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Estimating grapevine cultivated biodiversity: new indices for objective quantification

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ABSTRACT

The consequences of the decrease in number of cultivated grapevine varieties and in the diversity of plant material and clones available in nurseries and used by winegrowers are still the subject of much debate. With the aim of better understanding and defining more precisely the disadvantages or advantages of the different situations in terms of "cultivated biodiversity", we sought to develop different indices adapted to grapevine in order to compare diverse situations in a neutral and objective way. These indicators may consider different spatial levels (world, countries, regions, estates and plots) and may take into account different categories of plant material such as varieties, clones or rootstocks. They could also be applied to quantify the level of biodiversity for some labels or certification programmes as a guarantee for consumers.

KEYWORDS: Ampelographical biodiversity index, clone, grapevine richness index, rootstock, varietal assortment diversification index, variety, vineyard

INTRODUCTION

Over the past thirty years, global change has caused "biodiversity" to become an increasingly important, strategic and societal issue. This word is a neologism that arose from the concept of "biological diversity" proposed by Lovejoy (1980). Five years later, W. Rosen suggested the contracted form for a congress held in Washington under the name of "National Forum on Biodiversity". The proceedings of this symposium were published in 1988 under the direction of Edward Wilson and the title of "Biodiversity", giving the wording its first international recognition (Wilson, 1988). Three levels of analysis through this ecological concept have been proposed, which were initially based on natural and non-agricultural diversity. These levels are, from the most general to the finest: i) the systemic level; *i.e.*, the study of the diversity of ecosystems and interactions between natural populations and their physical environments, ii) the specific level; *i.e.*, the analysis of species diversity, which is the most useful taxonomic unit for the study of the natural populations in the field, and iii) the genetic level; *i.e.*, the analysis of gene diversity within a species.

Similarly, a few years ago in France, a law for the "reconquest of biodiversity, nature and landscape" was passed and published (Anonymous, 2016). In the text, biodiversity is defined as followed: "biodiversity, or biological diversity, is the variability among living organisms from all sources, including terrestrial, marine and other aquatic ecosystems and the ecological complexes of which they are part. It includes diversity within species, diversity between species, ecosystems diversity and the interactions between the living organisms".

Progressively, the relationships between the degrees of biodiversity which may exist and the sustainability (Ostrom, 2009), the potential for adaptation (Simonet, 2009; Rusch *et al.,* 2022) and the resilience (Döring *et al.,* 2015) have been studied and highlighted. In relation to these aspects, the concept of biodiversity has gradually been extended to the cultivated compartment and the study of the populations of crop species grown on farms (Brown, 2008; Jones *et al.,* 2021; Doncieux *et al.,* 2022). Concerning grapevine, Doncieux (2023) studied the role and influence of cultivated varietal diversity on inter-annual yield stability in different vineyards.

The aim of this work was to determine how biodiversity indicators can be applied to studies on cultivated grapevine. In addition to diversity between species, diversity within species (*i.e.*, intraspecific or varietal level, including scion and rootstock varieties) must be taken into consideration, as it is of the most importance and interest to winegrowers. While the intra-varietal level (*i.e.*, clones) could also be of interest to winegrowers, in our work, the systemic and genetic levels are not considered. We focused only on defining new indices to be able to quantify more objectively the biodiversity of cultivated grapevine plant material. To achieve this, existing biodiversity indicators are reviewed and alternative ones, which are better adapted and dependent on the scale of analysis are proposed. Examples are given that demonstrate how the indicators can be applied at different spatial scales; *i.e.*, worldwide, country and regional scales, as well as appellation, estate, vineyard and plot scales.

REVIEW OF SOME EXISTING INDICATORS

1. General indices for measuring biodiversity

Some indicators have been proposed to estimate the biodiversity of natural ecosystems. The following ones are the most well-known and commonly used and are based on inventories and spatial distribution analysis.

1.1. Richness index–HR (McIntosh, 1967)

$H_R = C - 1$, where C is the number of categories (species, variety, etc.).

1.2. Shannon index–HS (Shannon, 1948)

$H_S = -\sum_{s=1}^{S} p_s \ln (p_s)$ where p_s is the number of individuals of a species "s" compared to the total population.

1.3. Gini-Simpson index–HGS (Simpson, 1949)

$H_{G\text{-}S}(\text{p}) = 1 - \sum_{s=1}^{S} p_s{}^2$ where p_s is the number of individuals of a species "s" compared to the total population.

These different indices are especially useful at species level and under natural conditions, but they are not well suited to cultivated plants, as growers do not usually use mixtures of species for their crops. Concerning cultivated grapevine, the only existing indexes were proposed by Anderson (2014), as given below.

2. Anderson indices (Anderson, 2014; Anderson & Nelgen, 2020)

2.1. Varietal intensity index–VII

This index is used for a given variety (v) in a given country and its formula is as follows: $VII\ (v)\ \frac{\%vp}{\%vm}$, where %vp is the proportion of the variety "v" related to the total surface area of the vineyard in the country and %vm, the proportion of the same variety "v" in the world.

2.2. Varietal similarity index–VSI

The aim of this index is to compare varietal profiles between regions or countries, or to evaluate and situate a country in relation to the rest of the world.

$VSI\ (p1p2)\ \frac{\sum[(\%vp1)\times(\%vp2)]}{\sqrt{\Sigma\%vp1^2}\times\sqrt{\Sigma\%vp2^2}}$ where *%vp1* is the proportion of the variety "v" related to the total surface area of the vineyard in the country "1" (or region) and *%vp2* is the proportion (p) of the same variety "v" in the country "2" (or in another region or the world).

It can be seen that these indices are useful for comparing the relative importance of grape varieties between regions or countries, but they do not really provide any information on the level of biodiversity of grape varieties grown in different vineyards. This has led to the definition of more appropriate indexes for assessing and comparing the biodiversity of cultivated grapevines.

DEFINITION OF THREE GRAPEVINE BIODIVERSITY INDICATORS

1. Grapevine richness index–GRI

This indicator has been adapted from the richness index H_R (McIntosh, 1967) for cultivated grapevines. It depends on the type of plant material considered (varieties or clones) and can be useful at different spatial levels, such as appellation area (demarcated region), estate, vineyard or plot. Thus, it can be broken down into three categories. The sum of these three sub-indices give an estimate of the overall plant material richness in the vineyard studied. All these indices should be calculated to 3 decimal places.

1.1. Varietal richness index [0; 1 [

$GRI_V = (V - 1)/V$, where "V" is the total number of scion cultivated varieties.

1.2. Clonal richness index [0; 1 [

$GRI_{Cv} = (Cv - 1)/Cv$, where "Cv" is the total number of clones (or of lineages in the case of massal selection) for a cultivated variety "V" if this data is available. Otherwise, this index will stay undefined.

1.3. Rootstock richness index [0; 1 [

$GRI_{Rt} = (Rt - 1)/Rt$, where "Rt" is the total number of rootstock varieties.

1.4. Overall plant material richness index [0; 1 [

$GRI_{OPM} = (GRI_V + \Sigma GRI_{Cv}/V + GRI_{Rt})/3$

2. Varietal assortment diversification index–VADI [0; 1 [

This indicator is based on the surface areas of the cultivated varieties It can be applied at different spatial levels, such as world, countries or regions and to 10, 20 or 40 main cultivated varieties in these locations. "S" is the planted areas (in ha) of the varieties.

$VADI_{10} = 1 - [(\sum_{1}^{10} S \text{ main varieties}) / \text{S all varieties}]$

$VADI_{20} = 1 - [(\sum_{1}^{20} S \text{ main varieties}) / \text{S all varieties}]$

$VADI_{40} = 1 - [(\sum_{1}^{40} S \text{ main varieties}) / \text{S all varieties}]$

3. Ampelographical biodiversity index–ABI [0; 1 [

This indicator is suitable for appellation area (demarcated region), estate, vineyard or plot. It is defined as a weighting of the previous grapevine richness index (*GRI*) by the respective proportions of the varieties. In this way, it optimises the equi-distribution of varieties and thus the representation and effectiveness of real biodiversity. It is mainly used at varietal level (but it could also be used for and adapted to clones and rootstocks) and it requires a more precise inventory of varieties per area or per number of vines.

$ABIv = [1 - \frac{(\Sigma|\%v - 1/V|)}{V}] \times GRI_V$, where $\%v$ is the proportion of the variety "v" in the place studied and "V" the total number of varieties at the same location.

EXAMPLES OF INDICATOR APPLICATION

In order to demonstrate how these indicators can be used, three examples are given below, along with the way in which they are calculated.

1. Varietal assortment diversification index (VADI) for wine grape varieties: evaluating the intensity of varietal shrinkage over years

As maintaining grape vine biodiversity is a challenge for the future, using this particularly demonstrative indicator on a global and national scale could contribute to raising the awareness of stakeholders in the wine industry.

1.1. At world level and in relation to the surface area of the vineyard intended for wine production (Table 1)

These results show that the worldwide diversity of grape varieties for wine production remained relatively stable until the 2000s. Since then, there has been a gradual shift toward a predominance of the main internationally renowned varieties.

TABLE 1. Varietal assortment diversification index (VADI) for wine grape in the world. Sources: Organisation internationale de la vigne et du vin (2017); Anderson and Nelgen (2020); Fegan (2003); personal estimates).

	1990	2000	2010	2020
Σ 10 main wine grape varieties surface areas (1000 ha)	2 046	1 738	1 918	1 988
Σ 20 main wine grape varieties surface areas (1000 ha)	2 691	2 371	2 534	2 541
Total wine grape vineyard surface areas (1000 ha)	5 493	4 708	4 132	3 679
$VADI_{10}$	0.628	0.631	0.536	0.460
$VADI_{20}$	0.510	0.496	0.387	0.309

1.2. At national level, for example in France (Figure 1)

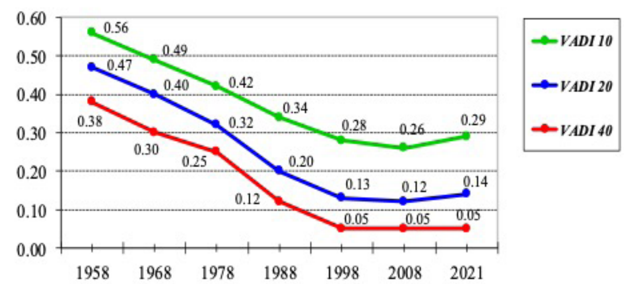

FIGURE 1. Varietal assortment diversification index (VADI) in France over the last 60 years (data sources: French vine registers, FranceAgriMer, Direction générale des douanes et des droits indirects, casier viticole informatisé).

Compared with the rest of the world, changes in varietal diversity in French vineyards began much earlier, reaching a major shrinkage from the end of the 1990s. Since then, it has remained relatively stable, since it seems difficult to regress further in terms of varietal diversity with index values for the 40 main varieties of 0.04 in 2018 *vs*. 0.38 in 1958. However, regarding these 40 main varieties, a certain rebalancing seems to be underway, since the VADI 10 and 20 indices have re-increased slightly over the last fifteen years.

The growing interest in heritage neglected varieties, foreign or new resistant cultivars is currently leading to a diversification in the vines planted across the different French regions; this could potentially result in future changes to this index, which currently indicates an overwhelming dominance of the main varieties.

2. Comparing the grapevine richness index (GRI) between regions

To illustrate the use of this indicator, we give here the examples of two protected designations of origin both located in the Rhone Valley (France): Châteauneuf-du-Pape, located in the south of this area and traditionally characterised by a blend of several varieties, and Côte Rôtie, located further North and mainly made from a single variety.

2.1. Côte Rôtie, AOP specifications (Anonymous, 2011b)

Main variety: 'Syrah'; accessory variety: 'Viognier'

$GRI_V = (2 – 1)/2 = 0.50$

2.2. Châteauneuf-du-Pape, AOP specifications (Anonymous, 2011a)

Varieties: 'Bourboulenc', 'Brun argenté', 'Cinsaut', 'Clairette', 'Clairette rose', 'Counoise', 'Grenache blanc', 'Grenache gris', 'Grenache', 'Mourvèdre', 'Muscardin', 'Picardan', 'Piquepoul blanc', 'Piquepoul gris', 'Piquepoul noir', 'Roussanne', 'Syrah', 'Terret noir'

$GRI_V = (18 – 1)/18 = 0.94$

The discrepancies between the vine populations of these two appellations are evident and are based on their respective wine-growing traditions. To improve the biodiversity of the former, it would thus be important to partially compensate for the lack of varietal diversity by using a more diverse clonal panel and possibly different rootstocks.

3. Characterisation of varietal and intra-varietal biodiversity using the ampelographical biodiversity index (ABI) on some vineyards

For this index, examples from South West France are used in order to compare the levels of biodiversity encountered in two recent vineyards, including a historic and exceptional plot that is at least 150 years old.

3.1. Example 1: one plot of 'Tannat' clone 717 grafted on one single rootstock (*e.g.*, 'SO4')

In this case there is no biodiversity:

$GRI_V = GRI_{Cv} = GRI_{Rt} = GRI_{OPM} = 0$ and therefore ABI_V is also equal to zero.

3.2. Example 2: one mixed plot of two varieties

'Gros Manseng' (60 %) and 'Petit Manseng' (40 %), each comprising three and two clones respectively (*i.e*., 397, 661, 731 and 440, 573) grafted on three rootstocks (*i.e*., '101-14 MGt', '3309 C' and 'Gravesac')

$GRI_V = (2 - 1)/2 = 0.50$

$GRI_{Cv} = [(3 - 1)/3 + (2 – 1)/2]/2 = 0.59$

$GRI_{Rt} = (3 - 1)/3 = 0.67$

$GRI_{OPM} = 0.5 + 0.59 + 0.67 = 1.76$

$ABI_V = [1 – ((|0.6 – 1/2| + |0.4 – 1/2|)/2)] \times 0.5 = 0.45$

3.3. Example 3: Pédebernade's plot at Sarragachies (32400, France)

This plot is made up of 563 vines with 17 different varieties, all ungrafted and without any selected clones (Yobrégat *et al.*, 2012). It is worth noting that this vineyard was inventoried vine by vine (Table 2) and officially classified as an Historical Monument in 2012 given its age, its ancestral method of management and the exceptional richness of its varietal assortment.

TABLE 2. Exhaustive inventory of the Pédebernade's plot.

	Number of vines	Proportions
'Tannat' N	461	0.819
'Fer' N	49	0.087
'Morrastel'/'Graciano' N	13	0.023
'Pédebernade 1' N	8	0.014
'Miousat'/'Humagne' B	6	0.011
'Arrat' N	4	0.007
'Muscadelle' B	4	0.007
'Pédebernade 2'/'Printillou Aigut' B	3	0.005
'Tardif' N	3	0.005
'Candolle' B	2	0.004
'Claverie' B	2	0.004
'Pédebernade 6' N	2	0.004
'Pédebernade 7' N	2	0.004
'Blanc Dame' B	1	0.002
'Canari' N	1	0.002
'Pédebernade 3' B	1	0.002
'Pédebernade 5' N	1	0.002
Total	563	

$GRI_V = (17 – 1)/17 = 0.94$

GRI_{Cv} = undefined

$GRI_{Rt} = (17 – 1)/17 = 0.94$

$GRI_{OPM} \geq 0.94 + 0.94 = 1.88$

ABI_V = [1 – ((|0.819 - 1/17| + |0.087 - 1/17| + |0.023 - 1/17| + |0.014 - 1/17| + |0.011 - 1/17| + |0.007 - 1/17| + |0.007 - 1/17| + |0.005 - 1/17| + |0.005 - 1/17| + |0.004 - 1/17| + |0.004 - 1/17| + |0.004 - 1/17| + |0.004 - 1/17| + |0.002 - 1/17| + |0.002 - 1/17| + |0.002 - 1/17| + |0.002 - 1/17|)/17)] x 0.94 = 0.85

These indices thus provide a more objective and rational basis for assessing production conditions in different vineyards or estates, and they can be useful for promoting the wines produced from them. They can also be very useful when objectively determining the areas of greatest diversity where priority prospecting efforts should be made before their disappearance (Lacombe, 2023).

CONCLUSION

Biodiversity is undoubtedly a positive and necessary factor that contributes to grapevine sustainability, resilience, resistance and ability to adapt to global change (Sargolzaei *et al.,* 2021). This is why issues related to biodiversity are numerous and complex.

However, many questions still remain unanswered. For instance, in terms of varieties, should the degree of biodiversity be the same, regardless of whether they are used for producing white or red wines? In terms of clonal biodiversity, the most convincing results to date tend to show that the best wines are obtained with a blend of the best clones (Arnold & Schneider, 2006), but such results may be dependent on variety or type of wine produced and it's a possibility to be explored. In certain cases, some selection programmes have adopted a multiclonal approach, which seems to confer a greater adaptability to the planted vineyard (Gonçalves *et al.,* 2019). The question thus arises of whether intra-varietal biodiversity is more advantageous for 'Syrah' or 'Pinot noir' than for 'Mourvèdre' or 'Cabernet franc'. Regarding rootstocks, even if the search for those that are the most highly adapted to the terroir must be the priority (Marin *et al.,* 2021), they can provide an interesting differentiation through their diversity (Renouf *et al.,* 2010), but to what extent? And more generally, what is the exact relationship between biodiversity and the typicality or quality of wines?

Finding the answers to all these questions is very important if the fitness of the vines and quality of the wines are to be improved in the future. The definition of the new indices described here should enable progress to be made in this area by increasing the objectivity of comparisons between different situations and vineyards.

The use of these indices could also prove useful for some labels or certification programmes, such as "High Environmental Value" in France or the protected designations of origin in Europe which aim at guaranteeing product quality for the consumer.

Finally, in the future, these biodiversity indices could be supplemented by cultural and historical factors, such as the use of local or disappeared synonyms to name a specific variety in old vineyards. This would make it possible to promote the type or number of products that can be obtained from a given area, as the different uses of varieties, linguistic heritage, agricultural practices, as well as food and culinary traditions are also part of ecosystem diversity (Saddoud Debbabi *et al.,* 2024).

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