \frac{(A + AB + ABC + ABCD + ABCDE + ABCE + AC + ACD + ACDE + AD + ADE + ABD + ABDE + ABE + ACE + AE)}{[S - (S - ABCDE)]}$$

$$p(A) = (20 + 1 + 0 + 0 + 13 + 3 + 11 + 0 + 0 + 0 + 0 + 0 + 0 + 0 + 0 + 4)/(77 - 11) = 0.788$$

Similarly

$$p(B) = \frac{(AB + ABC + ABCD + ABCDE + ABCE + ABD + ABDE + ABE + B + BC + BCD + BCDE + BCE + BD + BDE + BE)}{[S - (S - ABCDE)]}$$

$$p(B) = (1 + 0 + 0 + 13 + 3 + 0 + 0 + 0 + 1 + 0 + 3 + 0 + 0 + 0 + 0 + 0)/(77 - 11) = 0.32$$

And, finally, the proportion of individuals of the species unidentified occurrence is

$$p(S - A \cup B \cup C \cup D \cup E) = \frac{S - ABCDE}{S} = \frac{11}{77} = 0.14$$

2.4 Adaptation to Bayes Theorem

In order to apply the method based on the Bayes theorem, the authors need to define a sample space S = {A, B, C, D, E, S-ABCDE}, which differs from the previous structure by considering the events of Savannah and Forest typologies mutually exclusive. One believes, in this case, the typologies as connected geographical partitions forming the sample space S, so that the species which occur in these partitions corresponding to the event F. Thus one can calculate, given the occurrence of F from the data sample, their belonging to a particular typology.

In order to overcome the restriction of mutually exclusive events, in other words, in which there is no intersection among A, B, C, D, E, two procedures were adopted: (1) considering the division of the frequency of occurrence among the contemplated events; or (2) repeat the frequency of occurrence among events. The first one shows a trend, because the more restricted the occurrence of the major species the greater its contribution in the probability, meaning that endemic species will have greater weight. The second procedure reverses the trend and changes the original frequencies for species with more than one occurrence, giving greater weight to the cosmopolitan species.

In Fig. 2 the occurrences are presented of Table 1 transferred to the sample space in the structure of the Bayes theorem (Venn diagram).

Thus, twenty individuals are restricted to the subspace of Savannah (A), the individual with AB occurrence was allocated 1/2 to space A and 1/2 the space B in the procedure (1), and 1 for the space A and 1 to the space B in the procedure (2), and so on.

In order to obtain the probability of type A, with data from the event F, the authors use the conditional probability given by

$$p(A/F) = \frac{p(A \cap F)}{p(F)} \text{ and } p(F/A) = \frac{p(F \cap A)}{p(A)}$$

Where,

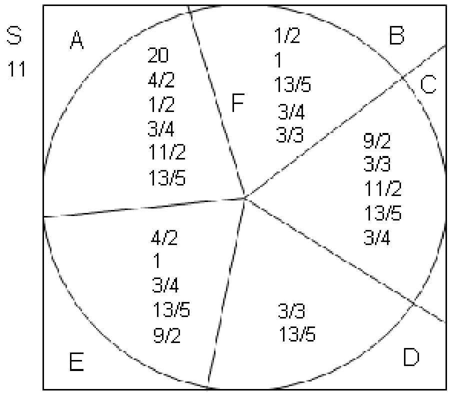
$$p(F) = p(A).p(F/A) + p(B).p(F/B) + \ldots + p(E).p(F/E),$$

The authors have

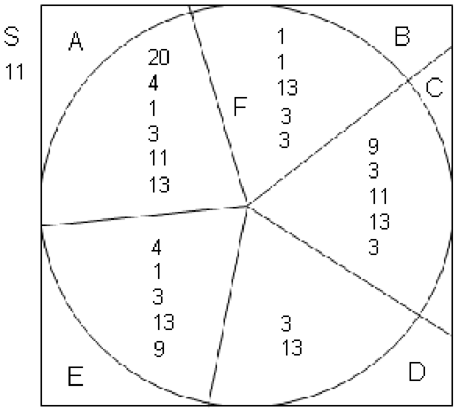
$$p(A/F) = \frac{p(A).p(F/A)}{[p(A).p(F/A) + p(B).p(F/B) + \ldots + p(E).p(F/E)]}$$

In this model, p(F/A) = p(F/B) = ... = p(F/E) = 1, because the data in each subspace, A, B, C, D, E occurs entirely in event F. The probability of A, given that F has occurred is

$$p(A/F) = \frac{p(A)}{[p(A) + p(B) + \ldots + p(E)]}$$



(a)



(b)

Fig. 2 Bayesian sampling space with events A, B, C, D, E and F of species occurrence, with fill data of the table 2 with split of occurrence by event (a); and with repetition of occurrence by event (b), the species with unidentified occurrence were allocated externally to events as part of S.

The authors can estimate for the procedure (1):

$$p(A) = \frac{p(A + AB/2 + ABCDE/5 + ABCE/4 + \ldots + E)}{S}$$

$$= \frac{(20 + 1/2 + \ldots + 1)}{77} = 0.4071$$

$$p(F) = p(A) + p(B) + \cdots + p(E) = 0.8571 = (77 - 11)/77$$

$$p(A/F) = \frac{p(A)}{p(F)} = 0.475$$

And for the procedure (2):

$$p(A) = \frac{p(A + AB + ABCDE + ABCE + \ldots + E)}{S}$$

$$= \frac{(20 + 1 + \ldots + 1)}{169} = 0.3077$$

$$p(A/F) = \frac{p(A)}{p(F)} = 0.329$$

What means that the probability of the event F to be Savannah is 47.5% (1) or 32.9% (2). From the other calculations one can infer domains of forest types to the analyzed event.

As the event F occurs entirely in the subspace of S, therefore it is assumption that the universe of S is completed by F, except from the species without identified occurrence, another way to analyze the classification of site in the types would be to compare the probabilities of the events A, B, C, D, E, directly, what would be considered as final results.

Calculations using the frequency of occurrence of species a priori obtained by bibliographic consulting [13-20] were performed by routines developed in VBA internal to Excel@ [21]. To survey of the Savannah and the fragment of Cascata park the consultation was held by another routine search to data TreeAltan [22].

The probabilistic adjustments to the problem of vegetation classification with the use of occurrence a priori of species were compared to conventional classification which use quantity of deciduous trees.

3. Results

In the survey in experimental farm of forest sites 1,227 individuals were sampled belonging to 42 families and 136 species, of which 14 were identified at the genus level and two at the family level (Table 2).

Among the dominant families, Fabaceae (21.7%), Rubiaceae (8.2%), Myrtaceae (7.7%), Sapindaceae (6.6%) accounted for 44% of individuals. The main dominant species were *Myracrodruon urundeuva* Allemão, *Protium heptaphyllum* (Aubl.) Marchand, *Copaifera langsdorffi* Desf., *Swartzia multijuga* Vogel, *Cordiera sessilis* (Vell.) Kuntze, *Dilodendron bipinnatum* Radlk, ranging from 3.7% to 5.1%, totaling 26.7% of the sampled individuals. The high mortality (8.2%) is due to the damage caused by fires. In all fragments traces of fire were verified, on the basis of trunks, fallen branches, through the mortality of young trees and charred remains in the soil.

The application of the conventional method of classification for forest sites, in Table 3, shows the

Table 2 Family, species, occurrence, deciduousness, number of individual, percentage, considering the joint of forest sites 11, 12, 13, 2, 3, 4, 51, 52, 6, 7, 81 and 82.

Family/specie	**Occurrence**	**Decid.**	**N.ind.**	**%**
Anacardiaceae			**63**	5.1
Astronium fraxinifolium Schott	A	Cad	1	0.1
Astronium graveolens Jacq.	CE	Semicad	15	1.2
Lithrea molleoides (Vell.) Engl.	BE	Cad	2	0.2
Myracrodruon urundeuva Allemão	AB	Cad	45	3.7
Annonaceae			**53**	4.3
Annona neolaurifolia H.Rainer	CE	Cad	18	1.5
Annona sylvatica A.St.-Hil.	ABCDE	Cad	34	2.8
Xylopia aromatica (Lam.) Mart.	A	Semicad	1	0.1
Apocynaceae			**14**	1.1
Aspidosperma cylindrocarpon Müll. Arg.	A	Cad	2	0.2
Aspidosperma spruceanum Benth. ex Müll.Arg.	CE	Ncad	2	0.2
Aspidosperma subincanum Mart.	E	Cad	10	0.8
Araliaceae			**5**	0.4
Aralia warmingiana (Marchal) J.Wen	BCE	Ncad	2	0.2
Dendropanax cuneatus (DC.) Decne & Planch.	ACE	Ncad	1	0.1
Schefflera morototoni (Aubl.) Maguire et al.	ABCE	Ncad	2	0.2
Arecaceae			**6**	0.5
Acrocomia aculeata (Jacq.) Lodd. ex Mart.	A	Ncad	6	0.5
Asteraceae			**1**	0.1
Vernonanthura phosphorica (Vell.) H.Rob	ABCDE	Ncad	1	0.1
Bignoniaceae			**8**	0.7
Handroanthus serratifolius (A.H.Gentry) S.Grose	ABCDE	Cad	3	0.2
Jacaranda macrantha Cham.	CE	Cad	1	0.1
Tabebuia roseoalba (Ridl.) Sandwith	BE	Cad	4	0.3
Burseraceae			**63**	5.1
Protium heptaphyllum (Aubl.) Marchand	AE	Ncad	63	5.1
Cannabaceae			**4**	0.3
Celtis iguanaea (Jacq.) Sarg.	E	Cad	1	0.1
Celtis pubescens (Kunth) Spreng.	B	Semicad	1	0.1
Trema micrantha (L.) Blume	E	Ncad	2	0.2
Cardiopteridaceae			**1**	0.1
Citronella cf. paniculata (Mart.) R.A.Howard	CE	Ncad	1	0.1
Celastraceae			**23**	1.9
Maytenus floribunda Reissek	E	Semicad	23	1.9
Chrysobalanaceae			**6**	0.5
Hirtella gracilipes (Hook.f.) Prance	AE	Ncad	4	0.3
Licania sp.1	S-ABCDE	Ncad	2	0.2
Clusiaceae			**1**	0.1
Calophyllum brasiliense Cambess.	BCDE	Ncad	1	0.1
Combretaceae			**15**	1.2
Terminalia glabrescens Mart.	ABE	Cad	15	1.2

Table 2 to be continued

Cunoniaceae			**1**	0.1
Lamanonia ternata Vell.	BCDE	Ncad	1	0.1
Ebenaceae			**54**	4.4
Diospyros hispida A.DC.	ABC	Cad	33	2.7
Diospyros inconstans Jacq.	ABCE	Semicad	21	1.7
Erythroxylaceae			**1**	0.1
Erythroxylum daphnites Mart.	AE	Cad	1	0.1
Euphorbiaceae			**9**	0.7
Alchornea glandulosa Poepp. & Endl.	CDE	Ncad	3	0.2
Sebastiania commersoniana (Baill.) L.B.Sm. & Downs	BCDE	Cad	6	0.5
Fabaceae			**266**	21.7
Albizia niopoides (Spruce ex Benth.) Bukart	BE	Ncad	1	0.1
Albizia polycephala (Benth.) Killip. ex Record	C	Semicad	2	0.2
Albizia sp.	S-ABCDE	Nclas	1	0.1
Anadenanthera colubrina var. cebil (Griseb.) Altschul	E	Cad	20	1.6
Anadenanthera peregrina (L.) Speg.	A	Cad	2	0.2
Anadenanthera sp. 1	B	Cad	2	0.2
Andira fraxinifolia Benth.	CE	Ncad	1	0.1
Bauhinia longifolia (Bong.) Steud.	ABE	Semicad	11	0.9
Cassia ferruginea (Schrad.) Schrad ex DC.	A	Cad	1	0.1
Chamaecrista ensiformis (Vell.) H.S.Irwin & Barneby	A	Cad	27	2.2
Copaifera langsdorffi Desf.	AE	Cad	47	3.8
Dalbergia miscolobium Benth.	A	Cad	1	0.1
Fabaceae sp. 1	S-ABCDE	Nclas	1	0.1
Hymenaea courbaril L.	E	Ncad	4	0.3
Inga marginata Willd.	ACDE	Ncad	1	0.1
Inga vera subsp. affinis (DC.) T.D.Penn.	E	Ncad	11	0.9
Lonchocarpus sp.	BC	Semicad	1	0.1
Machaerium aculeatum Raddi	B	Cad	2	0.2
Machaerium acutifolium Vogel	B	Semicad	1	0.1
Machaerium cf. villosum Vogel	ABCDE	Semicad	3	0.2
Machaerium hirtum (Vell.) Steelfeld	ABCE	Cad	1	0.1
Machaerium sp.	S-ABCDE	Cad	4	0.3
Machaerium stipitatum Vogel	BCD	Cad	25	2.0
Plathymenia foliolosa Benth.	E	Cad	1	0.1
Platycyamus regnellii Benth.	E	Cad	2	0.2
Platymiscium pubescens Micheli	A	Cad	1	0.1
Platypodium elegans Vogel	BE	Semicad	11	0.9
Senegalia polyphylla (DC.) Brutton & Rose	ABCD	Cad	4	0.3
Senna macranthera (DC. ex Collad.) H.S.Irwin & Barneby	E	Cad	1	0.1
Senna sp.1	S-ABCDE	Cad	3	0.2
Swartzia apetala Raddi	B	Cad	2	0.2
Swartzia multijuga Vogel	CE	Cad	56	4.6
Swartzia pilulifera Benth.	A	Cad	3	0.2
Swartzia sp.	S-ABCDE	Cad	1	0.1
Sweetia fruticosa Spreng.	A	Cad	7	0.6
Zollernia ilicifolia (Brongn.) Vogel	AD	Cad	4	0.3

Table 2 to be continued

Lamiaceae			**7**	0.6
Aegiphila verticillata Vell.	AC	Cad	2	0.2
Vitex polygama Cham.	CE	Cad	3	0.2
Vitex sp.1	S-ABCDE	Cad	2	0.2
Lauraceae			**21**	1.7
Nectandra membranacea (Sw.) Griseb	C	Semicad	1	0.1
Nectandra oppositifolia Nees	CDE	Ncad	3	0.2
Ocotea pulchella (Nees) Mez	AE	Cad	1	0.1
Ocotea velutina (Nees) Rohwer	AC	Ncad	16	1.3
Lecythidaceae			**1**	0.1
Cariniana estrellensis (Raddi) Kuntze	E	Semicad	1	0.1
Malvaceae			**19**	1.5
Apeiba tibourbou Aubl.	E	Cad	1	0.1
Eriotheca gracilipes (K.Schum.) A.Robyns	AE	Semicad	1	0.1
Guazuma ulmifolia Lam.	AE	Ncad	14	1.1
Luehea grandiflora Mart. & Zucc.	ABCE	Semicad	1	0.1
Pseudobombax tomentosum (Mart. & Zucc.) A.Robyns	AE	Cad	2	0.2
Meliaceae			**59**	4.8
Cedrela fissilis Vell.	B	Cad	3	0.2
Guarea kunthiana A. Juss.	E	Ncad	6	0.5
Trichilia catigua A.Juss.	BE	Semicad	5	0.4
Trichilia claussenii C.DC.	BCDE	Ncad	10	0.8
Trichilia pallida Sw.	AE	Ncad	17	1.4
Trichilia silvatica C.DC.	BC	Ncad	18	1.5
Monimiaceae			**1**	0.1
Mollinedia widgrenii A.DC.	E	Ncad	1	0.1
Moraceae			**1**	0.1
Ficus sp.	S-ABCDE	Ncad	1	0.1
Morta	S-ABCDE	Nclas	**101**	8.2
Myrtaceae			**95**	7.7
Calyptranthes sp.	S-ABCDE	Ncad	1	0.1
Eugenia dysenterica DC.	A	Cad	2	0.2
Eugenia florida DC.	AE	Nclas	35	2.9
Myrcia sp.1	S-ABCDE	Nclas	2	0.2
Myrcia splendens (Sw.) DC.	D	Ncad	13	1.1
Myrcia tomentosa (Aubl.) DC.	BE	Cad	30	2.4
Myrciaria floribunda (H.West ex Willd.) O.Berg	A	Ncad	2	0.2
Myrtaceae sp.	S-ABCDE	Ncad	10	0.8
Nyctaginaceae			**3**	0.2
Guapira opposita (Vell.) Reitz	ABE	Semicad	3	0.2
Ochnaceae			**2**	0.2
Ouratea castaneifolia (DC.) Engl.	A	Ncad	2	0.2
Oleaceae			**1**	0.1
Chionanthus trichotomus (Vell.) P.S.Green	CE	Ncad	1	0.1
Phyllanthaceae			**4**	0.3
Hieronyma alchorneoides Allemão	E	Ncad	4	0.3

Table 2 to be continued

Polygonaceae			**1**	0.1
Coccoloba sp.	S-ABCDE	Ncad	1	0.1
Rhamnaceae			**3**	0.2
Rhamnidium elaeocarpum Reissek	ABCDE	Cad	3	0.2
Rubiaceae			**101**	8.2
Chomelia cf. spinosa Jacq.	S-ABCDE	Cad	1	0.1
Chomelia obtusa Cham. & Schlecht.	A	Ncad	1	0.1
Cordiera sessilis (Vell.) Kuntze	ABCDE	Ncad	55	4.5
Coussarea hydrangeifolia (Benth.) Müll.Arg.	AB	Ncad	3	0.2
Coutarea hexandra (Jacq.) K.Schum.	DE	Ncad	10	0.8
Faramea hyacinthina Mart.	S-ABCDE	Ncad	3	0.2
Guettarda viburnoides Cham. & Schltdl.	A	Semicad	8	0.7
Ixora cf. brevifolia Benth.	ABCE	Ncad	1	0.1
Ixora gardneriana Benth.	E	Ncad	18	1.5
Rudgea viburnoides (Cham.) Benth.	A	Ncad	1	0.1
Rutaceae			**51**	4.2
Citrus sp.	S-ABCDE	Ncad	1	0.1
Galipea jasminiflora (A.St.-Hil.) Engl.	CE	Ncad	38	3.1
Metrodorea stipularis Mart.	CE	Ncad	10	0.8
Zanthoxylum petiolare A.St.-Hil. & Tul.	BCE	Ncad	2	0.2
Salicaceae			**36**	2.9
Casearia cf. guianensis (Aubl.) Urb.	A	Cad	10	0.8
Casearia decandra Jacq.	ABCE	Cad	3	0.2
Casearia sylvestris Sw.	ABCDE	Semicad	23	1.9
Sapindaceae			**81**	6.6
Allophylus sericeus Radlk.	ABCE	Cad	1	0.1
Cupania vernalis Cambess.	ABCDE	Ncad	16	1.3
Dilodendron bipinnatum Radlk.	ABCE	Cad	62	5.1
Matayba guianensis Aubl.	ABCE	Ncad	1	0.1
Matayba sp.	S-ABCDE	Ncad	1	0.1
Sapotaceae			**2**	0.2
Chrysophyllum marginatum (Hook. & Arn.) Radlk.	ABCE	Ncad	2	0.2
Siparunaceae			11	0.9
Siparuna guianensis Aubl.	ABCDE	Ncad	11	0.9
Urticaceae			**15**	1.2
Cecropia glaziovii Snethl.	ACDE	Cad	4	0.3
Cecropia pachystachya Trécul	ABCDE	Cad	11	0.9
Verbenaceae			**6**	0.5
Aloysia virgata (Ruiz & Pav.) Pers.	ABCE	Cad	6	0.5
Vochysiaceae			**11**	0.9
Callisthene major Mart. & Zucc.	ACE	Cad	9	0.7
Qualea grandiflora Mart.	ABCE	Semicad	1	0.1
Vochysia tucanorum Mart.	ACE	Ncad	1	0.1
Total			**1227**	**100**

Table 3 Classification of phytogeographic forest sites by method of counting trees of deciduous species [1].

Sites	Parcelas	Not identified	deciduous	Not deciduous	Semi deciduous	Total	Deciduous (%)	Not identified (%)	Tipology
11	2	7	48	18	4	77	68.57	9.09	Deciduous
12	2	14	39	7	6	66	75.00	21.21	Deciduous
13	2	7	83		25	115	76.85	6.09	Deciduous
2	3	21	105	24	12	162	74.47	12.96	Deciduous
3	1	2	3	42	1	48	6.52	4.17	Rain forest
4	2	15	56	100	9	180	33.94	8.33	Semideciduous
51	2	2	32	31	3	68	48.48	2.94	Semideciduous
52	2	5	44	27	21	97	47.83	5.15	Semideciduous
6	3	7	63	26	4	100	67.74	7.00	Deciduous
7	3	7	21	32	9	69	33.87	10.14	Semideciduous
81	2	11	22	81	30	144	16.54	7.64	Rain forest
82	2	6	33	54	8	101	34.74	5.94	Semideciduous
Total	**27**	**103**	**549**	**442**	**132**	**1,227**	**48.84**	**8.39**	**Semideciduous**

* Sites 11, 12, 13 and 2 are regenerations that are approximately 50 years old, since the pasture was abandoned, established by a 1949 aerial photo; the site of the fragment 7 has low tree density and predominance of large individuals.

frame work of the typology by the proportion of deciduous trees in the survey. For this, the sites 11, 12, 13, 2 and 6 were classified as deciduous forest. Site 3 was rated as tropical rain forest, as well as site 81. The remaining sites were framed in semideciduous forest typology, as well as all the survey, considering the junction of the forest sites.

In order to obtain the probability of belonging of the forest site to types, the data must be arranged as in Table 4, which shows the occurrences of the species of site 11 with the number of individuals in each tipology (other sites are not shown due to space restriction).

This table shows that 20 individuals from three species are endemic to Savannah: Anadenanthera peregrina (1), Chamaecrista ensiformis (17) and Sweetia fruticosa (2), and only one individual of Machaerium acutifoliumis considered endemic of deciduous flora. Another significant number of individuals are 11 Ocotea velutina, endemic to Savannah and semideciduous forest, in other words, the phytogeographical classification of deciduous forest to the site 11 is not compatible with the occurrences of the species inventoried on this site. Other similar situations are found in the other sites, with the classification diverging of predominance of species occurrence.

Table 5 shows the events for the sites, including surveys for Savannah and Cascata park fragments, without discrimination per species. At sites 12 and 13, 15 and 41 individuals occurred, respectively, of endemic species of semideciduous forest, seasonal forest always green (CE), consistent with the proximity of water bodies. The site 2 there are significant number of individuals endemic to deciduous forest, seasonal forest always green (26). The site 3, tropical rain forest, has a predominance of nearly 50% of endemic individuals to Savannah and seasonal forest always green (AE). The site 4 has similar prevalence but with a large number of generalist individuals (ABCDE). Sites 51 and 52 are more equitable, with no apparent predominance of occurrences. The site 6 has dominance of species of seasonal forest always green, and Savannah (E, AE, A). The site of fragment 7 shows dominance of species of semideciduous forest, seasonal forest always green (CE), as well as the sites 81 and 82, with the difference of presents greater dominance of species of Savannah, seasonal forest always green.

In most forest sites there is predominance of endemic joint Savannah, semideciduous forest and

Table 4 Occurrence of species inventoried in site 11 in typologies. A: Savannah. B: deciduous forest, C: semideciduous forest, D: tropical rain forest, E: seasonal forest always green, S-(A, B, C, D, E): unidentified occurrence.

Sítio 11	A	AB	ABCDE	ABCE	AC	AE	B	BCD	CE	E	S-ABCDE	Total
Annonaceae												
Annona sylvatica A.St.-Hil.			12									12
Apocynaceae												
Aspidosperma spruceanum Benth. ex Müll.Arg.									1			1
Burseraceae												
Protium heptaphyllum (Aubl.) Marchand						1						1
Cannabaceae												
Celtis iguanaea (Jacq.) Sarg.										1		1
Ebenaceae												
Diospyros inconstans Jacq.				3								3
Erythroxylaceae						1						1
Erythroxylum daphnites Mart.						1						1
Fabaceae												
Anadenanthera peregrina (L.) Speg.	2											2
Chamaecrista ensiformis (Vell.) H.S.Irwin & Barneby	17											17
Copaifera langsdorffi Desf.						2						2
Machaerium acutifolium Vogel							1					1
Machaerium sp.											1	1
Machaerium stipitatum Vogel								3				3
Swartzia multijuga Vogel									7			7
Sweetia fruticosa Spreng.	1											1
Lamiaceae												
Vitex polygama Cham.									1			1
Lauraceae												
Ocotea velutina (Nees) Rohwer					11							11
Morta											7	7
Myrtaceae												
Myrtaceae sp.											1	1
Rubiaceae												
Cordiera sessilis (Vell.) Kuntze			1									1
Coussarea hydrangeifolia (Benth.) Müll.Arg.		1										1
Faramea hyacinthina Mart.											2	2
Total	**20**	**1**	**13**	**3**	**11**	**4**	**1**	**3**	**9**	**1**	**11**	**77**

seasonal forest always green, showing that the area is transitional from Savannah to humid environments. This is also evidenced by the existence of selective hygrophilous species such as Bauhinia longifolia, Cecropia glaziovii and Inga marginata.

The sites present ultisols, oxisols and cambisols featuring distinct edaphic environments with nutrient levels reducing with increasing soil depth, indicating that the nutrient source to the surface layers of the soil is not the parent material but the recycling of organic matter. It follows that the soil water supply is the main condition for the formation of these floristic ecosystems.

For the Savannah and Cascata park inventory area

Table 5 Occurrence of species inventoried in forest sites, the fragments of Savannah and the Cascade park in typologies. A: Savannah, B: deciduous forest. C: semideciduous forest, D: tropical rain forest, E: seasonal forest always green, S-(A, B, C, D, E): occurrence unidentified.

Ocorr/sites	11	12	13	2	3	4	51	52	6	7	81	82	Sites flor. total	Savannah	Frag. p. cascata
A	20	3	9	11	0	8	4	11	4	0	1	7	78	2	0
AB	1	5	0	3	0	13	9	0	9	4	3	1	48	177	0
ABC	0	0	0	20	0	0	1	4	8	0	0	0	33	216	20
ABCD	0	4	0	0	0	0	0	0	0	0	0	0	4	912	74
ABCDE	13	7	11	10	2	57	10	7	8	11	17	5	158	-	-
ABCE	3	1	17	29	0	10	11	17	13	0	1	0	102	-	-
ABD	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
ABDE	0	0	0	0	0	0	0	0	0	0	0	0	0	-	-
ABE	0	3	6	0	0	4	2	4	3	0	4	3	29	-	-
AC	11	1	0	2	0	1	0	0	1	2	0	0	18	325	1
ACD	0	0	0	0	0	0	0	0	0	0	0	0	0	3	109
ACDE	0	0	0	0	1	0	0	0	0	4	0	0	5	-	-
ACE	0	0	0	5	1	0	0	1	0	0	0	4	11	-	-
AE	4	4	0	9	23	50	8	11	14	7	29	26	185	-	-
B	1	1	0	1	0	2	1	2	0	1	2	0	11	0	0
BC	0	0	0	3	1	1	2	7	2	0	3	0	19	0	0
BCD	3	0	20	0	0	0	0	0	0	0	2	0	25	0	1
BCDE	0	0	0	0	1	1	0	0	0	1	3	12	18	-	-
BCE	0	0	0	0	0	0	0	0	0	0	1	3	4	-	-
BD	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
BDE	0	0	0	0	0	0	0	0	0	0	0	0	0	-	-
BE	0	5	0	26	0	3	2	5	2	1	5	4	53	-	-
C	0	1	1	0	0	1	0	0	0	0	0	0	3	0	0
CD	0	0	0	0	0	0	0	0	0	0	0	0	0	0	8
CDE	0	0	0	0	1	1	3	0	0	1	0	0	6	-	-
CE	9	15	41	7	1	1	2	2	3	25	27	13	146	-	-
D	0	0	0	5	0	3	1	0	0	3	1	0	13	0	0
DE	0	0	0	0	0	0	0	0	0	0	10	0	10	-	-
E	1	2	3	8	7	6	8	21	22	1	17	12	108	-	-
S-ABCDE	11	14	7	23	10	18	4	5	11	8	16	9	136	54	22
S	77	66	115	162	48	180	68	97	100	69	144	101	1,227	1,689	235

Table 5 to be continued

* For the Savannah and the fragment of Cascata park was not considered the type E (information not existing in TreeAtlan).

(Table 5), only two endemic individuals were found. Their biggest difference compared to the fragment in the Cascata park is the occurrences AC with 325 individuals from Savannah and semideciduous forest, while the fragment in the Cascata park has 109 individuals occurring also in the tropical rainforest (ACD).

It can be seen, observing the occurrence data, that floristic not only separates the types; for example, in the comparison of the Savannah with the forest sites, there are more endemic individuals of Savannah in forest sites than in the Savannah itself.

Table 6 Probability by typology for forest sites and the fragments of Savannah and the Cascata park, considering the methods: intersection of sets, and $Bayes_1$ and $Bayes_2$, Prob. $Bayes_1$ and Prob. $Bayes_2$, the IBGE classification. Obs. fragments of the Savannah and Cascata park were evaluated only by the method of intersection of sets and was not considered in the analysis the type E (seasonal forest always green).

Method	Prob.	11	12	13	2	3	4	51	52	6	7	81	82	Sites total	Savan.	Cascata's Park
Int. sets.	P(A)	0.79	0.54	0.40	0.64	0.71	0.88	0.70	0.60	0.67	0.46	0.45	0.52	0.62	1.00	0.96
	P(B)	0.32	0.50	0.50	0.66	0.11	0.56	0.59	0.50	0.51	0.30	0.32	0.30	0.46	0.80	0.45
	P(C)	0.59	0.56	0.83	0.55	0.21	0.45	0.45	0.41	0.39	0.72	0.42	0.40	0.51	0.89	1.00
	P(D)	0.24	0.21	0.29	0.11	0.13	0.38	0.22	0.08	0.09	0.33	0.27	0.21	0.22	0.56	0.90
	P(E)	0.46	0.71	0.72	0.68	0.97	0.82	0.72	0.74	0.73	0.84	0.89	0.89	0.77	-	-
	P(S-ABCDE)	0.14	0.21	0.06	0.14	0.21	0.10	0.06	0.05	0.11	0.12	0.11	0.09	0.11	0.03	0.09
$Bayes_1$	P(A/F)	0.48	0.22	0.16	0.26	0.33	0.34	0.29	0.27	0.28	0.16	0.18	0.27	0.26		
	P(B/F)	0.09	0.19	0.14	0.24	0.03	0.16	0.21	0.18	0.17	0.10	0.11	0.09	0.15		
	P(C/F)	0.22	0.22	0.32	0.17	0.07	0.11	0.13	0.13	0.12	0.28	0.16	0.14	0.17		
	P(D/F)	0.06	0.05	0.08	0.05	0.03	0.09	0.06	0.02	0.02	0.11	0.09	0.05	0.06		
	P(E/F)	0.16	0.32	0.30	0.29	0.54	0.30	0.32	0.41	0.42	0.35	0.46	0.44	0.35		
$Bayes_2$	P(A/F)	0.33	0.21	0.15	0.24	0.33	0.29	0.26	0.26	0.28	0.17	0.19	0.22	0.24		
	P(B/F)	0.13	0.20	0.18	0.25	0.05	0.18	0.22	0.22	0.21	0.11	0.14	0.13	0.18		
	P(C/F)	0.25	0.22	0.30	0.21	0.10	0.15	0.17	0.18	0.16	0.27	0.18	0.17	0.20		
	P(D/F)	0.10	0.08	0.11	0.04	0.06	0.12	0.08	0.03	0.04	0.12	0.12	0.09	0.09		
	P(E/F)	0.19	0.28	0.26	0.26	0.46	0.27	0.27	0.32	0.31	0.32	0.38	0.38	0.30		
Pr. $Bayes_1$	P(A)	0.41	0.18	0.15	0.22	0.26	0.31	0.27	0.26	0.25	0.14	0.16	0.24	0.24		
	P(B)	0.08	0.15	0.13	0.20	0.02	0.14	0.20	0.17	0.15	0.09	0.10	0.08	0.13		
	P(C)	0.19	0.18	0.30	0.15	0.05	0.09	0.12	0.12	0.11	0.25	0.14	0.13	0.15		
	P(D)	0.05	0.04	0.08	0.04	0.03	0.08	0.06	0.01	0.02	0.10	0.08	0.05	0.06		
	P(E)	0.14	0.25	0.28	0.25	0.43	0.27	0.30	0.39	0.37	0.31	0.41	0.40	0.31		
Pr. $Bayes_2$	P(A)	0.31	0.19	0.14	0.23	0.30	0.28	0.26	0.25	0.27	0.17	0.18	0.22	0.23		
	P(B)	0.12	0.18	0.18	0.24	0.04	0.18	0.22	0.21	0.20	0.11	0.13	0.13	0.17		
	P(C)	0.23	0.20	0.30	0.20	0.09	0.14	0.17	0.17	0.16	0.26	0.17	0.17	0.19		
	P(D)	0.10	0.08	0.10	0.04	0.06	0.12	0.08	0.03	0.04	0.12	0.11	0.09	0.08		
	P(E)	0.18	0.26	0.26	0.24	0.41	0.26	0.26	0.31	0.29	0.30	0.36	0.37	0.28		
IBGE clas.	(% caduc.)	B	B	B	B	D	C	C	C	B	C	D	C	C		

The probabilities for the methods of occurrences a priori are shown in Table 6. The range of gray values for p(S-ABCDE) reports the probability of individuals without identification of occurrence. For example, 14.3% of the individuals did not have any identified occurrence at site 11. The calculation of the intersection of sets has no bias, while the calculation by $Bayes_1$ and $Bayes_2$ are adaptations of the events to Bayes' theorem.

Comparing the methods applied to forest sites, it was found that the order of the probabilities between the method of the intersections and the other methods of probability is almost identical. The only differences were the results of A and B sites for $Bayes_1$ at sites 13 and 2.

The probabilities of typology tropical rain forest (D) are always lower, except for the forest sites 3 and 7 and the fragment of the Cascata park, which had lower values for deciduous forest (B) (Table 6).

The greater probabilities are for seasonal forest always green (E), except for the sites11, 13 and 4, compared (Table 6), and 11 and 4 had the highest probabilities for (A) Savannah. The second greater probabilities are for Savannah (A) at sites 3, 51 and 52, 6, 81 and 82. The analysis considering all forest sites characterizes the area as seasonal forest always green with transition to semideciduous forest at Savannah. Using conventional analysis, the area would be classified as semideciduous forest.

The analysis in Savannah inventory area showed the maximum value for P(A) indicating that all species of the survey occur in the Savannah and the second largest value for semideciduous forest. In Cascata park's fragment inventory, occurrence of all species in semideciduous forest (C), with value one to P(C), and second highest for Cerrado (A). These two physiognomically distinct environments present inverse probabilities of relevance.

4. Discussion

The probabilistic methods generated information on the proportion of each typology, represented by the a priori occurrence of inventoried species in other regions. The similarity between new areas and other regions already classified is directed by the predominance of species with properties as hygrophilous selective or xerophytes, tolerant of shade (ombrophilous) and intolerant to shade (heliophytic), or of edaphic climax, or not tolerant seasonality, among other features ecophysiological, which will set the established flora. Other factors can interfere in floristic composition such as geological origin, or anthropism by changing the potential flora.

When assessing the floristic composition with the probability of occurrence of species a priori, it was possible to verify, with the support of the characterization of forest sites, if the classification using the conventional method matched with the relevance of types to species present in the survey in a probabilistic manner. This allowed revising or confirming the classification adopted for the surveys.

The limitations for the application of this methodology are due to the quality of information and to its access. Other is especially the degradation of typologies by human activities. The authors observed cases of divergence in the occurrence and information of deciduousness in species too, opting for the information published in more rigorous scientific media.

The Brazilian territory is vast and effort to inventory ecosystems is large with small sampling intensity. That is, there is a possibility that the information about occurrence of some species may not be complete, because they still were not found in other environments.

The access to this information requires large investment in reviews because they are dispersed in studies addressing floristic, phytosociological, phenology, plant physiology, plant geography, among others.

Nowadays, there is TreeAtlan, a useful initiative of [22], which corresponds to a database with approximately 8000 species of flora occurring in the Americas, which allows the consult of the information of the species present in the survey through user—developed routines, how made this work to species that occur in inventory of the Savannah and Cascata park areas.

Based on the presented results, the conventional method of counting the deciduousness induces misclassification because phytogeographic classification needs more characteristics of the environment, such as climate, hydrological, topography and soil. Another uncertainty in its application is that the ecophysiological species behavior may change according to environmental conditions, raising doubts about its deciduousness.

5. Conclusions

Probabilistic methods based on the occurrence a priori of species provide belonging information of the inventoried ecosystem to types of phytogeographical systems. This knowledge shows the prevalences of each typology and allows evaluating the classification given by the criterion of deciduousness.

Classification using the method of counting deciduousness is not sufficient for classification of forest sites in phytogeographical system, evidenced by the probabilities of belonging to the typologies.

With a database like TreeAtlan updated and supplemented with information and routines, the classification process with the support of the priori species occurrence becomes feasible for routine applications in floristics and phytosociological surveys.

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