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Rare7: An R package to assess the forms of rarity in a community

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ABSTRACT

Avoiding extinction rate is a challenge for scientists and decision-makers. In turn, identifying vulnerable species is a key step towards a consistent strategic planning and programming for species conservation. Rare species are of great interest to scientists because they are more prone to extinction. Rabinowitz proposed that rarity arises from the combination of three parameters: (1) geographic range, (2) local abundance, and (3) habitat specificity. By combining these parameters, the species of a community can be classified into seven forms of rarity. Many authors report the forms of rarity as a priority species for conservation. However, almost 40 years after it was first proposed there are no tools to apply this method. To remedy this gap, we propose the Rare7 package. Here, we provide an automated application of Rabinowitz's method to assess species rarity within a community. Rare7 present some advantages such as easy-to-follow instructions, robust methods, flexibility, applicability for different taxa, and a wide scale of distribution. Using the three parameters proposed by Rabinowitz, Rare7 distinguishes between common and rare species in a community. The output provided to Rare7 is a list comprising the species names and their respective classification as common or one of the seven forms of rarity of Rabinowitz. Because rarity precedes extinction events, Rare7 can be a powerful tool to planning species conservation.

1. Introduction

Avoiding species extinction is one of the main aims of biodiversity conservation (Ricketts et al., 2005). Flagging vulnerable species is a key step to preserve biodiversity. Rare species have attracted the attention of several enthusiastic researchers because species rarity is believed to be a step before extinction (Kricsfalusy and Trevisan, 2014; McIntyre, 1992; McKinney, 1997; Mouillot et al., 2013; Synge, 1980). The extinction risk of rare species is influenced by manifold drivers, including small population size, seed dispersal limitations, capacity for clonal spread (Duncan and Young, 2000) and restricted geographic range (Gaston and Fuller, 2009). Although they may disagree on the cause, several authors agree that rare species should be taken into account in conservation strategies (Kricsfalusy and Trevisan, 2014; Maciel et al., 2016; Mehlman et al., 2004).

In order to categorise species as common or rare, Rabinowitz (Rabinowitz, 1981; Rabinowitz et al., 1984) proposed an approach to classify the species of a community into seven forms of rarity. Rabinowitz's method is interesting because it is easy to follow, flexible in framing different situations, combines parameters across spatial scales, and provides a list of the rare species of a community. The classification process relies on a matrix organised along three axes: 1) geographic range, 2) habitat specificity, and 3) local abundance (Broennimann et al., 2005; Caiafa and Martins, 2010; Espeland and Emam, 2011; Yu and Dobson, 2000). Each axis represents one variable indicating whether a species should be considered as rare or common. The geographic range axis classifies species as restricted (stenotopic) or widely distributed (eurytopic). The habitat specificity axis classifies species as occurring only in a specific habitat (stenoecious) or in various habitats (euryoecious). Finally, the number of individuals classifies species in small populations, where there are only one or two individuals in a sample (singletons and doubletons), and large populations, where there are more than two individuals. Because of this combination, rare and common species of a community can be identified.

Studies in different parts of the world have provided empirical evidence that the Rabinowitz method works. Studies on plants have been conducted on the wet grassland habitats of the Sierra de Guadarrama in Central Spain (Rey Benayas et al., 1999), the flora of Norway (Sætersdal and Birks, 1997) and Switzerland (Broennimann et al., 2005), the Amazonian flora of Manu, Peru (Pitman et al., 1999) and the Brazilian Atlantic rainforest (Caiafa and Martins, 2010). There are also applications of the Rabinowitz method in studies on various animals, including mammals (Yu and Dobson, 2000), birds (Kattan, 1992) and arthropods (Fattorini et al., 2012). However, although there

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has been great interest and concordance about the Rabinowitz method, a tool to automatically classify all seven forms of rarity does not exist.

Here, we provide the first R tool to classify rare species according to Rabinowitz's method. Because Rabinowitz's method is a well-accepted approach to assess rarity, and considering that rarity is related to species vulnerability, the development of an automated tool based on this method is valuable for several reasons. First, a standardised tool helps to avoid mistakes, as the Rabinowitz method involves many procedural steps, it is prone to human error. Second, it reduces the manual effort required for species classification, particularly in situations like tropical regions. Third, although the method is easy to apply, some combinations are required, making the process more complex and time consuming, therefore, an easy-to-follow tool is useful. Finally, we hope that our tool broadens the application of the Rabinowitz method.

2. The Rabinowitz method: how can rare species be selected

The Rabinowitz method uses three parameters (geographic range, habitat specificity and population size) to classify rare species. Geographic range is a parameter of regional scale, while the other two are local (Rabinowitz et al., 1984). The combination of the three parameters results in the classification of a species as common or as one of seven forms of rarity (Table 1).

2.1. Geographic range

The Geographic range is a biogeographic parameter. Therefore, the total amplitude of species distribution should be considered. On a large scale, different variables such as temperature and precipitation, among others, can shape species distribution (Condit et al., 2013; Gaston and Fuller, 2009). According to the niche theory, these factors limit species distribution in different ways (Grinnell, 1917). As a result, some species may have a narrower distribution range than others. A comprehensive study of 973 species in the Netherlands, of which 190 were considered rare (Wamelink et al., 2014), concluded that rare species tend to have a narrower geographic range in response to 19 of 20 abiotic factors (e.g., soil phosphorus level, pH). Taking into account that species with a restricted geographic range are more vulnerable to extinction (Abbitt et al., 2000), the geographic range parameter is used to distinguish restricted from widely dispersed species. Originally, species that occurred in 10% of the study area were considered restricted (Sætersdal and Birks, 1997). In other cases, the number of latitudinal belts was used to assign the same classification (Caiafa and Martins, 2010). Here, we propose that the area of occurrence be calculated based on the latitude at which the species occurs. Thus, classification of the rarity of a species according to latitude range would be determined based on the maximum species distribution. Therefore, the extremes of latitude would be used to classify a species.

2.2. Local population size

On a local scale, the species niche is limited by biotic interactions (Elton, 1927). Rare species are likely to be at a great disadvantage when compared to high competitor species (Rabinowitz et al., 1984). As a result, some species will have a small population (Price and Kirkpatrick, 2009). The number of individuals per unit area is a measurement used to characterise population size (Guo, 2003). According to the Rabinowitz method, species should be classified as rare when there are only a few individuals on a local scale. Plant populations are identified as scarce when a small number of individuals (one or two) of a species are sampled in one plot, while species with many individuals in a plot are considered abundant (Caiafa and Martins, 2010; Pitman et al., 1999). For rare animals, the population size can be measured by the number of occurrences of a species recorded during visits to a particular site (Simaika and Samways, 2011). Species recorded only a few times are classified as scarce, while species recorded regularly are abundant. It was recently recognised that the majority of species in different taxa are singletons, and these species should be considered with caution (Lim et al., 2011). Therefore, to quantify local rarity, we considered scarce populations as those represented by only one individual (singletons) or two individuals (doubletons).

Table 1
The scheme to classify of the seven forms of rarity of Rabinowitz.

Geographic distribution	Wide		Restricted	
Habitat preference	Various	Single	Various	Single
Abundant population	common	Form 2	Form 4	Form 6
Scarce population	Form 1	Form 3	Form 5	Form 7

2.3. Habitat specificity

The habitat can be phytophysiognomies such as woodlands, scrub, savanna, steppe, deserts, and aquatic habitats (Yu and Dobson, 2000). Different species choose different kinds of habitats, and many species occur in just one of the many habitats within a region (MacArthur, 1960). Due to human pressure and stochastic factors, some habitats change to a greater degree and can be lost (Krauss et al., 2010; Spielman et al., 2004; Wilson et al., 2005). As a result, habitat specialist species are at greater risk to be lost (Munday, 2004). For this reason, it has been argued that habitat specialist species are more vulnerable than habitat generalist species, and that they should be considered with care in any relevant decision making (Maciel et al., 2016). Therefore, it aims to identify species that only occur in specific habitats.

3. Specification

Our package provides three functions (rareData, rarityForms and rarePlot) that work hierarchically. These functions are sufficient to classify the species into the seven forms proposed by Rabinowitz (1981). Below, we describe the functions and their outputs.

The first procedure in the 'rareData' workflow uses the space between the lowest and highest latitudes to quantify the range of a dataset. The function uses only the latitude degrees to quantify geographical range. The occurrence of all species is considered here. We report this as the sampled area, and the output is a numeric vector 'Sample_area', representing the total geographic area of a dataset. The second procedure in our workflow provides the number of latitudinal belts in which each species are present (Caiafa and Martins, 2010). The output from this is the numeric vector 'Detection_area', representing the total geographic range of a species in a region.

In the next step, 'rareData' seeks the greatest abundance of each species present at a site. A site is a row that contains the number of individuals of each species. The scale size is not a problem for this method. For example, the size of the site used to quantify rarity can range from 0.8675 to 2.5 ha (Pitman et al., 1999), and an abundance in grid cells of 1×1 degree has previously been used. Otherwise, a smaller scale can be used for abundance measurement, such as a 50×50 m plot (Soliveres et al., 2016). The output is a numeric vector 'Abundance' that represents the maximum number of individuals of a species listed at a site.

The last step in 'rareData' quantifies the number of different habitats where a species occurs. The output is a numeric vector 'Habitat', which represents the total number of habitats that a species inhabits in the dataset. When habitat and abundance data are absent, it should be 0 in the dataset. For these cases, the function will return 'NA' as the output.

The second function, 'rarityForms', uses the output data provided by 'rareData' to classify species into seven forms of rarity (Rabinowitz et al. 1984). The first procedure in the 'rarityForms' workflow uses the 'Sample_area' and 'Detection_area' to quantify the proportional area in

Table 2
Operational parameters to classifying of the seven forms of rarity in our package.

Form of rarity	Geographic range		Population size		Habitat	
	Wide (eurytopic)	Restricted (stenotopic)	Abundant	Scarce (singletons or doubletons)	Various (euryecious)	Single (stenoecious)
Common	> 10%		> 2		> 1	
Form 1	> 10%			≤2	> 1	
Form 2	> 10%		> 2			1
Form 3	> 10%			≤2		1
Form 4		≤10%	> 2		> 1	
Form 5		≤10%		≤2	> 1	
Form 6		≤10%	> 2			1
Form 7		≤10%		≤2		1

Table 3
Basic description of the code and the type of data required in then.

Code	Description	Font
Species	factor containing scientific names of species with or without author's names name (e.g. "*Caryocar brasiliense* Cambess.")	Publish paper or Herbarium data
Lat	numeric vectors with geographic information (e.g. −24.4444)	Publish paper or Herbarium data
NumIndiv	integer factor with the number from individual in a site or plot (e.g. 2 individuals by hectare)	Publish paper
habitat	a factor with habitat names (e.g. "forest") where the species was recorded	Publish paper

which each species occurs ('Sample_area') relative to all area in the dataset ('Detected_area') using the following equation:

$$Geographic\ range = \frac{Detection\_area\ 100}{Sample\_area}$$

Then, it classifies the species into two categories, wide (eurytopic species) or restricted (stenotopic species) geographic distribution. In 'rarityForms', eurytopic species are those that occur in more than 10% of the 'Sample_area' (Sætersdal and Birks, 1997), while stenotopic are species that occur in less than 10% of the area (Table 2).

In next step, the function uses 'Abundance' to classify the species into two categories: scarce population (singletons or doublets), where there are no more than two individuals of a species in the dataset; and large population, where there are three or more individuals of a species (Caiafa and Martins, 2010; Pitman et al., 1999) (Table 2). When NA is the output for 'Abundance', the function returns the message 'no abundance information'. This makes it possible to use data even when abundance information is missing.

The next function uses the character vector 'Habitat' to classify species as specialists (stenoecious species) that occur only in a single habitat, or generalists (euryecious species) that occur in more than one habitat (Caiafa and Martins, 2010; Rabinowitz et al., 1984). Like in abundance, when 'Habitat' information is NA, it reports the notification 'no habitat information'. The output provided by the 'rarityForms' function is a spreadsheet with two columns; the first is a list of the names of several species, and the second is the form of rarity as classified by Rabinowitz.

Additionally, the last function, 'rarePlot', generates graphics for the site with the proportion of the forms of rare species. Below, we provide a practical example of how the functions work. This function accepts three arguments: that the data frame is the same as the input data; rarity forms are generated by the second function; and locality, in this case, is a code from the input data. The output provide by 'rarePlot' is a plotted pie chart showing the proportions of species classified in each form of rarity in a given locality.

4. Using Rare7 package

The Rare7 package is freely available at the GitHub server https://github.com/evertonmaciel/Rare7. To install Rare7, devtools package is required, as in the steps below. Anyways, an easy-to-follow R routine is available on Supplementary material (Table S1).

```
> install.packages ('devtools')
> library (devtools)
> devtools::install_github (evertonmaciel/Rare7)
> library (Rare7)
```

The sort of data required by 'rareData' is a matrix data frame with numeric, integer and factor vectors (Table S2). A list of data sources used in the study are provided in Supplementary material S3. Each entry (row) of the data frame represents necessary parameters for the 'rareData' function to provide an output, and matrix data to use in the second function. Missing data for abundance or habitats should be indicated by 0 in the input data. The first lines of the data frame should include the code stated below (Table 3):

```
> data2 < - rareData (data)
```

The 'rareData' function quantifies the total number of latitudinal belts in the data. The function keeps the name of the species equal to the data input (Table 4). In our example, the total geographic range varies between −28 and −7 degrees of latitude. The function returns the total number of latitude belts, which in this example is 21 latitudinal belts ("Sample_area"). Then, for each species, the command quantifies the number of total latitudinal belts, the maximum number of individuals and the total number of habitats in which the species occurs (Table 4).

```
> summary(data2)
```

'Sample_area' is the total number of latitude belts in our dataset showing the same value in all rows. However, because some species geographically restricted while others have largeranges, the number of latitudinal belts differ in the 'Detection_area' for each species (Table 4). As some species are more abundant than others, and some only occur in a specific habitat, the numbers under 'Abundance' and 'Habitat' will differ between species (Table 4). Because some values for habitat and abundance in the input data were 0, NA values are present in this output. This happened because this specie had no record of abundance in our input database.

```
> sevenForms < - rarityForms (data2)
```

Then, data2 can be used as an input for the 'rarityForms'

Table 4
Data provided by rareData function. This data is required for classify the forms of rarity. Detection_area is a number of latitudinal were species occur. Abundance is a maximum number of individuals that species present in all data input. Habitat is a number of different habitat that species occur.

Species	Sample_area	Detection_area	Abundance	Habitats
Abarema brachystachya (DC.) Barneby & J.W.Grimes	21	1	1	1
Abarema cochliacarpos (Gomes) Barneby & J.W.Grimes	21	1	2	1
Abarema langsdorffii (Benth.) Barneby & J.W.Grimes	21	2	2	1
Abarema limae Iganci & M.P.Morim	21	1	20	1
Acca sellowiana (O.Berg) Burret	21	1	8	1
Actinostemon concolor (Spreng.) MÃ¼ll.Arg.	21	1	49	1
Actinostemon klotzschii (Didr.) Pax	21	1	703	1
Actinostemon verticillatus (Klotzsch) Baill.	21	2	58	2
Adenostemma brasilianum (Pers.) Cass.	21	1	NA	1
Aegiphila brachiata Vell.	21	1	2	1
Aegiphila integrifolia (Jacq.) Moldenke	21	1	4	1
Aegiphila sellowiana Cham.	21	1	10	1
Agonandra excelsa Griseb.	21	1	1	1
Aiouea saligna Meisn.	21	1	3	1
Albizia edwallii (Hoehne) Barneby & J.W.Grimes	21	1	2	1
Albizia polycephala (Benth.) Killip ex Record	21	2	13	3
Alchornea glandulosa Poepp. & Endl.	21	2	4	2

Table 5
The result of our package. Lists of species and their forms of rarity.

Species	Form
Abarema brachystachya (DC.) Barneby & J.W.Grimes	form7
Abarema cochliacarpos (Gomes) Barneby & J.W.Grimes	form7
Abarema langsdorffii (Benth.) Barneby & J.W.Grimes	form7
Abarema limae Iganci & M.P.Morim	form6
Acca sellowiana (O.Berg) Burret	form6
Actinostemon concolor (Spreng.) MÃ¼ll.Arg.	form6
Actinostemon klotzschii (Didr.) Pax	form6
Actinostemon verticillatus (Klotzsch) Baill.	form4
Adenostemma brasilianum (Pers.) Cass.	No abundance information
Aegiphila brachiata Vell.	form7
Aegiphila integrifolia (Jacq.) Moldenke	form6
Aegiphila sellowiana Cham.	form6
Agonandra excelsa Griseb.	form7
Aiouea saligna Meisn.	form6
Albizia edwallii (Hoehne) Barneby & J.W.Grimes	form7
Albizia polycephala (Benth.) Killip ex Record	form4
Alchornea glandulosa Poepp. & Endl.	form4

calculation. This function combines the values of the three parameters to classify the seven forms of rarity. The function returns a list of species and the rarity forms (Table 5). The function keeps the name of the species equal to the input data. Note that some “no habitat information” and “no abundance information” messages are present in our results, resulting from NAs in the data2 input. Using the command below to visualize the results, you may notice that our package is able to classify the species in different forms of rarity. The species in the preceding example (*A. brasilianum*) has not been sorted in any of the rarity forms (Table 5). This is an important facet of our package, which reports the lack of information for a species without compromising the classification of the other species.

```
> summary(sevenForms)
```

Two final products can be generate from our package (a species list or graphics). If the user is interest in making a list of species with their respective forms of rarity, you can save the results using ‘write.csv’. This list is a starting point for management strategies.

Assuming that the database includes many sites, the ‘rarePlot’ function can easily provide a visualisation of the proportion of rare species in each site.

```
> rarePlot(data, sevenForms, locality = “Site1”)
```

This function can be quite useful, for example, to compare different proportions of rare species in each site. The command par mfrow of the R, as in the example below, creates charts with the proportion of species per sites. The output of this function will be a graph that combines the proportions of species by rarity form (Fig. 1).

```
> par(mfrow = c(2,3))
> rarePlot(data, sevenForms, locality = “Site1”)
> rarePlot(data, sevenForms, locality = “Site2”)
> rarePlot(data, sevenForms, locality = “Site3”)
> rarePlot(data, sevenForms, locality = “Site4”)
> rarePlot(data, sevenForms, locality = “Site5”)
> rarePlot(data, sevenForms, locality = “Site6”)
```

5. Discussion

There is several agreement of the seven forms of rarity described by Rabinowitz are more prone to extinction (Broennimann et al., 2005; Caiafa and Martins, 2010; Cofre and Marquet, 1999). However, to our knowledge, a tool that automatically assesses rare species into Rabinowitz seven forms of rarity was still not available. Here, we introduce Rare7, an R package that uses a multiscale approach combining local parameters such as abundance and habitat and regional parameters like geographic distribution.

Time is a scarce resource, therefore, our package is particularly useful as it takes only seconds to sort a list of 797 species. When we manually applied the method using a PivotTable in Excel, it took us circa 70 h to analyse the same data. In addition, the PivotTables were not accurate because they counted ‘NA’ as a habitat. Thus, the data requires additional processing before classification can occur. Furthermore, our package can also help to reduce errors during the classification process.

The package is easy-to-follow, as it only has three functions that operate with few arguments. We prioritised a simple package that could be widely used by people with various knowledge backgrounds, without the need for extensive programming knowledge.

Our package is flexible with regard to data type. Rare7 uses each parameter independently. Thus, a record of occurrence from a herbarium that has no information on abundance, for example, can be used to calculate the geographic range of the species. We prioritised this framework to allow the combination of data from biological collections with survey data.

It has been suggested that rare species are not often identified by

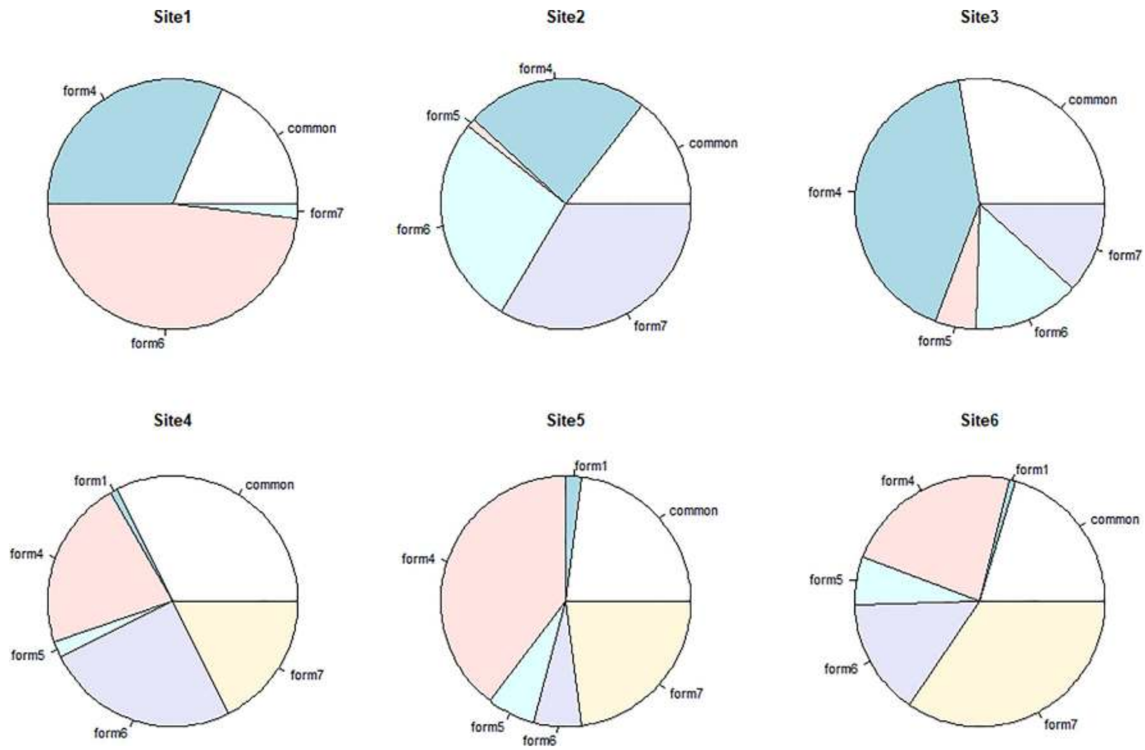

Fig. 1. A graphical example of the forms of the rarity in different study areas. The chart area means the ratio in each form of rarity.

other methods used to classify threatened species (Lõhmus, 2015), such as International Union for Conservation of Nature and Natural Resources (IUCN, 2012). This occurs because rare species end up falling into the deficient data class. However, species with deficient data are more likely to be rare (Corlett, 2016). In this sense, Rabinowitz's method of classification could contribute to the complementary analysis of these methods. Therefore, a tool such as Rare7 can assist in decision making.

At the end of the process, a list of rare species is provided by Rare7. The role of the threatened species list has already been proven in other places. Therefore, to take the rare as the main species group in conservation planning is not the point advocate here. But, once the highlight the 'cornerstone' role that rare species can play on the community (Bracken and Low, 2012), we believe that they can be combined with threatened species (Maciel and Eisenlohr, 2016; Mehlman et al., 2004) for making more efficient conservation planning.

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.2020.106419.

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