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An index for assessing the rare species of a community

Everton A. Maciel

Institute of Biology, Monteiro Lobato St, 255/Block M, University of Campinas – UNICAMP, 13.083-862 Campinas, SP, Brazil

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ABSTRACT

Rarity has long been a question of great interest in a wide range of fields. A method to classify rare species should be simple and easy for different professional groups to learn. Rabinowitz is not only easy-to-follow but also one of the most accepted methods to classify rare species. This study proposes a rarity index (*rr*) based on Rabinowitz's scheme. The index operates at the species level. Given a list of n species, the inverse of the geographical range in decimal degree (geographic range index – *gri*) of the maximum number of species habitats (habitat specificity index – *hsi*), and the maximum population size anywhere (population size index – *psi*) were calculated for each species. An average index $rr = \text{med}(gri + hsi + psi)$ was calculated for each species from the *gri, hsi*, and *psi* indexes. The *rr* varies from 0 to 1: the closer *rr* is to 1, the rarer the species. A code in the R language to calculate each proposed measure is provided. The output of this code is a list of species with their respective indices. *RR* is useful in the ecology and biodiversity conservation fields. This index has the following advantages: (1) it uses three aspects of rarity to gain a synthetic index; (2) the three parameters have equal weights; and (3) it is easily followed by anyone who feels inclined to use it. Some directions on how it might be used are discussed.

1. Introduction

There are several approaches available for measuring rare species, and Rabinowitz's method is by far one of the most widely used (Rabinowitz, 1981). As Kelly Johnson's principle followed (Rich, 1995), "keep it simple, stupid (KISS)", Rabinowitz proposed that rare species in a community can emerge from the combination of three parameters: geographic range, habitat specificity, and population size (Rabinowitz, 1981). According to Rabinowitz each species of the community can be classified as follows: the geographic range leads to restricted or widely distributed species; habitat specificity leads to habitat specialist species or generalists; and, the number of individuals leads to a small population size for species or a large population. Following Rabinowitz's archetype, this paper considers rare species to be those that, in any given time or space, present one or more of the following characteristics: geographic restrictions, habitat specificity, or a small population.

Geographic range is a biographical parameter (Schmeller et al., 2008) that could be applied on a regional or continental scale (Söderström et al., 2007). Current patterns of biodiversity have been influenced by regional and historical factors (Ricklefs, 2004). As a result, some species have restricted geographical range while others have a large range. This is because the range of supported ecological levels is specific for each species (Pandit et al., 2009; Pärtel et al., 2004; Rabinowitz, 1978), and outside this range, the niche becomes narrow (Murray and Lepschi, 2004). On the basis of that principle, the purpose of this parameter is to classify a species based on its detected area of occurrence relative to a sampling area (Maciel and Arlé, 2020). Examples of how to quantify geographic range in the literature include the percentage of areas where a species occurs relative to the total of areas sampled (Rey Benayas et al., 1999; Sætersdal and Birks, 1997), the number of biogeographic domains in which the species could occur (Betanio and Buenavista, 2018; Maciel et al., 2016; Söderström et al., 2007), the number of grid cells occupied by a species relative to the total grid cells (Roselaar et al., 2007; Selvi, 1997; Villaseñor et al., 2006), or the extreme latitude and longitude (e.g. Sheth et al., 2020). Here, the extreme latitude and longitude was used to quantify species geographic range (Fig. 1).

Habitat specificity is the particular affinity that a species has for a kind of habitat or microhabitat (Vitt, 1981). Species that thrive on a narrow range of conditions are called habitat specialists, and species that succeed in a variety of conditions are call generalists (Pandit et al., 2009; Pitman et al., 1999). Habitat can be defined on a local or regional scale (Mayor et al., 2009). Different ways have been used to classify habitat specialists (Le Berre et al., 2019). For example, xerothermic and hygrophilic species were classified as habitat specialists while mesophilic species were classified as generalists (Reinhardt et al., 2005). Another example in the savanna rainforest ecotones suggested that one species group were savanna specialists, another group were forest

E-mail address: everttonmaciel@gmail.com.

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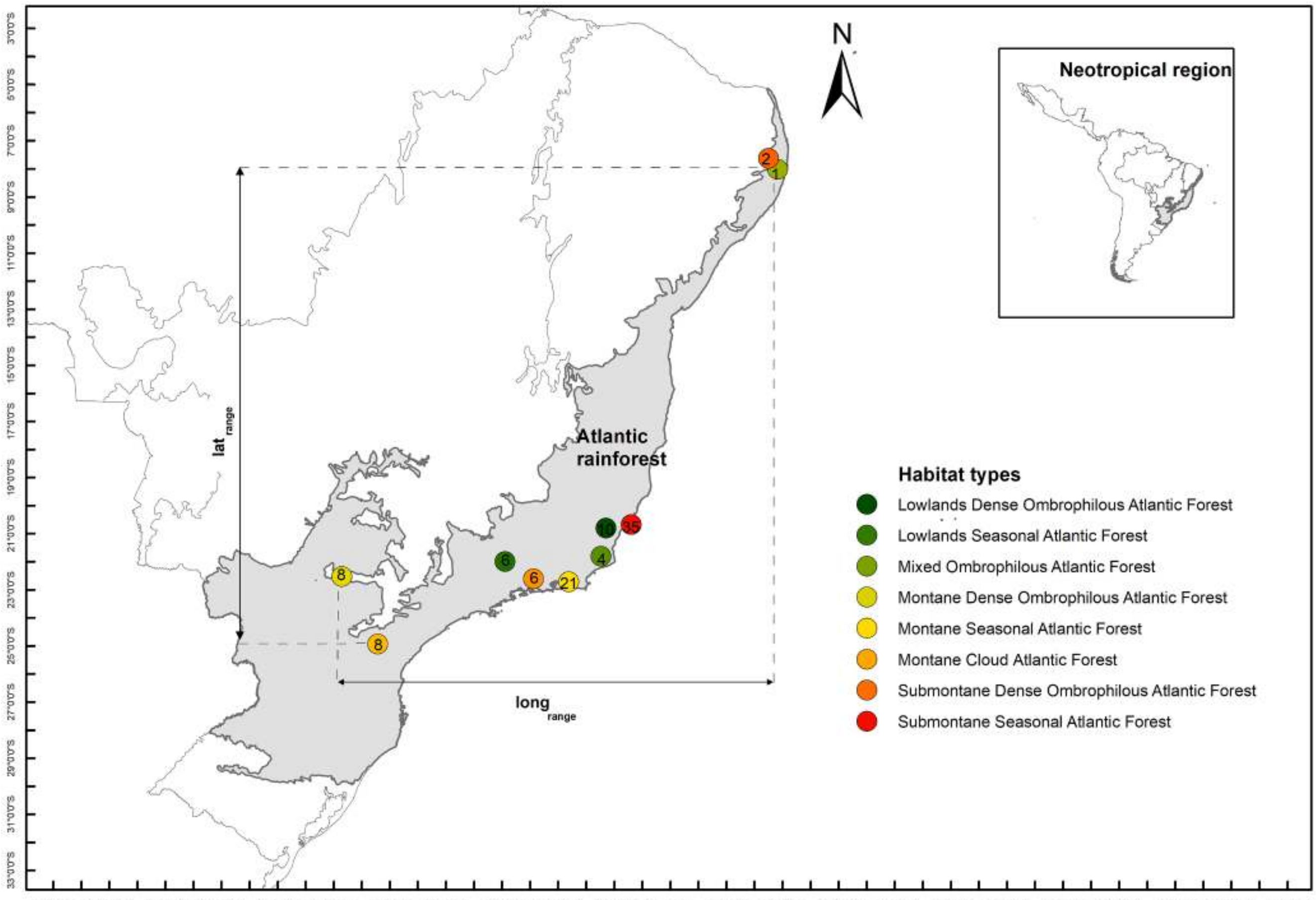

Fig. 1. Scheme showing Rabinowitz's parameters. The circles are the records of the *Guapira opposita* (Vell.) Reitz species in the Atlantic rain forest. The dashed lines are used to indicate the latitude (latrange) and longitude range (longrange) of the species' records. The colours show the different types of habitat in which *G. opposita* was found. The number inside is the population size of the *G. opposita* per one hectare site, with the maximum population size.

specialists, and a third group occurred in both types of vegetation (Maciel et al., 2016). Habitat is applied on a local scale (Borges, 2006) as well as on a micro (Fattorini, 2013). Once the habitat scale has been defined, the maximum number of habitats containing the species will be used as a parameter of its specificity (Fig. 1).

Population size is a local scale parameter. Traditionally the parameter was quantified based on the number of individuals (Rabinowitz, 1981), such as singletons (when a species is represented by one specimen) and doubletons (Caiafa and Martins, 2010; Maciel and Arlé, 2020; Maveety et al., 2011; Pitman et al., 1999), but body size (Mims et al., 2018) and density of a species (Wiegand et al., 2020) have also been considered as parameters to quantify rare species. Different population size measures have different advantages and disadvantages (Magurran, 1988), and this article does not intend to indicate the best measure. The best indicator of population size can be chosen according to the species under study. The objective here was to classify the species of a community in relation to the maximum population that it could have reached anywhere (Rabinowitz, 1981). The analysis scale can also be used based on the study organism. Considering the number of individuals per species as an example (Fig. 1), the maximum population can be measured relative to an area of different sizes.

Although Rabinowitz's method has been employed in a variety of ways (Espeland and Emam, 2011), she proposed a work approach based on the three parameters described above, geographic range, habitat specificity, and population size (Rabinowitz, 1981). These three Rabinowitz parameters can be thought of as three dimensions (Fattorini, 2014). Originally, it was proposed that these three dimensions were combined into eight categories of species (Rabinowitz, 1981). Some researchers use the traditional approach, which combines Rabinowitz's three parameters to classify the species of the community into seven forms of rarity, and a common form (Caiafa and Martins, 2010; Fattorini, 2010a; Rey Benayas et al., 1999; Toledo et al., 2014; Yu and Dobson, 2000). Others researchers have used Rabinowitz's parameters as a starting point to provide a kind of index or score of rarity (Betanio and Buenavista, 2018; Pritt and Frimpong, 2010; Williams, 2000). A more detailed account of indexes or scores is given in the following section.

2. Measures of rarity after Rabinowitz

Seeking to reach a more thorough understanding of approaches using Rabinowitz as an index or score, a literature survey for published studies from 1981 to 2020 was carried out. The focus of this research was mainly on the literature produced using the terms "index of rarity" and "scores of rarity". The search was made through Google Scholar's advanced search engines (details of the search in Supplementary Material). This research retained only studies that reported a rarity measure ranging from 0 to 1 (Fattorini, 2006a; Leroy et al., 2014) or from 0 to 100 (e.g. Cogălniceanu et al., 2013; Ouédraogo et al., 2017). Due to the scores linking rarity to priority class (Le Berre et al., 2019) and addressed rarity in International Union for Conservation of Nature's scope (Palazy et al., 2012) are conceptually different to those in the proposal of this paper, they were omitted from the review. After this refinement, 33 studies that had reported some index or score for the first time, or that used an existing index was retrieved (Table S1).

Selecting rare species based on the three dimensions proposed by Rabinowitz has been advocated (Fattorini and Di Giulio, 2013; Hartley and Kunin, 2003), and so one of the most relevant questions is whether the studies consider all the Rabinowitz parameters. According to my analysis, only 18.18% of 33 studies used the three dimensions, 24.24% used two parameters, and 57.58% used only one of them (Table S2). When only one parameter was considered in these studies, 45.45% used the geographic range (e.g. Bagella et al., 2009; Chantepie et al., 2011; Hodgson, 1993; Leroy et al., 2013), 9.09% population size (Acosta et al., 2009; Astudillo-Scalia and de Albuquerque, 2019; Siqueira et al., 2012) and 3.03% used habitat specificity (Crain et al., 2015). For example, geographic amplitude was used to create a rarity index ranging from 0 (widespread species) to 100 when a species was rare (Cogălniceanu et al., 2013). In some cases, a unique parameter is partitioned to capture different scales (Betanio and Buenavista, 2018; Borges et al., 2000). For example, the geographic range was partitioned into local distribution, phytogeographical distribution within sub-continents, and phytogeographical distribution globally (Betanio and Buenavista, 2018). This demonstrates that many studies tend to reduce rarity to only one or two Rabinowitz' dimensions (Rabinowitz, 1981).

Rabinowitz did not originally assign weights to any parameter, but my analysis revealed that 42.42% of the 33 studies had performed some weighting in one or more parameters (e.g. Astudillo-Scalia and de Albuquerque, 2019; Chantepie et al., 2011; Chifundera, 2019; Crain et al., 2015). Attempts to highlight a species characteristic meant that some studies increased the weight of one of the parameters (e.g. Perrin and Waldren, 2020; Potter, 2018). For example, the weight of some rarity indexes were increased so as to also increase the importance of species with a small population size (Perrin and Waldren, 2020) or restricted geographical range (Potter, 2018; Roselaar et al., 2007). In some case, three indexes of rarity were created separately for each of the three Rabinowitz parameters, and then weighted by only one of them (Godet et al., 2016). Rarity was also weighted by the total richness of the community (Astudillo-Scalia and de Albuquerque, 2019; Fattorini, 2010b; Villaseñor et al., 2006), which results in a final rarity measure dependent on the total richness.

To avoid the rarity index being inflated by the effect of the correlation between parameters, some approaches used down-weighting (Leitão et al., 2016; Trevelin et al., 2017). Down-weighting tends to decrease the final weight of parameters that are correlated (Kark et al., 2002; Leitão et al., 2016). The correlation control in this case could present some disadvantages. Consider a species that is both geographically restricted and a habitat specialist: applying a down-weight is supposed to decrease the final value of this species. Many lines of evidence support the idea that species in one or more of the following categories are more prone to extinction: restricted geographical range, small population size, or habitat specialist (Harnik, 2011; Kéry and Matthies, 2004; Purvis et al., 2000; Staude et al., 2020). These rare species characteristics may respond synergistically (Charrette et al., 2006; Davies et al., 2004), as shown by an experiment in Australia, which found a greater decline in species that were simultaneously habitat specialists and of small population size (Davies et al., 2004). Conversely, generalist habitat species with large population sizes presented less decline (Davies et al., 2004).

Rare species are becoming important in conservation biology and other fields, and so the methods used to measure rare species should be clear for scientists and decision-makers. The description of any rarity measure should thus follow some basic points for applying any method. Two general points are: (1) the description of a method should ensure the diversity of users who may be interested in it (Christian, 2003; Hoefnagels, 2005), and (2) to make it possible, a method must provide the detail and information necessary to ensure replication in an easy way (Culina et al., 2020; Duursma, 2011). The other point (3) is the availability of open code in R language or similar, raised as of particular importance for advancement in the ecology field (Culina et al., 2020). A scrutiny of the methods of the 33 studies revealed that 66.67% use mathematical equations to describe rarity. While some studies provide an explanation of each parameter and make their approaches more accessible for replication, other studies simply cite the parameter used to classify rarity (Bagella et al., 2009), and consequently, the method will probably be difficult to replicate. Only one of the analysed studies (Leroy et al., 2012) had an open code in R language for one of the published indexes (Guisande, 2017).

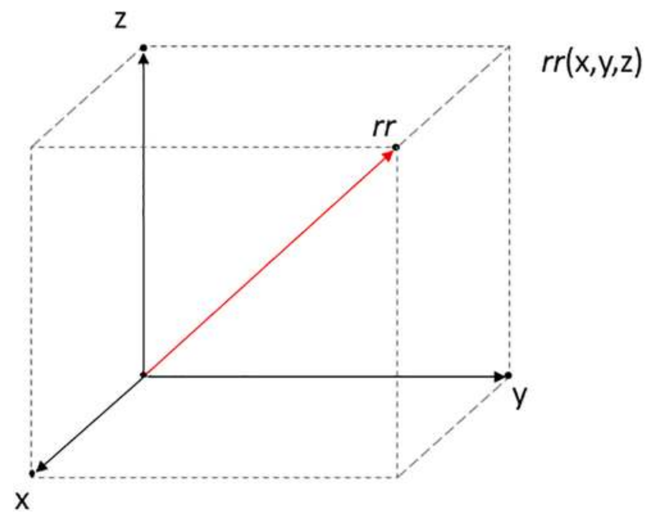

Fig. 2. The scheme of Rabinowitz' three-dimensional space. The x, y, and z axes represent the three parameters of Rabinowitz. The red axis in the central space represents the synthesis of the three dimensions (here, *rr* index). (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

In summary, the scores and indexes published omit three important issues. The first two issues make the index conceptually different from Rabinowitz's approach. Because the three dimensions of Rabinowitz have been advocated for quantifying rarity, reducing rarity to less than three dimensions is the main issue missing in the published indexes. The second issue involves the use of down-weighting and up-weighting in one or more rarity parameters. The third is a general issue about the lack of procedure followed by an open code for the rarity method application. All the papers analysed presented one or more of the three issues mentioned here.

3. Proposal for the rarity index

Propose a synthetic rarity index. This is not the first proposal for a rarity index but at least three elements make it different from the others. This index tried to keep as close as possible to the Rabinowitz concept. (1) the three dimensions of rarity proposed by Rabinowitz were considered, and (2) assigning weight to any dimensions was avoided here. (3) It's an easy-to-follow approach, with an R code step by step. To maintain the simplicity of Rabinowitz's method, this index is not a complex index with many mathematical equations. The present rarity index (*rr*) will follow the same reasoning as Rabinowitz when considering the three dimensions that she proposed (Rabinowitz, 1981). Here, each of the three dimensions represents a continuous space, that could be represented as three axes which together shapes a three-dimensional space (Fig. 2).

Each dimension limits species in different ways. Thus, the same species could occupy a narrow part of one dimension and at the same time be widespread in another one. The combination of the three dimensions shapes a complex three-dimensional space occupied by a species. The rr index is a central axis that catches the three-dimensional space. Mathematically, this index may be expressed as follows:

$$rr = \sum_{i=1}^{3} \bar{x}_i \tag{1}$$

Table 1
Data matrix required for rarity index calculation. The study area (CodArea), name of species (spp), geographical coordinates in decimal degree (lat and long), the name of habitat (habitat) and abundance per site or plot (abundance).

CodArea	spp	lat	long	habitat	abundance
area6	*Abarema brachystachya*	−19.6167	−43.4	Montane Seasonal Atlantic Forest	1
area5	*Abarema cochliacarpos*	−22.6167	−43.8833	Montane Seasonal Atlantic Forest	2
area4	*Abarema langsdorffii*	−28.7333	−49.75	Montane Dense Ombrophilous Atlantic Forest	2
area10	*Abarema langsdorffii*	−21.9992	−43.8908	Montane Dense Ombrophilous Atlantic Forest	2
area1	*Abarema limae*	−20.7983	−41.2928	Submontane Seasonal Atlantic Forest	20
area12	*Acca sellowiana*	−27.8161	−50.3242	Mixed Ombrophilous Atlantic Forest	8
area4	*Actinostemon concolor*	−28.7333	−49.75	Montane Dense Ombrophilous Atlantic Forest	49

where $\bar{x}$ is the mean of *x, y* and *z*. The *x, y* and *z* are the Rabinowitz' rarity parameters, respectively, the geographic range (*gr*), the habitat specificity (*hs*), and the population size (*ps*). Note that rr assume that the Rabinowitz' rarity parameters are subsets (Z*) of the natural numbers (Z). Thus, it was concluded that Rabinowitz' rarity parameters are Z* ($N \subset Z > 1$). Accordingly, for any species observed in a time and space, the value of these parameters could vary from 1 to ∞. In order for rare species have a final index that is higher than common species, an inverse sequence of natural number was applied in each parameter. The index for each parameter can be expressed mathematically as $1/x$, a procedure that resembles the inverse Simpson index (Hill, 1973; Jost, 2006; Simpson, 1949). This approach using the inverse of the parameters is simple and widely used in the scientific literature for rarity measures (e. g. Bergerot et al., 2008; Borges et al., 2005; Chantepie et al., 2011; Chiatante and Meriggi, 2016; De la Montaña et al., 2011; Diniz-Filho et al., 2005; Fattorini, 2006b; Herzog and Kattan, 2011; Kerr, 1997; Rey Benayas and de la Montaña, 2003; Roselaar et al., 2007; Trevelin et al., 2019; Williams et al., 1996). This operation enabled the calculation of an inverse index for each Rabinowitz' rarity parameter (from now on, *gri, hsi, and psi*), as shown below.

The *gri* is calculated from the inverse of the sum of the latitude and longitude intervals as follows:

$$gri = 1/\left\{\left[\left(lat_{range}\right)^{*}\left(long_{range}\right)\right] + c\right\} \tag{2}$$

where lat_{range} is given by the range of the two extreme latitude points of a species and $long_{range}$ is given by the range of the two extreme longitude points of a species. Since some species could have a latitude and longitude of no more than 0, the constant c = 1 is added to avoid the sum of lat_{range} and $long_{range}$ being < 1.

The habitat specificity index (*hsi*) was given by the inverse of the maximum habitat number (h_{max}) where species *i* is found. The *hsi* was calculated as follows:

$$hsi = \frac{1}{h_{max}} \tag{3}$$

The population size index (*psi*) was given by the inverse of the maximum population (p_{max}) of species *i*, presented anywhere. The *psi* was calculated as follows:

$$psi = \frac{1}{p_{max}} \tag{4}$$

The above steps provide four indices (*gri, hsi, psi*, and *rr*). All of these measures range from 0 to 1 (e.g. Palmer et al., 2002; Guisande, 2017), which has the advantage of making indexes comparable between themselves and with other variables on the same scale. The closer the index gets to 0, the more common the species; conversely, the closer it gets to 1, the rarer the species. The *rr* index corresponds to the basic average as calculated using *gri, hsi,* and *psi* values. For a species to have a final rr of 1, it must have a geographic range of 1, only occur in 1 habitat and population size 1 max, respectively. If, on the other hand, a species has a geographic range of 2, occurs in 2 kinds of habitat, and a population size of 2 max, it will have a rr of 0.5. The higher the value of each parameter, the small the final rr a species will have.

4. Implementations of 'rrindex' package

To make *rr* easy-to-follow, a package in the R environment called 'rrindex' (R CoreTeam, 2019) was created. This package consists of three functions: 'rareindex', 'rareboxplot', and 'rareplot'. The idea behind the 'rareindex' function is to obtain the geographic range index (*gri*), habitat specificity index (*hsi*), and population size index (*psi*). The 'rareindex' function operates in five steps: (1) the first procedure in the 'rareindex' workflow creates a list of species with unique values (*spp.*); (2) using the *gri* calculation for each species, lat_{range} and $long_{range}$ are calculated, then the function multiplies lat_{range} by $long_{range}$ resulting in $latlong_{range}$, and adds the constant 1 to it, resulting in $latlong_{range} + 1$ then the *gri* is calculated by taking the inverse of the $latlong_{range} + 1$ ($1/ latlong_{range} + 1$); (3) in the *hsi* calculation for each species, the function returns the maximum habitat number (h_{max}), divides $1/ h_{max}$, and returns the *his*; (4) for the *psi* calculation for each species, the function looks for the maximum population size in the sample (p_{max}), then divides $1/p_{max}$, and returns the *psi*; and (5) the function then sums the *gri, hsi*, and *psi* values to provide an average between them (*rr*).

The 'rrindex package' provides 'rareboxplot' and 'rareplot' functions in order to explore the index made in the last command. These two functions bring nothing new to the data programming field. They create a visualisation tool for exploring the indexes using the default boxplot function to extract descriptive statistics using the median and percentile, and a default scatterplot function (Becker et al., 1988; Chambers et al., 1983) to extract the indexes' distribution pattern by species. For each index, the 'rareboxplot' draws a box extending from the 25th percentile to the 75th percentile. The 50th percentile drawn inside the box is the median. The 'rareplot' function uses the basic functions of R: 'par (mfrow)' and plot. It then uses the 'par(mfrow = c(2,2))' function (Becker et al., 1988) to split the graphic into four windows. The plot function is then used to create four scatterplots from the index distribution against species.

The 'rrindex package' requires a data matrix with a series of parameters (Table 1). These parameters are the same as proposed by Rabinowitz (Rabinowitz, 1981) recently used to create a R package to classify the seven forms of rarity into the community 10. The first parameter is a list with the name of the species as a factor, for example, 'Ziziphus joazeiro'. The name of each species can appear in the list more than once. The second and third parameters are numeric vectors containing the information for latitude and longitude where the species was registered, which are normally linked to a sample area. This geographic information must be in the decimal degree format. The fourth parameter is of the string type, and represents the variable population size of the species in a given area. The fifth and last parameter is a factor containing information on the type of habitat in which the species was collected. It can be just a word, for example, 'savanna', but it can also be a composite name with more refined habitat characteristics, such as 'low land savanna'.

5. A practical example in the rrindex package

An R routine containing the steps needed to apply the 'rrindex' is available in the supplemental material S1. Because the 'rrindex package'

Table 2
Data format after entry in R. The name of species (spp), geographical coordinates in decimal degree (lat and long), the name of habitat (habitat) and abundance per site or plot (abundance).

parameter	Description	Data structures
spp	"Ziziphus joazeiro"	factor
lat	−24.4444	numeric vectors
long	−50.000	numeric vectors
habitat	"savanna" or "Lowlands Seasonal Atlantic Forest"	factor
abundance	3 (ind.ha −1 or body mass)	integer factor

Table 3
The output provides by 'rareindex' function, as a species list (*spp*), geographic range index (*gri*), habitat specificity index (*his*), population size index (*psi*), and rr index (*rr*).

spp	gri	hsi	psi	rr
Ocotea minarum	0.999	0.5	0.5	0.666
Pouteria gardneriana	0.999	0.5	0.5	0.666
Aniba firmula	0.995	0.5	0.5	0.665
Eugenia brasiliensis	0.995	0.5	0.5	0.665
Vernonanthura divaricata	0.999	0.5	0.333	0.611
Piptadenia gonoacantha	0.883	0.5	0.333	0.572
Alseis pickelii	0.999	0.5	0.2	0.566
Chomelia sericea	0.999	0.5	0.142	0.547
Guapira graciliflora	0.999	0.5	0.125	0.541
Coussarea verticillata	0.999	0.5	0.076	0.525
Miconia buddlejoides	0.997	0.5	0.076	0.524
Miconia urophylla	0.999	0.5	0.062	0.520

is available at the GitHub server https://github.com/evertonmaciel/rrindex, the first step is to install the 'devtools' and 'usethis' packages (Wickham et al., 2020; Wickham and Bryan, 2020), as shown in the instructions below. After depositing 'devtools' into your library, go to git using the next command, to download the 'rrindex package'.

```
> install.packages("usethis")
> library(usethis)
> install.packages ("devtools")
> library (devtools)
> devtools::install_github (evertonmaciel/rrindex)
> library (rrindex)
```

A case study approach was used to analyse the applicability of the 'rrindex' and the functions to calculate it. This case study used a real dataset with 12 areas of the Atlantic rainforest as an example (Table S2). Details of this dataset can be found in Maciel and Arlé (2020). This dataset comprises a code area (optional), species list per area, latitude and longitude information, the name of the features of each area, and the number of individuals per species. The parameters ranged as follows between species: the latitude from −28.73333 to −7.6333 decimal degree, the longitude from −50.715556 to −35.174167 decimal degree, the habitat number where the species could occur from 1 to 8, and the number of individuals per area from 1 to 1,062 individuals. It is important that the data follows the format proposed below (Table 1). When running the next command below, the result must be a dataframe, as shown in the following Table 2.

```
> summary (data)
```

After the 'rrindex package' is loaded, and the data matrix has been imported into R, the next step is to compute the 'rrindex' itself using the command below.

```
> result <- rareindex (data)
```

The output of this function is a matrix with five columns, containing the following parameters for each species: *spp, gri, hsi, psi* and *rr* (Table 3).

Once the indexes are calculated, the command below is used to build the boxplot and scatterplots, respectively. The box plots in Figs. 3 and 4 are constructed from Data Table 3.

```
> rareboxplot (result)
> rareplot (result)
```

6. Discussion

For the data set analysed here, the 'rareindex' function was able to return the list of all the species from the input data and their respective values of *gri, hsi, psi*, and *rr*. The values of *rr* ranged as follows: *gri*, from 0.026 to 1; *hsi*, from 0.166 to 1; *psi*, from 0.02 to 1; and *rr*, from 0.22 to 1 (Fig. 2). According to the results provided by the function, 471 species (60% of total species) had a *rr* above the average (*rr* = 0.63) measured for all species (n = 689). A study that used the Rabinowitz method, according to the traditional approach, showed that 58.9% of the tree species of Atlantic rainforest were rare (Caiafa and Martins, 2010). The percentage of species with rr above rr average rarity value was therefore close to the percentage of rare species (all form of rarity of Rabinowitz) already classified in the same biome.

One limitation of the *rr* is that it is too simplistic to capture the complexity of rarity. For example, the population size of a species here is given by the inverse of the maximum population (i.e. individuals number) that a species could have anywhere. Two reasons led me to choose a simplistic way to propose this index. The first is fidelity to Rabinowitz's approach. Rabinowitz's method is simply the result of the combination of three measures, so the greater the alteration in the index, the further away from Rabinowitz's approach the index will be. The second is an attempt to make the index applicable to everyone who wants to use it. Rare species have become the focal species for conservation in the field of biodiversity conservation. In this sense, a simple

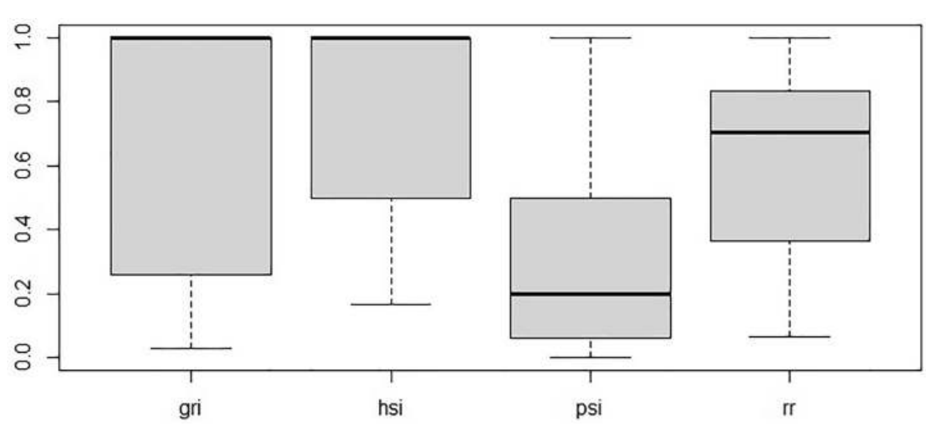

Fig. 3. Boxplot provide by 'rareboxplot' function. Indexes values range from 0 to 1 (y-axis). The indexes are presented in the x-axis as *gri* (geographic range index), *hsi* (habitat specificity index), *psi* (population size index) and *rr* (rare index). The median (black line) breaks the species down into two groups. The above-median index is the species group with the highest rarity index, and below it less index value.

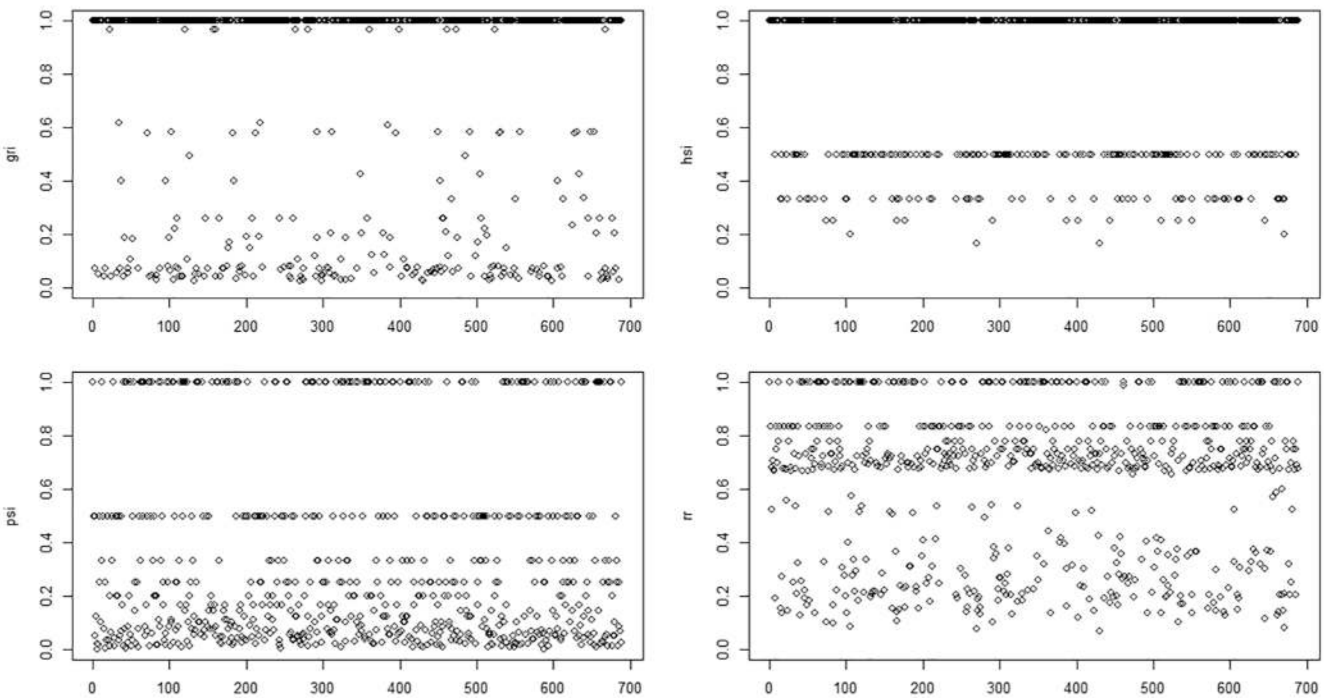

Fig. 4. Scatterplots provide by the 'rareplot' function. The indexes values range from 0 to 1 (y-axis). The indexes are presented in the y-axis as *gri* (geographic range index), *hsi* (habitat specificity index), *psi* (population size index) and *rr* (rare index). The species are present on the x-axis (n = 689).

approach can reduce the gap between science and decision-making.

There are many ways in which this index can be applied. Some questions involving rarity include, for example, the relationship between the age and rarity of taxa. This question has already been addressed using abundance as an aspect of rarity (Schwartz, 1993). Another challenge is to try to understand how rarity can be associated with risk of extinction. These questions have already been addressed using geographic range or population size as a variable response. The index proposed here provides the ability to test this and other questions from the synthesis of three parameters (geographic range, habitat specificity, and population size) that are already recognised as important aspects of classifying rare species in a community of different taxa. In turn, this index has several applications in the field of ecology and conservation biology.

7. Conclusions

Rabinowitz left an incredible legacy for science by introducing the seven forms of rarity. The method requires only three parameters that are commonly collected in ecological studies. Here, the three parameters of Rabinowitz were used to create three measures: geographic range index (*gri*), habitat specificity index (*hsi*), and population size (*psi*). Then these three measures were combined to create a synthetic index of rarity called *rr* for classifying rare species of the community. The main characteristics of the index are: (1) it is a synthesis of Rabinowitz's three rarity dimensions, (2) the three parameters have equal weights, and (3) a simple mathematical description and an open code in R language are provided. This index is robust due to it operates on both a local and regional scale. This index can make Rabinowitz's method applicable to a greater range of possibilities than those already observed in the literature.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.ecolind.2021.107424.

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