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A Fournier Index upgrade as a new approach for quantitative phenological studies in plant communities

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Abstract: This paper proposes a new quantitative approach, based on the association of species basal area, as a dominance indicator, weighted by the arcsine transformation of the current Fournier Index, for studying quantitative plant phenology at the community level. Since plant basal area is strongly correlated with its height and crown volume, this upgrade enhances the ecological importance of phenodynamics at the canopy level for plant community analysis. The curves in phenograms of the original Fournier´s index of intensity and those ones produced by this new approach did not overlap in a standardized ranging scale. These differences resulted in distinct phenological patterns, in particular concerning phenophase peaks. This new approach broadens our ability to evaluate resource availability and seasonality patterns in plant communities. It provides a more adequate basis for hypothesis testing on the influence of environmental factors on plant phenodynamics, and refines the quantitative description of all phenophases when the community structure is described.

Resumen: Este artículo propone un nuevo enfoque cuantitativo, basado en la asociación del área basal de las especies como variable indicadora de la dominancia, ponderada por la transformación arco seno del Índice de Fournier actual, para el estudio de la fenología vegetal cuantitativa en el nivel de la comunidad. Dado que el área basal de las plantas está correlacionada fuertemente con su altura y volumen de la copa, este mejoramiento realza la importancia ecológica de la dinámica fenológica en el dosel para el análisis de la comunidad vegetal. Las curvas en los fenogramas del índice de intensidad de Fournier original y las que se producen por este nuevo enfoque no se traslapan en una escala estandarizada de rangos. Estas diferencias resultaron en patrones fenológicos distintos, en particular en relación con los picos de las fenofases. Este nuevo enfoque amplía nuestra habilidad para evaluar la disponibilidad de recursos y los patrones de estacionalidad en las comunidades de plantas, ofrece una base más adecuada para la prueba de hipótesis sobre la influencia de factores ambientales sobre la dinámica fenológica de las plantas y refina la descripción cuantitativa de todas las fenofases cuando se describe la estructura de la comunidad.

Resumo: Para estudar quantitativamente a fenologia da planta ao nível da comunidade este trabalho propõe uma nova abordagem quantitativa, baseada na associação da área basal das espécies, como um indicador de dominância, ponderada pela transformação arcoseno do índice usual de Fournier. Como a área basal das planta está fortemente correlacionada com a

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sua altura e volume da copa, essa atualização melhora a importância ecológica dos dinâmica fenológica ao nível do dossel para a análise da comunidade de plantas. Os fenogramas do índice original de Fournier para intensidade e os produzidos por esta nova abordagem não se sobrepõem numa escala estandardizada padronizada. Estas diferenças resultaram em padrões fenológicos diferentes, em particular os relacionados aos picos das fenofases. Esta nova abordagem amplia a nossa capacidade para avaliar a disponibilidade de recursos e os padrões de sazonalidade nas comunidades vegetais. Ela fornece uma base mais adequada para o teste de hipóteses quanto à influência dos factores ambientais na dinâmica da fenologia das plantas, e refina a descrição quantitativa de todos as fenofases quando a estrutura da comunidade é descrita.

Key words: Basal area, forest canopy, phenodynamics, phenophase, phenological intensity, plant resource, tree crown.

The phenological pattern of any life cycle event can be quantitatively defined as a statistical distribution characterized by such parameters as time of occurrence, duration, synchrony and skewness (Rathcke & Lacey 1985). By the end of 1960s, pioneer observational and analytical methods proposed on the quantitative phenology of tropical trees were based on the identification and the proportional importance of different phenophases in plant communities, which led to the first characterization of phenological patterns in the neotropical forests (Croat 1969; Daubenmire 1972). From the 1990's to date, many studies on phenology of neotropical trees have been based on the Fournier Index (Fournier 1974), which applies a non-parametric simple correlation measure to establish relationships between phenodynamics and climate features (Bullock & Solis-Magallanes 1990; Morellato *et al.* 2000; Tesfaye *et al.* 2011). Fournier method is applicable in community studies, because it requires simple and short-term training and is useful for any kind of tree. Moreover, the method is independent of plant architecture and size, as it is based on the percentage of crown coverage, and this facilitates both data collection in the field and data analysis.

The floristic and structural spatial anisotropy of plant communities challenge the manner in which appropriate descriptions of the ecological importance of plant species in a given area are generated, and, therefore, question arises as to how to classify the ecological importance of each phenophase. Thus, a quantitative approach involving phenophase biomass of trees is relevant to determine the phenological patterns of forests at the community level. The ecological importance of each phenophase biomass should be first based on the qualitative evaluation of floristic composition, which is a major indicator of resource diversity in a community, and second, on the quantitative relationships among individuals that represent the populations of plant species (Opler *et al.* 1980).

In this paper we propose a new quantitative approach for plant vegetative and reproductive phenology at the community level, based on the association of the plant basal area as dominance indicator, weighed by the arcsine transformation of the current Fournier Index as a quantitative expression of phenological events in plant community structure.

As a test case, we use the weighed Fournier Index to characterize the flowering pattern of the tree community in an area of 3.126 ha of a lowland Atlantic Forest at União Biological Reserve (Rebio União), southeastern Brazil (22º 27' 30" S and 42º 02' 14" W). The Atlantic Forest occupied a large part of the coast of Brazil, which borders the Atlantic Ocean, hence the name of this phytogeographic province; current remains at lowland areas typically harbor more than one hundred species of trees with diameter at breast height (DBH) > 10 cm (Scudeller *et al.* 2001). Most of those species are found in few sites, indicating their restricted distribution, in addition, few species show a high local abundance and many species (ca. 20 %) are represented by one individual within one-hectare sites (Scudeller *et al.* 2001). The field sampling occurred in nine plots (20 x 50 m) in the lowland forest at Rebio União, which experiences a humid tropical climate. Floristic and structure of the tree community were previously studied within these plots by sampling of all individuals with DBH > 10 cm (Gabriel 2009; Rodrigues 2004), which comprised our sample. Binoculars were used for crown observation. The intensity of flowering phenophase was registered following Fournier methodology (Fournier 1974) for a total of 172 individual trees of 91 species (i.e., excluding individuals and species that did not flower during the study period). We calculated monthly Fournier's percent index of intensity. Afterwards, the Fournier index of intensity was weighted by the species basal area, after log-transformation of data, as illustrated below. We compare the observed curves after the two measures and discuss about the reasons and the possible ecological consequences of observed differences.

The Fournier technique estimates the intensity of phenophases by an analogical quartile scale. The intensity of the phenophases is estimated for each individual through a semi-quantitative scale of five categories (0 to 4) in 25 % intervals among the categories (Fournier 1974). The Fournier Index remains one of most useful tools for semi-quantitative description of the intensity of phenophases, both at the population and community levels. However, crude results obtained by the Fournier Index are, in fact, expressions of proportionalities, and proportions naturally suffer by circularity and asymmetry in their datasets, it means, it produces values that are equally limited for hypothesis tests that have normality as an assumption, and even the estimation of means and standard deviations (Zar 2010). In order to associate plant phenophase intensity with an expression of plant dominance, we multiplied the Fournier proportion by the plant basal area. We transformed the Fournier proportion values into the arcsine of their square root, expressed in radians. In sequence, the arcsines were multiplied by the decimal logarithm of the plant basal area added of one, to avoid negative logarithm values.

In each census that was made, the value of the original Fournier Index is a ratio ranging from 0 up to 1, and corresponds to a given phenophase intensity for the species, and was estimated according to the formula below:

$$FI = \sum_{i=1}^{N} \frac{Fi}{4N}$$

FI = Fournier Index

Fi = Phenophase intensity for each plant individual

N = Total number of observed plants.

The sum of these values for all species, multiplied by 100, represents the percentage of Fournier's intensity of the community (Fournier 1974). However, instead of the Fournier Index, we propose to change the expression of the results in a categorical scale to a potentially continuous one. The correspondence of Fournier Index Scale with the proportion of each ratio category is made as follows: score 4 is equivalent to 1.00; score 3 to 0.75; score 2 to 0.5; score 1 to 0.25, and score 0 to 0.00. This way of estimation produces an upgrade in Fournier Index that follows the equation:

$$FI' = \sum_{i=1}^{N} \frac{\arcsin\sqrt{Fi}}{1.57 * N}$$

FI' = Transformed Fournier Index

Fi = Phenophase intensity for each individual

1.57 = Maximum individual intensity, expressed by the arcsin transformation of 100 %

N = Total number of observed species

We also propose the multiplication of Fournier's Index by the species basal area as a dominance indicator, to assess the role of the different phenophases in the structure of a plant community. Community biomass is traditionally estimated using a dominance descriptor and basal area is the most common parameter applied in plant community structure (Brower *et al.* 1998). Besides, studies on plant allometry and architecture have evidenced a strong correlation between the basal area and the size and shade projection of the crowns (Barthemy & Caraglio 2007; Chave *et al.* 2005). So, we propose that in studies at the plant community level, the Fournier's Index should be weighted by the species basal area, transformed in its logarithm, as a normalization trail, added with one to avoid negative values as results, according the formula:

$$FI'' = FI' * \log(1 + BA)$$

FI"= Fournier's Index weighted by the species basal area

FI'= Arcsine transformed Fournier's Index

log = Decimal logarithm

BA= Total basal area of the species.

In our dataset, we found that phenogram of the Fournier´s index of intensity did not overlap the phenogram obtained after correction by basal area for flowering (Fig. 1), when both indexes are transformed by ranging to homogenize the values between zero and one, and then plotted under that ranging scale. For instance, from December 2006 up to February 2007, we may notice flowering peaks produced by the traditional Fournier Index at the plant community, mainly due to the high intensity values achieved by species with only one individual in the sampled area, such as *Balizia pedicellaris* (DC.) Barneby & J. W. Grines (Fabaceae

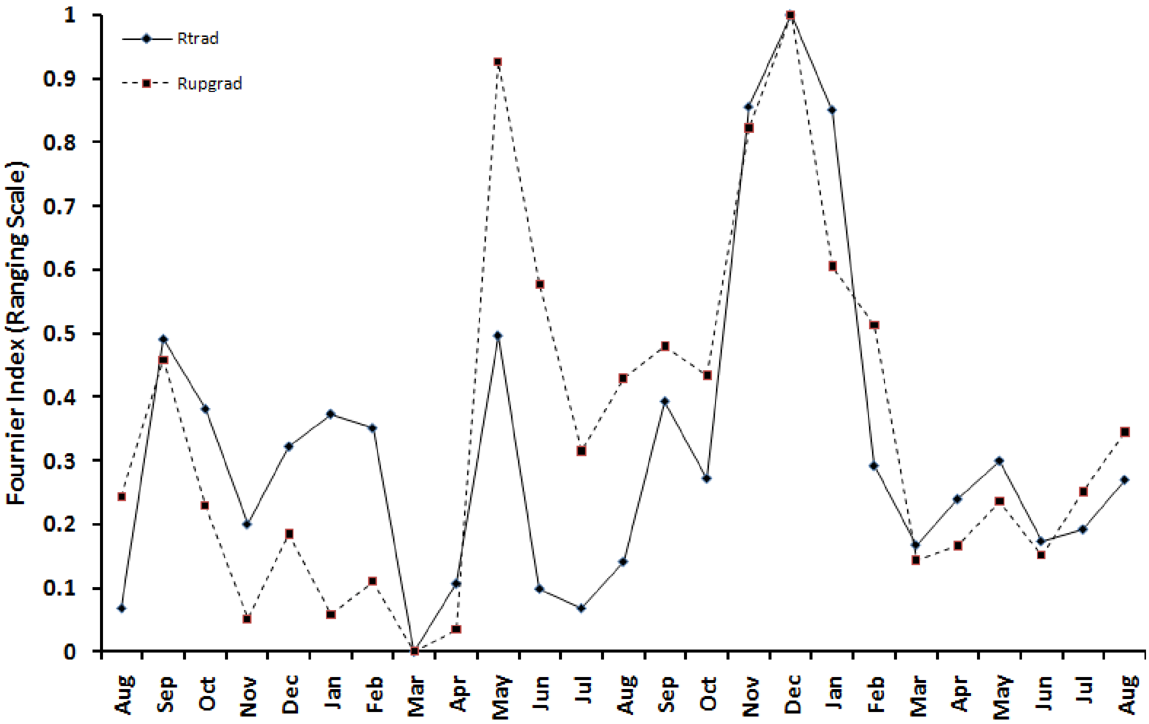

Fig. 1. Flowering phenograms of the tree community of a lowland tropical forest in southeastern Brazil. Note the difference of behavior and intensity amplitude between the curves obtained by the traditional and the upgraded Fournier Indices, compared in a ranging transformed scale.

Sloanea monosperma Vell. (Elaeocarpaceae), and *Clethra scabra* Pers. (Clethraceae). However, at the plant community quantitative structure, it had in fact overestimated the ecological contribution of flowering phenophase, because it had only considered the phenological state of species crowns, without regarding those species had low dominance, as a consequence of low basal area values and low species abundance contribution to the community structure. On the other hand, from May up to October 2007, the flowering peaks were underestimated by the traditional Fournier Index, since it did not consider the species dominance contribution to the community structure, such as that of the most abundant and dominant species, *Cupania racemosa* (Vell.) Radlk. (Sapindaceae). Only in those cases when plant species did not show discrepant dominance values, as it happened in November and December 2007, the traditional Fournier Index and our proposed upgrade had overlapped their phenograms.

Although the Fournier Index is useful for quantitative characterization of plant communities, it was developed in fact for population studies, and it does not consider biomass differences among plant species, and then it may underestimate the detection of quantitative phenological patterns in tropical forests. The correction of the Fournier Index by basal area provides broader perspectives on resource availability evaluation in a community, because it considers the indirect correlation between phenological intensity and canopy volume. This fact may enhance the ecological importance of phenological events that occur at the canopy level in community analysis that was previously underestimated when only the number of species in a specific phenophase was counted.

In addition to the sampling restrictions, the subsequent data analysis is a main problem in tree phenology (Schirone *et al.* 1990) because the collected data may not allow further statistical treatments. The classical representation of tree phenological patterns at the community level does not consider the community phytosociological structure, and the short-term phenology of one or few individuals (phenodynamics) is often considered as the population phenological pattern (phenorhythm). In part this reflects the fact that the importance of the biomass of leaves, flower, fruits and seeds of trees has been underestimated at the community level, despite of their ecological roles. Canopy phenophases were considered an insignificant and ephemeral proportion of the total biomass produced by trees in tropical forest ecosystems (Heithaus 1974), exclusive of their biological role in the environment. Besides that, this new quantitative approach may be used for hypothesis tests on the evolution of ecological attributes in tropical forests, as exemplified by some studies on the distribution of sexual systems of tree species (Silva *et al.* 1997; Vamosi 2006).

Some characteristics of the Fournier Index restrict both the causality interaction of effects of climate features on tree phenology and the accuracy of the phenological patterns detected by this method. Thus, we here propose an upgrade of Fournier Index by data transformation integrated with a phytosociological parameter, as a new approach that associates phenophases with plant biomass of the plants, what may allow the use of parametric statistics and enhancing the quantitative representation and analysis of phenological events that occur at the canopy level. In a more prospective approach, the correction of phenological intensity measures by basal area may provide a valuable tool for calibration of phenological analysis using meteorological satellite data at ecosystem scale (Fisher *et al.* 2006; Justice *et al.* 1985; Studer *et al.* 2005; Studer *et al.* 2007), which is one of the most promising methods to assess the effects of global climatic changes on dynamics of ecosystems.

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