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# How to hierarchise species to determine priorities for conservation action? A critical analysis

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## Abstract

Hierarchisation and prioritisation methods represent a crucial step to determine priorities and implement actions in conservation biology: they are required to determine how to allocate available resources to the different components of biodiversity. However, they are very heterogeneous in terms of targets and goals. The main differences are presented with a focus on hierarchisation methods targeting species. This paper reviews 40 studies using 24 different point-scoring or rule-based methods aiming to determine conservation concerns for species. Only the hierarchisation methods targeting species were compared and their differences were highlighted in terms of study area, taxa, criteria assessment and summarisation. Then six different studies using the same hierarchisation method for species were compared as well. This study enables to analyse the different existing methods in order to perform more relevant methodological choices adapted to the objective and the context of each selection process. A consistent framework is designed to help managers to choose an appropriate method using well-defined goals, study areas and taxonomic targets, and take into account data availability.

**Keywords** Hierarchisation · Prioritisation · Methods · Species conservation

## Introduction

Facing a global decline of biodiversity, resources allocated to taxa and ecosystems conservation are usually limited (Myers et al. 2000). Moreover, in the Anthropocene era, an increasingly human-dominated period, species conservation in the wild is becoming more important

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(Stockes 2018). Usually, in situ conservation is only implemented by considering opportunities rather than using a well-defined strategy. Recently, Can and Macdonald (2018) highlighted that conservation policies are solely based on utilitarian considerations when sacred values are concerned (e.g. fundamental beliefs, national and ethnic identities, key emblematic species). Governance affects the way we respond to new knowledge and ultimately what is implemented in a conservation strategy (Wyborn et al. 2016). During those last ten years, emphasis on the integration of science and other fields of knowledge in governance and management has been improved (Armitage et al. 2011). Several studies have examined the intersection between knowledge and governance (e.g. Leach et al. 2010; van Kerkhoff 2013; Wyborn et al. 2016). As financial and human resources are not sufficient to implement conservation actions for all of the biodiversity targets in a given area, it is necessary to set up conservation priorities to direct available resources towards species, habitats, populations or locations which are the most vulnerable (Brooks et al. 2006; Crain and Tremblay 2014; Pullin et al. 2013). In a biodiversity conservation strategy, different steps can be identified (Joseph et al. 2009; Margules and Pressey 2000; Pullin et al. 2013; Wilson et al. 2009). The first step consists in identifying priorities; it can be based on potential threats or on asset values. Priorities can be identified for different assets: areas, habitats or vegetation, species (potentially other taxonomic levels) or populations. The next step is to prioritise conservation projects or actions to be implemented for taxa or areas. The last step consists in choosing and implementing conservation actions, and then in assessing their success.

Priority setting is now a cornerstone of conservation biology (Game et al. 2013): many scientific papers were published over the last 30 years offering methods which led to a proliferation of tools, strategies and guidelines (e.g. IUCN 2012; Mace et al. 2007; Master 1991). Therefore, it can be very difficult for conservation managers to understand the differences between red lists, priority lists and protection lists, and between the numerous methods for determining priorities. In fact, people conducting conservation prioritisations are generally not the same as those making conservation decisions (Game et al. 2013). Consequently, there is often a research-implementation gap between peer-reviewed literature and the implementation of conservation actions (Knight et al. 2008). Andelman et al. (2004) reviewed nine methods for selecting endangered species, Brooks et al. (2006), nine major approaches of global biodiversity conservation prioritisation targeting areas (spatial prioritisation), and Schmeller et al. (2008c), fifteen studies determining national conservation responsibilities for species and evaluating the international importance of a biological population. Despite the importance of this topic in conservation biology, to our knowledge there hasn't been any published comprehensive synthesis of hierarchisation methods for species for 10 years.

Here, we reviewed the scientific literature in order to: (i) examine the different kinds of classification methods for species; (ii) compare the aims of priority lists, red lists and protection lists; (iii) compare 40 studies using hierarchisation methods for species and compare 6 different applications of the same hierarchisation method; and (iv) provide a consistent framework to help managers choose an appropriate method to preserve this level of biodiversity.

## **Concepts of hierarchisation and prioritisation**

### **Definitions**

To hierarchise is a neologism which means to arrange in a hierarchy, i.e. to classify units according to their value or their given importance. To prioritise is also a neologism which

means to arrange in order of priority, i.e. to give a greater or lesser importance to something. Prioritisation is a synonym of priority setting. Consequently, a hierarchisation is based on the idea of order, and can lead to a prioritisation, though prioritisation is not necessarily hierarchical. Hierarchisation is defined as the ranking of habitats, species, populations, or locations according to defined criteria. Prioritisation is defined as the setting of priorities for actions associated with habitats, species, populations, or locations. Here, we considered only hierarchisation methods targeting species.

Hierarchisation or classification methods using specific criteria enable us to rank assets, and then prioritisation methods targeting actions enable us to decide how to allocate conservation resources (Dunn et al. 1999; Mace et al. 2007). Game et al. (2013) consider that only actions can be legitimately prioritised, because prioritisation is about resource allocation, and locations, species or habitats don't use conservation resources, whereas actions do. Therefore, the ranking of species or locations alone cannot be considered a prioritisation (Joseph et al. 2009). However, the word prioritisation is often used to assess species or locations, aside from actions or projects, as highlighted by Game et al. (2013) "Mistake 3: Not prioritising actions".

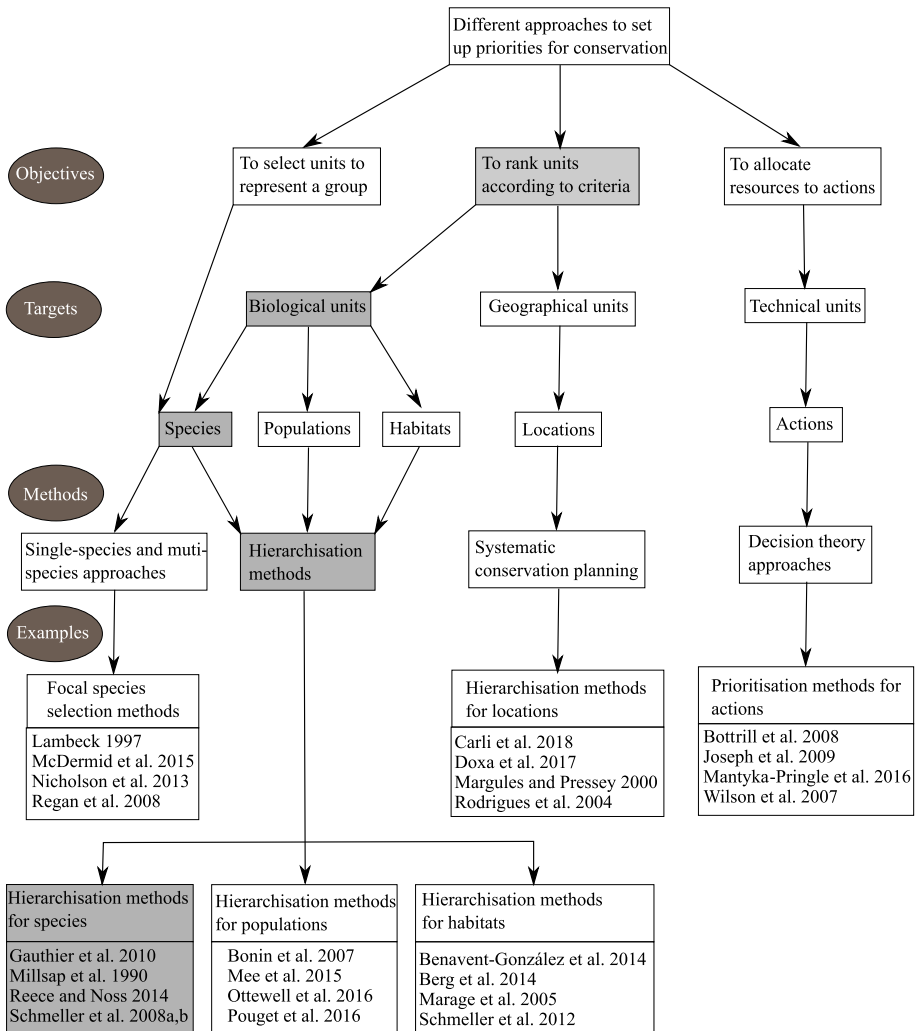
## **Different approaches**

Mace et al. (2007) compared different approaches enabling to set priorities: single-species approaches, multi-species approaches, approaches based on ecosystems or habitats, systematic conservation planning (or gap analysis), species priority setting methods and decision theory approaches (or optimal allocation). Wilson et al. (2009) considered a prioritisation of assets (e.g. species), locations, or actions, whereas Henle et al. (2013) distinguished topical priorities (e.g. species, habitats) from spatial priorities (e.g. geographic areas, geographic populations of a species). Here, hierarchisation and prioritisation methods were classified according to their targets: geographical units, biological units, or technical units. Among biological units, three levels can be distinguished: the ecosystem level (or habitat or plant communities' level), the taxonomic level (mainly species' level) and the populations' level (Fig. 1). In this study we focused only on methods aiming to rank species according to criteria, i.e. hierarchisation methods for species.

## **Different hierarchisation methods for species**

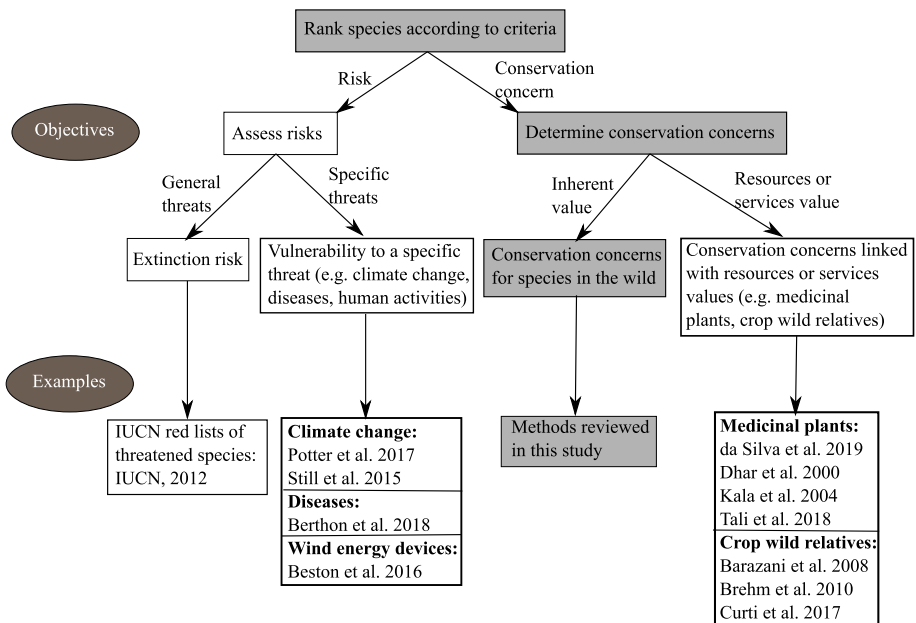
Hierarchisation methods for species have different goals. The most common is risk or threats assessment (Possingham et al. 2002; Schmeller et al. 2008c), for example the red lists of threatened species developed by the International Union for Conservation of Nature (IUCN 1994, 2001). Red lists assess the extinction risk of species (IUCN 2012) and can determine conservation urgency (e.g. Martín 2009). There are also methods assessing other kinds of risks, for example climate change vulnerability, diseases sensibility, and risk from wind energy devices. Moreover, hierarchisation methods can have goals other than risk assessment: for example, determining conservation concerns regarding resources or services values (e.g. crop wild relatives, medicinal plants); or determining conservation concerns for species linked to their inherent value (Fig. 2). Here, we focused only on point-scoring methods and rule-based methods aiming to determine conservation concerns for species in the wild.

Among methods for species, point-scoring methods, rule-based methods, and conservation status ranks methods can be distinguished (Andelman et al. 2004; Mace



**Fig. 1** The different approaches to set priorities for conservation can be distinguished according to their objectives and their targets (in grey: focus of this study)

et al. 2007). In point-scoring methods, scores are assigned to each species according to quantitative criteria, and then added to highlight the conservation priority. Rule-based methods rest on the attribution of pre-established priority groups from quantitative or qualitative criteria, as for example in the IUCN system, based on five quantitative rules highlighting an extinction risk. Conservation status rank methods use qualitative criteria to determine species' threats based on available information and expert opinion. In the reviewed literature, we didn't find any studies using this approach. Rule-based methods usually require less data than point-scoring methods, which require data for each criterion to establish an overall score. Despite various criticisms on reliability and



**Fig. 2** The different hierarchisation methods for species can have different objectives (in grey: focus of this study)

reproducibility of rule-based and point-scoring methods, they are usually considered relevant and useful for species hierarchisation (Andelman et al. 2004).

### Can we use protection lists or red lists to determine species conservation concerns?

Many protection lists were created in the previous decades, when some tools currently used today were not available (e.g. databases, geographic information systems). Therefore, in most cases, protection lists were not based on objectively assessed criteria (but see Abbitt et al. 2000; Crain and White 2011 for examples that do), but rather on expert opinion (e.g. Donlan et al. 2010; Harris et al. 2015). As they depend on political and empirical decisions, these lists can be very different between two adjacent countries or regions. For example in France, the regional protection lists for species have been established by different groups of experts, using different methodologies and different criteria (or only expert opinion), over a period of up to 20 years. Because of this lack of objective methods and geographical cohesion, and because they have different goals, many protection lists can't be directly used to determine species conservation concerns (Jiménez-Alfaro et al. 2010). On the contrary, hierarchisation methods may be used to improve protection lists (e.g. Gauthier et al. 2010; Martín et al. 2010; Schatz et al. 2014) or to complete them by using additional criteria. They may also be used in protected area strategies, and thus contribute to reach the Aichi Targets (Convention on Biological Diversity 2010).

Red lists of threatened species using IUCN criteria constitute a hierarchisation method for species (rule-based method), with a particular goal: to determine species extinction risks in a given area (IUCN 2012). Consequently, IUCN red lists are not a priority list for species conservation, because they were not created for this purpose: extinction risk and

conservation priority, though being linked, are different concepts (IUCN 2012). Moreover, extinction risk assessment could be different according to the method used (Mounce et al. 2017). However, red lists are often mistakenly considered as hierarchical lists of priorities for conservation actions, and thus conservation priorities are mainly or only based on this assessment of extinction risk (Miller et al. 2006). To allocate money based only on IUCN categories is not the most efficient way to help species recovery or to minimise extinction rates, because some of the most highly ranked species require huge efforts with a low success probability, whereas other less threatened taxa might be secured for relatively little cost (Marsh et al. 2007; Possingham et al. 2002). The threat status of red lists doesn't always reflect current conservation needs, especially when it considers a relatively narrow area (e.g. which doesn't cover the whole distribution area of the considered taxa), in which it would be wiser to focus conservation efforts on endemic or sub-endemic species for which territory responsibility will be high (Keller and Bollmann 2004; Schmeller et al. 2008a, b; Warren et al. 1997). Although extinction risk is an essential component of any priority setting system for conservation, it shouldn't be the only one. It is important to take into account other biological, biogeographical, financial, and cultural factors besides extinction risk to maximise the efficiency of conservation actions (Fitzpatrick et al. 2007; Kricsfalussy and Trevisan 2014; Miller et al. 2006; Possingham et al. 2002). However, red lists remain a crucial tool in priority setting for conservation actions, considering the urgency for species that are highly threatened (Fitzpatrick et al. 2007; Rodríguez et al. 2004; Schmeller et al. 2008a).

## **Review of different hierarchisation methods for species**

### **Literature selection**

An analysis of the scientific literature from 1990 to 2018 related to priority setting for species conservation was conducted. Searches were made using the key words “species hierarchisation”, “species prioritisation” and “species priority setting”, sorted by relevance. Unpublished technical reports were not considered here. A large number of papers correspond to these terms, but we selected only the point-scoring and rule-based methods aiming to determine species conservation concerns. We did not consider methods targeting geographical areas, actions or projects, populations, habitats, methods for focal species selection, or hierarchisation methods with a different goal (e.g. extinction risk assessment) (see Figs. 1, 2). Hence, 40 studies about species hierarchisation were reviewed. For each selected paper, the study area, the number and group of targeted taxa, the number and type of criteria used, and the summarisation method were recorded. Among these 40 reviewed hierarchisation methods, more than half were published between 2007 and 2018, which indicates an increasing interest in the subject (see ESM\_1). 33 studies used point-scoring methods, and seven used rule-based methods.

### **Differences and similarities between the hierarchisation methods**

Among the 40 reviewed papers, we distinguished 24 newly published methods, and 16 applications of already published methods. Consequently, six methods (i.e. Avery et al. 1995; Gauthier et al. 2010; Marsh et al. 2007; Millsap et al. 1990; Redding and Mooers 2006; Schmeller et al. 2008a, b) were reused for other studies.

Among the 24 analysed methods, study areas, taxa, criteria number, assessment and summarisation were compared (see *ESM\_2*): 13 (54%) targeted fauna (12 targeted vertebrates, including six birds), nine (38%) targeted flora and two (8%) targeted fauna and flora. These methods were applied to variable numbers of taxa, between 36 and 3255. Ten methods considered all taxa of their targeted group in their study area, whereas 13 other methods considered only some categories of taxa, for example threatened, protected, endemic, rare, vulnerable, or determinant taxa. The two remaining methods did not present a concrete case study, but only a methodological framework. Some of these papers (Gauthier et al. 2010; Marsh et al. 2007) presented two distinct study areas (see *ESM\_2*). Therefore, 26 different study areas were considered. 18 studies (69%) considered administrative areas: nine considered countries, four considered states, two considered regions, one considered a province, one a county, and one a business park (i.e. John F. Kennedy Space Center). Conversely, five (19%) considered biogeographical or ecological areas. The last three respectively considered a river basin, the distribution range of the targeted taxa and the whole world.

The number of criteria used is variable between methods, from 1 to 8, with some including up to 30 different sub-criteria (see *ESM\_2*). The various criteria used can be classified into three principal groups (Table 1): threats (or vulnerability) often assessed using IUCN status, rarity (or local distribution) and national responsibility (or endemism or national importance). Other criteria are often related to genetic uniqueness (or taxonomic uniqueness, phylogenetic distinctiveness), management, protection, economical value, social value (attractive species, cultural importance) or ecological distinctiveness (e.g. ecological range, functional role, keystone species, propagation potential). Among the 24 reviewed methods, four different means of criteria assessment can be distinguished. Real measures and scores are numerical (point-scoring methods), whereas categories and yes/no answers are categorical (rule-based methods) (Table 2). In methods using real measures, criteria values, measured or calculated, are directly used as criteria scores. In methods using scores, discrete values (scores) are attributed to criteria. Score range is usually the same for all criteria, and varies between 3 and 11, except for three methods in which criteria range vary among criteria. In methods using categories, categories (3, 5 or 6) are assigned according to their criteria (e.g. high, medium, low). In methods using yes/no answers, the criteria are assessed answering “yes” if the criterion affects the species and “no” if it doesn’t. Assigning categories and assigning scores produce similar results, both corresponding to levels. We could for example replace “high”, “medium” and “low” categories by “3”, “2” and “1”, or the opposite. Also, methods using real values, measured or calculated, are close to methods using discrete values. The advantage of the first ones is that they produce more accurate scores, and the advantage of the second ones is that they are easier when using both qualitative and quantitative criteria, and when values don’t follow a normal distribution. Methods assessing criteria using yes/no answers are close to red list assessment: if a species is affected by a criterion, it is included in the priority list (or red list), if not, it is not included.

Ways of summarisation are also different according to the different methods (Table 2). For rule-based methods, it can’t be a calculation. Usually, species are clustered by priority levels according to criteria affecting them. It can also be a graphical representation. For point-scoring methods, summarisations can be diverse. Half the methods use either addition or average of scores (which gives the same outcome). Scores can be weighted to give more importance to some criteria. Other calculations are possible instead of addition: multiplication of scores (e.g. Redding and Mooers 2006; Rodríguez et al. 2004), factorisation of scores (e.g. Jiménez-Alfaro et al. 2010), or a formula using natural logarithm



**Table 1** Comparison of chosen criteria in the 24 methods

| Method                           | Threats/vulnerability                        | Rarity   | Responsibility/endemism           | Other criteria   |
|----------------------------------|--|--|-----------------------------------|--|
| Millsap et al. (1990)            | Biological variables                         | Biological variables   | Supplemental variables            | Action variables   |
| Given and Norton (1993)          | Vulnerability                                | Population features  |                                   | Distinctiveness<br>Potential<br>Values   |
| Avery et al. (1995)              | National threat<br>International threat      | –  | International importance          | –  |
| Freitag and van Jaarsveld (1997) | Vulnerability                                | Occupancy  | Endemism                          | Relative taxonomic distinctiveness   |
| Breinger et al. (1998)           | Vulnerability to extinction                  | –  | Area relevance                    | Functional role  |
| Dunn et al. (1999)               | Concern (population decline + vulnerability) | –  | Responsibility                    | –  |
| Schmittler and Günther (1999)    | Threats status                               | –  | Responsibility                    | –  |
| Carter et al. (2000)             | Threats                                      | Relative abundance   | Distribution                      | –  |
|                                  | Population trends                            |  | Area importance                   |  |
| Coates and Atkins (2001)         | Threatened flora                             | Rare and poorly known flora                                      | –                                 | –  |
| Sapir et al. (2003)              | Declining rate and habitat vulnerability     | Rarity   | Distribution type                 | Attractivity   |
| Keller and Bollmann (2004)       | Threat status                                | Historical rarity  | Importance of national population | –  |
| Rodríguez et al. (2004)          | Extinction risk                              | –  | Degree of endemism                | Taxonomic uniqueness<br>Public appeal  |
| Pärtel et al. (2005)             | Threat due to collecting                     | Local distribution<br>Small population size<br>Very rare habitat | Global distribution               | Dependence on: management<br>disturbance<br>agriculture                        |
| Redding and Mooers (2006)        | Extinction probabilities                     | –  | –                                 | Genetic distinctness values  |
| Fitzpatrick et al. (2007)        | Global or European conservation status       | –  | International importance          | Protected species<br>Keystone species<br>Economic value<br>Cultural importance |
|                                  | Regional conservation status                 |  |                                   |  |

**Table 1** (continued)

| Method                       | Threats/vulnerability   | Rarity       | Responsibility/endemism    | Other criteria            |
|------------------------------|-------------------------|--------------|----------------------------|---------------------------|
| Marsh et al. (2007)          | –                       | –            | Consequences of extinction | Potential for recovery    |
| Schmeller et al. (2008a, b)  | Conservation status     | –            | National responsibility    | –                         |
| Gauthier et al. (2010)       | Habitat vulnerability   | Local rarity | Regional responsibility    | –                         |
| Jiménez-Alfaro et al. (2010) | Threat                  | Rarity       | Endemism                   | Protection                |
| Crain and White (2011)       | –                       | Local rarity | –                          | –                         |
| Bacchetta et al. (2012a, b)  | Threats                 | Rarity       | Endemism                   | Status                    |
| Reece and Noss (2014)        | Vulnerability           | –            | –                          | Lack of adaptive capacity |
|                              |                         |              |                            | Conservation value        |
| Gaiarsa et al. (2015)        | Intrinsic vulnerability | –            | –                          | Information availability  |
|                              | Extrinsic vulnerability | –            | –                          | Ecological oddity         |
| Zhang et al. (2015)          | Extinction risk         | –            | –                          | Phylogenetic distinctness |
|                              | Future threat           | –            | –                          | Taxonomic singularity     |
|                              |                         |              |                            | Economic value            |

**Table 2** Comparison of criteria assessment and summarisation in the 24 methods (some methods use more than one way of summarisation)

| Method type  | Rule-based methods  |  | Point-scoring methods                                     |  | Scores   |
|--|---|--|---|--|--|
|  | Yes/no answers  | Categories   | Real measures   |  |  |
| Criteria assessment and summarisation                        |   |  |   |  |  |
| Clustering   | Coates and Atkins (2001)<br>Fitzpatrick et al. (2007)<br>Keller and Bollmann (2004)<br>Pärtel et al. (2005) | -  | -   |  | Dunn et al. (1999)<br>Given and Norton (1993)  |
| Graphical representation                                     | -   | Avery et al. (1995)<br>Schnittler and Günther (1999) | -   |  | Marsh et al. (2007)<br>Millsap et al. (1990)   |
| Sorting by criteria  | -   | -  | -   |  | Bacchetta et al. (2012a)<br>Carter et al. (2000)<br>Gauthier et al. (2010)   |
| Sum/average of scores  | -   | -  | Freitag and van Jaarsveld (1997)<br>Gaiarsa et al. (2015) |  | Bacchetta et al. (2012a)<br>Breininger et al. (1998)<br>Carter et al. (2000)<br>Dunn et al. (1999)<br>Given and Norton (1993)<br>Jiménez-Alfaro et al. (2010)<br>Millsap et al. (1990)<br>Reece and Noss (2014)<br>Sapir et al. (2003)<br>Schmeller et al. (2008a, b)<br>Zhang et al. (2015) |
| Other calculation (multiplication, factorisation, logarithm) | -   | -  | Redding and Mooers (2006)                                 |  | Jiménez-Alfaro et al. (2010)<br>Rodríguez et al. (2004)  |

(e.g. Isaac et al. 2007). Multiplying instead of adding allows for the assignment of a more important relative weight to higher rank taxa (Rodríguez et al. 2004). ‘Sorting by criteria’ is another possible summarisation which can be implemented in different ways: either all species are sorted out for one criterion, then another criterion and so on for all criteria (e.g. Bacchetta et al. 2012a; Gauthier et al. 2010), or a threshold is determined for each criterion, below which species can’t be in the priority list (e.g. Carter et al. 2000). The methods using scores to assess criteria can use any summarisation of criteria. Summarisation of scores in one priority index is subject to methodological uncertainties because a lot of different mathematical processes exist. When criteria independence is not certain, Carter et al. (2000) advise to choose the “sorting by criteria” summarisation method, otherwise it can give more weight to criteria which are dependent.

### **Differences and similarities between the studies using a same method**

It is interesting to see how a method can be adapted in terms of area, taxa, criteria assessment and summarisation (Table 3). Among the 24 different reviewed methods, one developed by Gauthier et al. (2010) was used in six different studies, with data adaptation according to the local context. Three studies considered administrative areas, two considered biogeographical or ecological areas, and one considered both. Three studies were conducted in France, one in Canada, one in Brazil and one both in France and Italy at a regional biodiversity hotspot scale. All studies targeted flora: two studies considered all the taxa of their targeted group (trees, orchids), whereas the others considered only some plant taxa, for example threatened, protected, endemic, rare. The three criteria were always the same, even though names can vary: (i) regional, territorial, national or biogeographical responsibility; (ii) local, regional or national rarity; (iii) habitat vulnerability, vulnerability or potential threats. All these criteria were assessed with scores from 1 to 5.

In three studies, the regional responsibility criterion was based on the number of administrative areas of presence, in two studies it was assessed using chorological types, and in one study it corresponded to the number of ecoregions of presence. The local rarity criterion was based on the number of administrative areas of presence in most cases (municipalities, regions), or on the number of ecoregions of presence or a finer measure (number of grid cells of presence, number of occurrences, number of flowering plants). The habitat vulnerability criterion was the most variable. In four studies, it was based on a pre-existing assessment (habitat priority, habitat conservation) or on an expert assessment (habitat vulnerability, ecoregion vulnerability). The two others used spatial measures: the percentage of administrative areas (departments) where the species is extinct (Schatz et al. 2014), or the presence of species in forest or savannah (Maciel et al. 2016). Half the studies used several sub-criteria to assess habitat vulnerability. These sub-criteria were evaluated using reduced score range, and were then summed. After addition, their scores were between 1 and 5.

Four studies summarised scores sorting by criteria; starting with responsibility, then rarity, and finally vulnerability, except one (Maciel et al. 2016) which started with rarity, then responsibility, and finally vulnerability. Schatz et al. (2014) used a different method, enabling to group taxa according to their scores for the different criteria, in order to suggest adding them to national or regional protection lists (or no list). Le Berre et al. (2018) used an addition to summarise the scores of the different criteria, in order not to give more importance to one criterion than to another.

**Table 3** Comparison of different studies using the Gauthier et al. (2010) method

| Papers                           | Study area                         | Study area type                   | Study taxa                                  | Regional responsibility                               | Local rarity                              | Habitat vulnerability                    | Summarisation  |
|----------------------------------|------------------------------------|-----------------------------------|---|---|---|--|--|
| Gauthier et al. (2010)           | Languedoc-Roussillon (France)      | Administrative area               | 492 plants (determinant)                    | Nb. of departments (administrative areas) of presence | Nb. of municipalities of presence         | Vulnerability assessment                 | Sorting by criteria<br>RR > LR > HV                        |
| Gauthier et al. (2013)           | Causse Méjan (France)              | Bioregion                         | 118 plants (rare, protected)                | Chorological types                                    | Nb. of flowering plants                   | Habitat priority<br>Habitat conservation | Sum of sub-criteria<br>Sorting by criteria<br>TR > LR > VH |
|                                  | Pyrenees National Park (France)    | Administrative National Park area | 124 plants (protected)                      |   | Nb. of grid cells                         | Occurrence in core area                  |  |
| Kricsfalussy and Trevisan (2014) | Saskatchewan (Canada)              | Administrative area               | 418 plants (rare)                           | Nb. of provinces (administrative areas)               | Nb. of occurrences                        | Ecoregion vulnerability index            | Sum of sub-criteria<br>Sorting by criteria<br>RR > LR > VH |
| Schatz et al. (2014)             | France                             | Administrative area               | 157 <i>Orchidaceae</i> (all)                | Nb. of countries of presence (administrative areas)   | Nb. of administrative regions of presence | Threats awareness                        | Gathering → Protection lists                               |
|                                  | French regions                     | Administrative area               |   | % occurrences region/France (administrative areas)    | Nb. of occurrences                        | % of extinction in departments           |  |
| Maciel et al. (2016)             | Cerrado-Amazon ecotone (Brazil)    | Bioregion                         | 1755 tree species (all)                     | Nb. of ecoregions of presence                         | Nb. of sites of presence                  | Occurrence in savannah/forest            | Sorting by criteria<br>LR > RR > HV                        |
| Le Berre et al. (2018)           | South-Western Alps (France, Italy) | Biogeographical area              | 913 plants (endemic, threatened, protected) | Chorological types                                    | Nb. of grid cells                         | Habitat vulnerability                    | Sum of scores  |
|                                  |                                    |                                   |   |   |   | Artificialisation                        |  |

RR regional responsibility, LR local rarity, HV habitat vulnerability, TR territorial responsibility, Nb. number

## Discussion

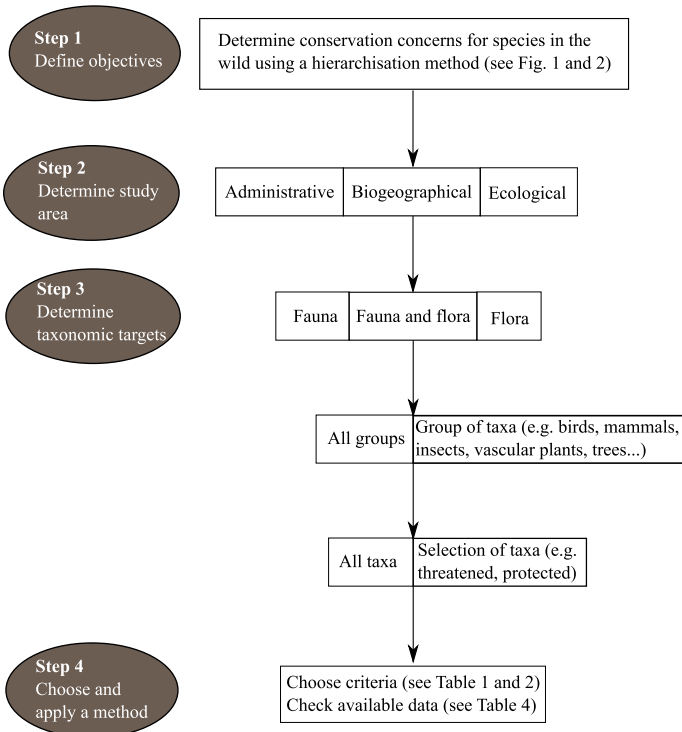
### The research-implementation gap and the choice of criteria

One problem faced in conservation biology is the research-implementation gap, in which theory ignores practice and practice ignores theory (Knight et al. 2008; Marris 2007). The majority of conservation assessments published in the peer-reviewed literature were not designed with the intention to implement conservation action (Knight et al. 2008) and conversely, numerous implemented conservation actions are not based on peer-reviewed studies (Pullin et al. 2013). That can be due to managers not having the resources (in terms of time and people) to read the numerous publications about this subject and to choose one well adapted to their problematic.

Priority setting in conservation research and action will always reflect human-oriented values and be forever changing and contested (Pullin et al. 2013). In fact, chosen criteria, criteria weight, score assessment and score summarisation, can lead to different results according to initial choice (Carter et al. 2000; Jiménez-Alfaro et al. 2010; Reece and Noss 2014). Criteria must be chosen accordingly to what managers want to prioritise, e.g. rare, endemic, threatened, protected, or taxonomically unique taxa (Fig. 3). Consequently, the choice of the method depends on the expected results, available data, and allocated time to undertake the evaluation (Andelman et al. 2004; Game et al. 2013; Given and Norton 1993). It also should take into account social, political and ecological values to enable the understanding of the implications for practical conservation, as it was highlighted by Wyborn et al. (2016) for conservation orientations. Finally, it is important to bear in mind that no classification system can give the “right answer” for all species or all users, whatever the number of criteria or their weight. The differences between priority classification systems are less important than the need to implement these processes and to provide well defined objectives, in order to define strategies to improve the efficiency of conservation actions (Dunn et al. 1999).

### The choice of a hierarchisation method for species

To be relevant, the choice of the species' hierarchisation method should be directed towards an adapted approach for the conservation policy and practice. If we ask ourselves the ‘right’ questions and scientifically justify our choices, a useful method for reaching our objectives will stand out (Fig. 3). The first and most crucial step is to define the objectives properly. In fact, managers can have trouble explicitly defining prioritisation problems because the objectives relevant to the decision have not been clearly articulated (Game et al. 2013). If conservation goals are to be achieved, it is vital to be explicit about what these are, and make decisions in an open and consultative manner before making choices (Mace et al. 2007). Here, the goal is to determine conservation concerns for species in the wild using a hierarchisation method. The second step is the determination of the study area (e.g. administrative, biogeographical, or ecological). Some criteria, e.g. IUCN Red lists were mainly developed for administrative areas (e.g. countries or regions), but some methods use them for other types of areas (e.g. Schnittler and Günther 1999). The third step refers to the taxonomic targets (e.g. fauna, flora, both fauna and flora, one group, one family), which may be selected (e.g. all taxa in a defined group, only those protected, threatened, indigenous). Schmeller et al. (2008c) recommend that a method should be applicable



**Fig. 3** Framework helping managers to choose a method

to all or most taxa and be adaptable to different spatial scales. Some methods developed for fauna can be adapted to flora, or vice versa, but the criteria must be adapted; so, the use of a method developed for the target group should be the simplest option. The last step is to choose a method adapted to the objectives and the data available. The criteria used and the different ways of assessment and summarisation were compared (Tables 1, 2) in order to help managers choose which criteria are important to them according to their objective. The three main criteria suggested by Gauthier et al. (2010) were adapted to various cases, so we consider that taking into account rarity, area responsibility and threats can be sufficient and relevant to determine conservation concerns, even if other choices are possible according to objectives and local context.

In the end, it may not matter which prioritisation scheme is the most scientifically defensible; what matters is that the people carrying out a scheme feel that it makes sense and will save species (Marris 2007). Therefore, a checklist of the data needed for each group of methods was set up (Table 4) in order to help managers determine which method they can implement according to their available data and time. Rule-based methods can be easier to use if data is not available for all taxa or for the whole area (Andelman et al. 2004), whereas point-scoring methods can help gather and rationalise available knowledge of taxa. The greater the number of criteria (or sub-criteria) and data are used in a method, the more difficult it will be to implement it for a great number of taxa. Consequently, the choice will be a trade-off between the complexity of the method and time required to implement it, and the ability of the method to help managers reach their objectives for

**Table 4** Checklist of the data needed in the 40 reviewed studies

| Data needed                      | A | B | C | D | E | F | G | H | I | J | K | L | M | N | O | P | Q | R | S | T | U | V | W | X | Y | Z |
|----------------------------------|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| IUCN red lists                   |   | x | x | x | x |   | x | x | x | x | x |   | x |   |   |   |   |   |   | x |   | x |   |   |   |   |
| Regulatory lists                 |   |   | x |   |   |   | x |   |   |   |   |   | x |   |   |   |   |   |   |   |   | x |   | x |   | x |
| Local distribution               | x |   | x | x | x | x | x | x | x |   | x | x | x |   | x |   | x |   |   | x |   | x | x |   | x |   |
| Global distribution              |   | x | x | x | x | x | x | x | x | x | x | x | x |   | x |   | x |   |   | x |   | x | x |   | x | x |
| Phylogeny                        |   | x |   |   |   |   | x | x | x | x |   |   |   |   | x |   | x |   |   | x |   |   | x | x | x | x |
| Number of populations            |   |   |   |   |   |   |   |   |   | x |   |   |   |   |   |   |   |   |   |   |   | x |   |   |   | x |
| Size of populations              |   |   |   |   |   |   |   |   | x | x |   | x |   | x |   |   |   |   |   | x |   | x | x | x |   | x |
| Population trend                 |   |   |   | x | x |   |   |   |   | x |   | x |   |   |   |   |   |   |   | x |   | x | x |   | x | x |
| Population isolation             |   |   |   |   |   |   |   |   |   |   | x |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |
| Population genetics              |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   | x |
| Threats on populations           |   |   |   |   |   |   |   |   |   | x |   | x |   |   |   |   |   |   |   |   |   |   |   |   |   | x |
| Number of species habitats       |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   | x |
| Distribution of species habitats |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   | x |
| Threats on species habitats      |   |   |   |   |   |   |   |   |   |   | x |   |   |   |   |   |   |   |   |   |   |   |   |   |   | x |
| Ecological factors               |   |   |   |   |   |   |   |   |   |   |   |   | x |   |   |   |   |   |   |   |   |   |   | x |   | x |
| Biological factors               |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   | x |
| Reproductive factors             |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   | x |
| Economic factors                 |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   | x |
| Societal factors                 |   |   |   |   |   |   |   |   |   | x |   | x |   | x |   |   |   |   |   |   |   |   |   |   |   | x |
| Practicability                   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   | x |

Methods: A = Crain and White (2011); B = Isaac et al. (2007, 2012), Redding and Mooers (2006), Redding et al. (2010), Vereecken (2017); C = Schmeller et al. (2008a, b, 2014); D = Schmittler and Günther (1999); E = Avery et al. (1995), Keller and Bollmann (2004), Warren et al. (1997); F = Dunn et al. (1999), Schatz et al. (2014); G = Gauthier et al. (2010, 2013), Kricsfalussy and Trevisan (2014), Le Berre et al. (2018), Maciel et al. (2016); H = Jiménez-Alfaro et al. (2010); I = Freitag and van Jaarsveld (1997); J = Rodríguez et al. (2004); K = Coates and Atkins (2001); L = Carter et al. (2000); M = Sapir et al. (2003); N = Fitzpatrick et al. (2007); O = Pärtel et al. (2005); P = Gaiarsa et al. (2015); Q = Zhang et al. (2015); R = Knapp et al. (2003); S = Marsh et al. (2007); T = Breiningger et al. (1998); U = Martin et al. (2010); V = Bacchetta et al. (2012a, b); W = Lunney et al. (1996); X = Millsap et al. (1990); Y = Given and Norton (1993); Z = Reece and Noss (2014)



conservation. Fitzpatrick et al. (2007) recommend that a priority system should comprise only a limited number of criteria and should not try to incorporate a long list of factors with a complex weighting system. Schmeller et al. (2008c) recommend that a method should be precise and clear in defining categories, have minimal data requirements, and maintain conservation status and responsibility as two separate factors. Some methods can be quite easily adapted to different contexts, as different studies used an existing method and adapted it to their context (see *ESM\_2*). The comparison of six different studies using the same method (see *Table 3*) showed how a method can be adapted in terms of areas, taxa, criteria assessment and summarisation, and data. It is also interesting to highlight that two methods developed for species (Gauthier et al. 2010; Schmeller et al. 2008b) were modified to be applied to habitats or plant communities (Benavent-González et al. 2014; Schmeller et al. 2012). There is always a solution to adjust an approach to fit available data and goals, but if time is a limiting factor, we advise to choose a method which can be easily adapted, using criteria matching the defined goals, and using data that can be easily available for each species to rank.

Finally, the most important challenge could be to anticipate the future changes in order to suggest a progressive and reproducible approach. To define the goals with clarity at the beginning of the work enables to obtain relevant outcomes in order to mitigate the consequences of global environmental changes. As indicated in other conservation orientations such as utilitarian considerations (e.g. Karpouzoglou et al. 2016; Wyborn et al. 2016), the choice of methods and parameters in hierarchisation and prioritisation should take into account social, political and legislative values. Therefore, decision-making is an exercise in implementing technical, social or organisational options. With the frameworks and the comparative tables of existing peer-reviewed methods presented here, managers should be able to choose one well adapted to their goals and local context. This synthesis can help bridge the research-implementation gap by developing and implementing conservation plans in a scientific way.

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## Compliance with ethical standards

**Conflict of interest** The authors declare that they have no conflict of interest.

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