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New method to identify and map flagship fleets for promoting conservation and ecotourism

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ABSTRACT

Evaluating flagship species and their potential for biological preservation and ecotourism development is a key issue for many audiences within the conservation and social fields. Despite several methods available to identify flagships, their application is often constrained in remote, poorly studied regions. Developments are needed in statistical and spatially-explicit approaches to assess species' traits influencing flagship appealing, to identify flagship fleets, and to map the location of flagship hotspots. Here, we developed a new method to identify flagship species in regions with knowledge gaps, using a two-stage statistical approach (ordination and clustering algorithms) to assess variable's contribution to appealing and to group species sharing similar characteristics into flagship fleets. We then mapped areas concentrating the highest richness of flagships. Unique morphologies and behaviours, conservation status, endemicity, body size and weight, and feeding habits were the traits contributing the most to the flagship appealing. Nine flagship fleets were identified, from which two were the most suitable for conservation marketing and ecotourism promotion campaigns in Sahara-Sahel: Fleet A comprising 36 large-bodied species (18 mammals, 18 reptiles) and Fleet B including 70 small-bodied species (10 birds, six mammals, 54 reptiles). A total of 19 and 16 hotspots were identified for large-bodied and small-bodied flagships, respectively. The methodology was suitable to identify flagship species for conservation marketing and for developing ecotourism operations in the Sahara-Sahel, to independently assess which species' traits are relevant for flagship appealing, and to organise fleets for multispecies-based marketing campaigns. The framework is scalable and replicable worldwide.

1. Introduction

Flagship species are defined as "a species used as the focus of a broader conservation marketing campaign based on its possession of one or more traits that appeal to the target audience" (Veríssimo et al., 2011), serving as symbols to stimulate conservation awareness and action, drawing financial support to protect habitats and other species (Simberloff, 1998). Despite several reinterpretations by academics (Barua, 2011), the latest definitions focus on the strategic, socio-economic, and marketing character of the concept (Veríssimo et al., 2011; Walpole and Leader-Williams, 2002). Flagship species act as a marketing (the process of planning and executing the value and distribution of products and services between organizations and target audiences) strategic tool to influence target audiences' preferences and behaviours for the benefit of conservation efforts, by placing them at the core of the marketing process (see Wright et al., 2015 for a full review). Thus, they have been used in conservation awareness (Veríssimo et al., 2009), fundraising (Clucas et al., 2008), ecotourism (Walpole and Leader-Williams, 2002) and community-based conservation initiatives (Barua et al., 2011), in the protection of species and habitats (Smith et al., 2012), in policy making (Jepson and Barua, 2015), and in the development of pro-conservation behaviours (Smith and Sutton, 2008).

Flagship fleets were recently developed as a tool to group several species into one single, more successful, flagship marketing campaign. Thus, they can raise the profile of more than one species and benefit a wider range of biodiversity (Barua et al., 2011; Veríssimo et al., 2014), while ensuring that multiple stakeholder groups' preferences (e.g. of desert ecotourists; avitourists; 'Big-Five' tourists; academics; conservationists; international NGOs) are covered in flagship campaigns (Di Minin et al., 2013; Lindsey et al., 2007). Flagship fleets were proposed

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to answer concerns regarding fund diversion from less to high charismatic species (e.g. Andelman and Fagan, 2000; Joseph et al., 2011) and to lead behavioural change within and between different audiences (Root-Bernstein and Armesto, 2013). Pooling species belonging to different taxonomic groups into one single fleet can help targeting the desires of different audiences, thus maximizing the return-on-investment in multiple-species conservation efforts (Veríssimo et al., 2014).

Many criteria for selecting flagship species have been proposed (Bowen-Jones and Entwistle, 2002) but selection is mostly based in morphological, behavioural and cultural traits that are likely to be appealing to the planned target audience (Batt, 2009; Barua et al., 2011, 2012; Veríssimo et al., 2009, 2011). These typically include, amongst others, body size, endemicity level or conservation status. A key aspect in flagship choice is the extent to which it builds attitudinal, behavioural, financial or political support, without which their effectiveness as flagships may be compromised (Veríssimo et al., 2011). Thus, flagship species can be selected according to different methodologies, following social marketing, environmental economics, or conservation biology objectives (Veríssimo et al., 2011). In the past, they were selected mostly based on charisma, i.e. cultural value, rather than on objective principles (Home et al., 2009). Several conservation initiatives selected flagships for marketing campaigns based on preconceptions about the types of species favoured by the public, including potential tourists, conservationists, and academics. However, in conservation marketing, product familiarity is critical to consumer preference and any research on flagship preferences should take into account the knowledge level of the audience for properly identifying flagships (Garnett et al., 2018). To overcome this issue, choice experiment (CE) approaches have been developed to identify flagships for ecotourism promotion and conservation marketing campaigns (e.g. Di Minin et al., 2013; Veríssimo et al., 2009, 2013). These tools are derived from marketing theory and explore how particular attributes of a product are valued (Brown, 2010) and capture the heterogeneity of respondents preferences towards biodiversity attributes (Di Minin et al., 2013; Hausmann et al., 2016; Naidoo and Adamowicz, 2005). However, to be informative, CE relies on the principle that the public is well informed about the available species diversity in a given area to take a decision about attractiveness. Understanding people's preferences towards every possible option from a large species pool may be an impractical task and even be unfeasible in remote regions with knowledge gaps about local biodiversity (Veríssimo et al., 2009). Photography-based studies have been used to address this shortcoming (e.g. Macdonald et al., 2015, 2017), but confounding effects of differing photograph colouration and angle have been raised (Batt, 2009), suggesting that flagship selection needs methodological developments that allow refining the identification of suitable species for different flagship campaigns in regions where the public is not well informed about the local biodiversity (Garnett et al., 2018). Furthermore, the contribution of species traits to flagship appealing in CE approaches is evaluated only after respondents have chosen their preferred species, which is only possible in well-studied regions. In remote regions, non-heuristic methods using multi-criteria in large datasets of species may allow evaluating the suitability of a species for the development of conservation marketing and ecotourism campaigns (Veríssimo et al., 2011). Non-heuristic methods, such as Principal Component Analysis (PCA), depend only on the dataset traits to assess variables contribution, whereas heuristic methods are affected by the subjective judgments of individuals that can lead to different, even antagonist answers to the same question (Pathak et al., 2017). Unsupervised learning methods, such as Cluster Analyses, are used to group a set of objects (e.g. species) based on the observed values of several variables for each individual object (e.g. Batt, 2009), in a way that objects in the same group are more similar to each other than to those in other groups (Tryon, 1939). The potential of non-heuristic methods has been successfully explored in grouping water-bodies with similar traits for ecotourism development (e.g. Santarém et al., 2018) or in bioregionalization exercises based in environmental variation and species distribution (e.g. Brito et al., 2016). Non-heuristic methods have the potential to eliminate biases from analytical processes (Batt, 2009) and thus may help identifying flagship fleets efficiently.

In developing nations, often rich in endemic biota but lacking common charismatic megafauna (large-sized vertebrates; Hausmann et al., 2016), international ecotourism can be highly beneficial for the national gross domestic product and local development (UNESCO, 2003; Twining-Ward et al., 2018; Weaver, 2001). This is the case of Sahara-Sahel range countries in Africa that are categorised as low human development (Brito et al., 2014) and are underfunded for poverty alleviation and biodiversity loss retention schemes (Durant et al., 2012; Waldron et al., 2013), display extensive remote areas, lack large populations of common African flagship species (e.g. elephant, lion) but are rich in endemic vertebrates (Brito et al., 2016). Ecotourism marketing campaigns have been set as regional conservation priorities (Brito et al., 2016; Hosni, 2000), but detailed knowledge about biodiversity levels in the Sahara-Sahel is still limited (Brito et al., 2014), as well as people's understanding of the local potential flagship species. Effective methodologies are needed to identify flagship species in contexts of endemic-rich desert developing countries lacking common flagships and exhibiting biodiversity knowledge gaps (Santarém and Paiva, 2015).

Mapping the location of flagship hotspots, i.e. particular areas concentrating exceptional flagship species richness suitable for conservation marketing and ecotourism promotion (adapted from Marchese, 2015), is in need of development. These areas are defined by one or more species-based metrics (e.g. species richness, number of species restricted to a particular area, or functional diversity within the ecosystem) in order to protect species supporting unique roles (Marchese, 2015). Despite the potential to indicate the location of suitable regions to allocate flagship-based conservation initiatives and to positively influence public behaviour through biodiversity, mapping the richness of flagship species or flagship fleets remains unexplored. Species abundance data is scarce in Sahara-Sahel (Brito et al., 2014, 2016) but mapping hotspots in such desert areas would help setting priorities for ecotourism development and conservation, which is highly relevant for such poorly known areas and for minimizing local species extinction (Vale et al., 2015; Durant et al., 2014).

Here, we propose a systematic method to identify flagship species in regions where the public is not well informed about the local species diversity and where CE would be impossible to perform to identify flagships, using Sahara-Sahel vertebrates as case-study. We first assess objectively which species traits drive flagship appealing, then assess which fleets of species can be used in flagship campaigns, and finally map flagship hotspots. Particularly, we want to answer the following questions: 1) which species' traits contribute the most to explain species' flagship appealing?; 2) how many flagship fleets can be distinguished according to their shared characteristics to flagship suitability?; 3) which flagship fleets display potential characteristics for conservation marketing and ecotourism promotion campaigns?; and 4) where are located flagship hotspots in the Sahara-Sahel? Specifically, we hypothesize that: 1) physical attributes, appearance, likelihood of extinction and endemicity are the most relevant traits for flagship selection in the Sahara-Sahel; 2) the most important variables will help shaping flagship fleets given the variabilities in those traits; 3) species displaying similar traits will tend to be clustered together and form different fleets suitable for distinct conservation marketing and ecotourism promotion campaigns; and 4) flagship hotspots will generally tend to be concentrated in local biodiversity hotspots and will tend to spatially overlap hotspots of total species richness.

Table 1
Variables used to evaluate the 1126 Sahara-Sahel species to be used in flagship marketing campaigns, their code, description, type (num: numerical; cat: categorical), units, and data sources.

Variables	Code	Description	Type	Source
Area of occupancy	AOC	Area within a species' extent of occurrence which is occupied in Sahara-Sahel: number of half-degree cells	num	IUCN, 2017; BirdLife International and NatureServe, 2017
Body size	BSIZE	Maximum body size (total length): cm	num	AmphibiaWeb, 2017; Jones et al., 2009; Encyclopedia of Life, 2017; Myhrvold et al., 2015; Text S1
Body weight	BWEIG	Maximum weight: gr	num	AmphibiaWeb, 2017; Jones et al., 2009; Encyclopedia of Life, 2017; Myhrvold et al., 2015; Text S1
Morphology	MORPH	Unique morphological adaptations to desert environments: number of	num	AmphibiaWeb, 2017; Encyclopedia of Life, 2017; Text S1; expert-knowledge
Behaviour	BEHAV	Unique behavioural adaptations to desert environments: number of	num	AmphibiaWeb, 2017; Encyclopedia of Life, 2017; Text S1; expert-knowledge
Colour number	NCOL	Colours in the body: number of	num	AmphibiaWeb, 2017; Encyclopedia of Life, 2017; Text S1
Colour pattern	COLPAT	Colour patterns in the body: uniform; patches; spots; or stripes (1); pa + sp or pa + st or sp + st (2); pa + sp + st (3)	cat	AmphibiaWeb, 2017; Encyclopedia of Life, 2017; Text S1
Conservation	CS	Conservation status: NE; DD; LC; NT; VU; EN; CR; EW	cat	IUCN, 2017
Endemic	END	Endemic in the study area: yes/no	cat	IUCN, 2017
Activity	ACTIV	Activity patterns: diurnal, nocturnal or cathemeral (active in both periods of the day)	cat	Jones et al., 2009; Text S1; expert- knowledge
Seasonality	SEAS	Annual activity of species that influences the availability and easiness to observe the species: all-year round; seasonal	cat	Text S1
Feeding	FEED	Feeding habits: herbivorous; frugivorous; omnivorous; necrophage; carnivorous	cat	Jones et al., 2009; Text S1
Cultural use	CRM	Animal representations in cultural and religious art, and use of animal components for medicine: yes/no	cat	Text S1; expert-knowledge

2. Methods

2.1. Study area

Includes the Sahara and the Sahel ($\approx$11,200,000 km^2) ecoregions (Dinerstein et al., 2017; Fig. S1) and comprises 4072 grid cells of 0.5 degree resolution (WGS84 coordinate reference system).

2.2. Species list and trait data

The list of continental vertebrates of the Sahara-Sahel and their distribution polygons was retrieved from IUCN (2017), and updated according to Brito et al. (2016, 2018). It comprises 1126 species, including 52 amphibians, 188 reptiles, 584 birds, and 302 mammals (Table S1). For each species, we collected data on 13 variables related to distributional variation, morphophysiological and behavioural characteristics, conservation status, and cultural representation (Table 1), based on relevant literature and other sources (see Text S1). The variables were:

1) Area of occupancy (AOC): the size of the geographical distribution of the species under analysis has been suggested as a key criterion for the selection of flagship species, as species with narrow ranges can reinforce allegiance with the region and influence people's willingness to pay for conserving low distributed animals, while large ranged species help promoting global priority areas (Barua et al., 2011; Bowen-Jones and Entwistle, 2002; Root-Bernstein and Armesto, 2013; Veríssimo et al., 2013). Using a Geographical Information System (GIS; ESRI, 2012), we calculated the area of occupancy as the area within a species extent of occurrence (area contained within the minimum convex polygon encompassing the known species locations) that is occupied by that species (IUCN, 2017);
2) Body size (BSIZE) and 3) body weight (BWEIG): these traits have been extensively used in other flagship selection studies, as larger sizes and weights usually influence the easiness to observe species in the wild and animal attractiveness (Barua et al., 2012; Clucas et al., 2008; Ebner et al., 2016; Home et al., 2009; Macdonald et al., 2015, 2017; Smith et al., 2012; Veríssimo et al., 2014). We quantified the maximum body size (total length, TL) and the maximum weight irrespectively of sexual dimorphism in these variables (sexual differences in measurements were not considered; we recorded only the longest body length and the largest weight value of the two sexes);
4) Morphologies (MORPH) and 5) behaviours (BEHAV): species exhibiting unique characteristics are highly valued by the public (Jepson and Barua, 2015; Macdonald et al., 2015; Root-Bernstein and Armesto, 2013; Veríssimo et al., 2009). We accessed morphological - such as keeled scales and tuft of hair on ears to protect against sand - and behavioural adaptations - such as sand swimming and adapted feathers to transport water - to local desert environments, as a proxy for these uniqueness's;
6) Number of colours (NCOL) and 7) colour patterns (COLPAT): species with complex body colourations and recognizable colour patterns are considered more appealing to international audiences (Batt, 2009; Barua et al., 2011, 2012; Macdonald et al., 2015). We quantified the maximum number of colours and colour patterns, irrespectively of ontogenetic shits and sexual dimorphism. For colouration, we considered 10 basic colour schemes (white, black, yellow, green, blue, orange, grey, red, brown, and purple). For body pattern, we considered main patterns - uniform, patches, spots, and stripes (longitudinal or transverse bars) - and then quantified the cumulative number of patterns in each species: three (patches + spots + stripes), two (e.g. spots + stripes), one of those, or none (see Fig. S2 for examples);
8) Conservation status (CS): likelihood of extinction of a species has been extensively explored within the flagship literature, because threatened species urge the development of international conservation campaigns to attract conservation funds and ecotourists are seen as the mean to attract the money needed (Barua et al., 2011; Bowen-Jones and Entwistle, 2002; Clucas et al., 2008; Ebner et al., 2016; Macdonald et al., 2015, 2017). Species conservation statuses were based on IUCN Red List of Threatened Species (IUCN, 2017). The Scimitar-horned Oryx (*Oryx dammah*) was considered in this study as Extinct in the Wild, following IUCN categories, but the species has been recently reintroduced in Chad (Brito et al., 2018);
9) Endemicity (END): species with restricted distribution provide symbols of regional and national adherence and reflect strong local identity (Bowen-Jones and Entwistle, 2002; Takahashi et al., 2012; Veríssimo et al., 2009, 2014). Species were categorised as endemic

from the Sahara-Sahel or as non-endemic (if the distribution covered areas outside the Sahara-Sahel);

10) Daily (ACTIV) and 11) seasonal (SEAS) activities: the easiness to observe a species is influenced by its daily and seasonal activity patterns (Macdonald et al., 2015; Root-Bernstein and Armesto, 2013; Veríssimo et al., 2009, 2013). Species that are easy to spot in the wild are usually preferable as flagships in comparison to others less conspicuous (Reynolds and Braithwaite, 2001). We accessed daily activity by considering the species as being diurnal, nocturnal or cathemeral (day and night activity). We accessed species seasonal activity by evaluating if the species is sedentary (constantly present in the study area) or seasonal (exhibiting migratory movements and thus not available all year round);

12) Feeding habits (FEED): different species feeding habits attract distinct types of audiences that feel linked to one or another diet type (Ebner et al., 2016). Usually, carnivores are preferred by people who are raising the profile of potential flagships (Clucas et al., 2008; Macdonald et al., 2015, 2017). The trophic levels we considered were: carnivore (meat-eating, including arthropods and fishes), herbivore (vegetation protein-eating), omnivore (vegetation, fruit, seed, grain, and/or nectar and animal protein-eating), frugivore (fruit, seed, grain and/or nectar-eating), and necrophage (carrion-eating);

13) Cultural, religious and medical uses (CRM): the cultural significance of a species is a major characteristic to be foreseen in a flagship. Relationships to local art, folklore and handicraft, or uses of venoms for medical, or religious representations are highlighted in flagship species (Barua et al., 2012; Bowen-Jones and Entwistle, 2002; Takahashi et al., 2012). We evaluated where species have any of those cultural, religious and/or medical uses described above and treated this as a binomial variable (yes or no).

2.3. Statistical analyses

We applied two procedures to identify which traits are contributing the most to the appealing character of species for flagship marketing (see Text S2 for details). First, we performed a PCA for mixed (numerical and categorical) data (PCAmix), after standardised the numerical data, and then applied an orthogonal rotation to the PCA loadings (Chavent et al., 2012). Contribution of variables is given by the squared loadings (correlation coefficients) of species traits with the first two rotated axes of the PCAmix. Squared loadings are the squared correlation for numerical variables and the correlation ratios for categorical variables with the rotated components, respectively (Chavent et al., 2012, 2017b).

Flagship fleets, i.e. groups of species sharing similar characteristics for different flagship-based marketing campaigns, were identified using a model-based clustering approach (Scrucca et al., 2016). Fourteen multivariate normal mixture models with different parameterizations concerning the distribution, volume, shape and orientation of the covariance matrix of the multivariate data of the species were estimated by maximum likelihood using an expectation-maximization algorithm. The best model and the optimum number of clusters were chosen using the Bayesian Information Criterion (BIC) applied to the two first rotated axes of the PCAmix. The optimum number of clusters defined the number of different flagship fleets and for each cluster we matched a flagship fleet (Text S3).

All analyses were performed in R version 3.4.3, using the functions *PCAmix* and *PCArot* of the package 'PCAmixdata' (Chavent et al., 2017a) for variables contribution, and 'mclust' of MClust package (Scrucca et al., 2016) for flagship fleets quantification.

From the groups identified in the clustering analysis, we identified which ones are the most interesting flagship fleets for conservation marketing and ecotourism promotion campaigns. The identification of these fleets were based on the presence of traits (such as body size/weight, endemism, conservation status or unique adaptations; Clucas et al., 2008; Veríssimo et al., 2009, 2013) in the species that belong to each identified flagship fleet and that are commonly appreciated by different audiences (e.g. desert ecotourists; avitourists; academics; conservationists).

2.4. Mapping flagship hotspots

To identify and map flagship hotspots of the selected fleets for conservation marketing and ecotourism promotion campaigns, we first intersected species distribution polygons with grids of 0.5-degree resolution to generate matrices of species presence/absence by grid cell in a GIS (ESRI, 2012). A species was considered to occur in a cell if any portion of the species' range overlapped the cell. Then, flagship hotspots for each of the fleets were obtained by summing the number of flagship species occurring in each grid cell. In order to identify the areas that maximize the likelihood of observing flagships belonging to multiple fleets, the distributions of retrieved fleets were overlapped to generate the combined flagship hotspots, representing 50% of the richness of each of the two groups. Protected areas network (IUCN and UNEP-WCMC, 2018) was overlapped with the flagship hotspot map to identify gaps in the representation of hotspots in currently protected areas.

3. Results

3.1. Traits driving flagship appealing

Several variables contributed to the flagship appealing: unique morphologies and behaviours, conservation status and endemicity on the first dimension of the PCAmix, and body size, body weight, conservation status and feeding habits on the second dimension. The two first dimensions accounted for 17.23% of the variability (Table 2; Fig. 1).

3.2. Identification of flagship fleets

The model with the highest BIC value (Text S3) was selected to identify the number of flagship fleets. The BIC increased with the number of clusters and reached the plateau at nine clusters, which was chosen as the optimum number of flagship fleets. Some groups were more cohesive than others (e.g. fleet H is very cohesive while fleet A is heterogeneously dispersed along the two dimensions; Fig. 2), due to the weight of each species traits on grouping species into flagship fleets (Fig. 1). Each flagship fleet displays distinct characteristics potentially suitable for different flagship-based conservation and ecotourism initiatives and audiences' preferences (Table S1).

3.3. Suitability of flagship fleets for conservation and ecotourism campaigns

From the nine flagship fleets identified, fleets A and B were the most suitable for conservation and ecotourism campaigns in Sahara-Sahel (Fig. 2). Group A (N = 36 species), hereafter designated as large-bodied flagships, included mostly large and heavy mammals (18 species; e.g. *Addax nasomaculatus*) and reptiles (18 species; e.g. *Uromastyx nigriventris*), approximately half of them are regional endemics and exhibited some unique desert adaptations, more than a half is threatened with extinction, and most are herbivorous (Table 3). Group B (N = 70 species), hereafter designated as small-bodied flagships, includes small and light birds (10 species; e.g. *Passer luteus*), mammals (six species; e.g. *Ctenodactylus vali*) and reptiles (54 species; e.g. *Acanthodactylus aureus*), most are regional endemics, exhibit several desert adaptations, are not threatened, and are carnivorous. In total, 7.8% of mammals, 36% of reptiles, and 1.7% of birds occurring in the Sahara-Sahel were identified as flagships, whereas no single amphibian was identified.

Table 2
Correlation coefficients of species traits with the first two axes (Dimension 1 and Dimension 2; highly correlated values are in bold) of the Principal Component Analysis with mixed data (PCAmix), the eigenvalues and the percentage of explained variation of these two axes. See Fig. 1 for the squared loadings of the species traits within the two first rotated axes.

Species traits	Dimension 1	Dimension 2
Area of occupancy	0.183	−0.034
Body size	0.027	**0.841**
Body weight	−0.048	**0.692**
Morphology	**0.746**	0.026
Behaviour	**0.721**	0.045
Colour number	0.005	−0.163
Colour patterns	0.111	0.012
Conservation	**0.461**	**0.341**
Endemic	**0.343**	0.000
Activity	0.019	0.111
Seasonality	0.000	0.003
Feeding	0.108	**0.376**
Cultural use	0.004	0.088
Eigenvalue	2.160	2.149
Cumulative variance (%)	8.64	17.23

3.4. Flagship hotspots

A total of 19 hotspots were identified for large-bodied flagships (regions number 1, 2, 3, 4, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15, 16, 17, 19, 20, and 21 in Fig. S1) and 16 hotspots for small-bodied flagships (regions number 1, 5, 7, 8, 9, 10, 11, 12, 13, 14, 15, 16, 17, 18, 20, and 21 in Fig. S1). The combined map for large- and small-bodied flagships indicates the presence of flagship hotspots for both fleets combined in the mountains of Aïr, Hoggar, Tassili n'Ajjer and Mauritania, the Grand Erg Occidental, the Complex of Chotts, and the Nile River valley, and in sections of the Eastern Mountains, of the rivers White Nile, Niger and Senegal, and of the Western Corridor (see Fig. S1 for details). In both groups, flagship hotspots were located in particular Sahara-Sahel regions, such as mountains and waterbodies and are poorly overlapped by the current protected areas network (Fig. 3; Fig. S1).

4. Discussion

4.1. Methodological improvements from previous approaches

The two-step statistical approach here used, allowed the identification of flagship species and fleets in a systematic way. By assessing statistically which species traits contribute to flagship appealing, we answered researchers' call for effective flagship evaluation methods that avoid biases inherent to people's responses to questionnaires (Home et al., 2009; Veríssimo et al., 2011). Our approach is independent from questionnaire-based assessments, which would be impractical in the Sahara-Sahel anyway, as many species are unknown to the public but may display currently hidden characteristics suitable for flagships (Smith et al., 2012). The use of PCA with mixed data allowed assessing the contribution of numerical and categorical variables and improved the evaluation of traits contributing to flagship appeal. The use of clustering algorithms allowed identifying several flagship species

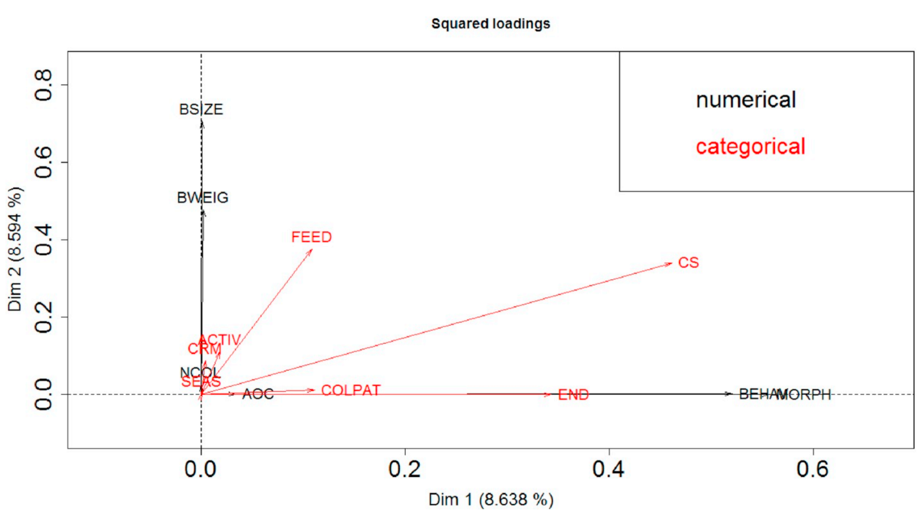

Fig. 1. Squared loadings of species traits within the first and second axes (Dim 1 and Dim 2) of the rotated Principal Component Analysis (PCA) with mixed data. The PCA is performed based on six numerical variables and seven categorical variables. See Table 2 for the correlation coefficients of the variables within the two rotated axes.

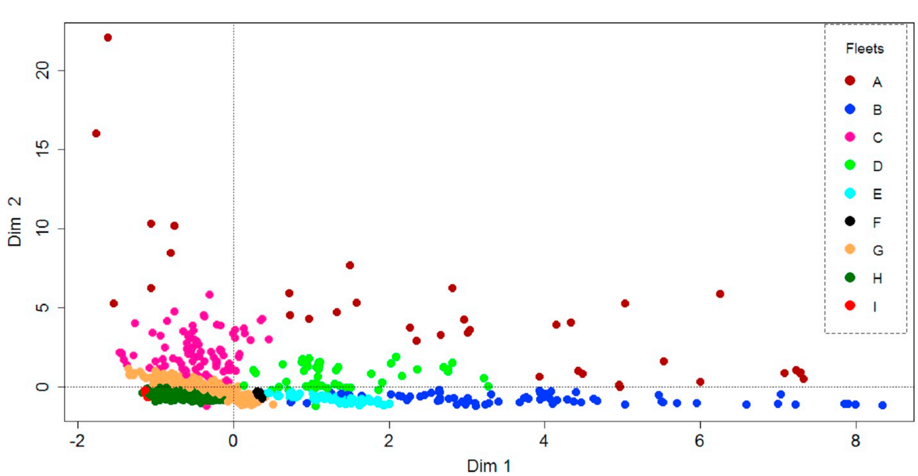

Fig. 2. Flagship fleets identified by the Bayesian Information Criterion (BIC) applied to the two first rotated axes (Dim 1 and Dim 2) of Principal Component Analysis with mixed data (PCAmix; see Text S2 for methodological details). Large-bodied flagships (brown points) and small-bodied flagships (dark blue points) were used to map flagship hotspots. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

Table 3

List of species within flagship fleets suitable for conservation and ecotourism flagship marketing campaigns in the Sahara-Sahel and indication of the class, taxa, common name, endemic status (END; Sahara or Sahel), IUCN conservation status (CS), and flagship hotspot (numbered by location) where they can be observed (see Fig. S1 for details on the areas considered). Species that are distributed outside the flagship hotspots are signalled (Outside). Species data follow IUCN (2017).

Class	Taxa	Common name	END	CS	Flagship hotspot
Fleet A – large-bodied flagships					
Mammalia	*Addax nasomaculatus*	Addax	Sahara	CR	6
	Ammotragus lervia	Barbary sheep	Sahara	VU	1; 6; 7; 9; 12; 13; 14; 16; 17; 19
	Equus africanus	African wild ass	–	CR	1; 20
	Eudorcas rufifrons	Red-fronted gazelle	Sahel	VU	2; 3; 4; 8; 10; 11
	Gazella cuvieri	Cuvier's gazelle	Sahara	EN	12; 13; 15
	Gazella dorcas	Dorcas gazelle	Sahara	VU	1; 6; 7; 8; 9; 10; 11; 12; 13; 14; 15; 16; 17; 19; 20
	Gazella leptoceros	Slender-horned gazelle	Sahara	EN	20
	Giraffa camelopardalis	Giraffe	–	LC	3; 4; 5
	Hippopotamus amphibius	Common hippopotamus	–	VU	2
	Kobus megaceros	Nile lechwe	–	EN	2
	Loxodonta africana	African elephant	–	VU	1; 2; 3; 4; 5; 8
	Nanger dama	Dama gazelle	Sahara	CR	6; 7
	Nanger soemmerringii	Grant's gazelle	–	VU	1
	Oryx beisa	Fringe-eared oryx	–	NT	1
	Oryx dammah	Scimitar-horned oryx	Sahara	EW	19
	Panthera leo	African lion	–	VU	2; 3; 4; 5
	Syncerus caffer	African buffalo	–	LC	2; 3
	Trichechus senegalensis	African manatee	–	VU	8; 10
Reptilia	*Acanthodactylus spinicauda*	Doumergue's fringe-fingered lizard	Sahara	CR	13
	Crocodylus niloticus	Nile crocodile	–	LC	1; 2; 20; 21
	Crocodylus suchus	West-African crocodile	–	NE	2; 3; 4; 5; 8; 10; 11; 19
	Naja nubiae	Nubian spitting cobra	Sahel	NE	1; 7; 19; 20
	Pseudocerastes fieldi	Field's horned viper	–	LC	Outside
	Pseudocerastes persicus	Perisan horned viper	–	LC	Outside
	Python sebae	Royal python	–	NE	1; 2; 3; 4; 5; 8; 10; 11
	Testudo kleinmanni	Egyptian tortoise	Sahara	CR	20
	Uromastyx acanthinura	Schmidt's spiny-tailed lizard	Sahara	NE	13; 15
	Uromastyx aegyptia	Egyptian spiny–tailed lizard	–	VU	20
	Uromastyx alfredschmidti	Schmidt's mastigure	Sahara	NT	16
	Uromastyx dispar	Sudan mastigure	Sahara	NE	2; 9; 11; 12; 14; 16; 17; 21
	Uromastyx geyri	Geyr's spiny-tailed lizard	Sahara	NE	7; 9; 14
	Uromastyx nigriventris	Moroccan spiny-tailed Lizard	Sahara	NE	12; 13; 15
	Uromastyx occidentalis	Giant spiny-tailed lizard	Sahara	NE	12
	Uromastyx ocellata	Ocellated spinytail	–	LC	1; 20; 21
	Uromastyx ornata	Ornate mastigure	–	LC	Outside
	Varanus griseus	Desert monitor	–	NE	1; 6; 7; 9; 11; 12; 13; 14; 15; 16; 17; 20; 21
Fleet B – small-bodied flagships					
Aves	*Passer cordofanicus*	Kordofan sparrow	Sahel	LC	Outside
	Passer luteus	Sudan golden sparrow	Sahel	LC	5; 7; 8; 9; 10; 11; 12
	Pterocles alchata	Pin-tailed sandgrouse	–	LC	12; 13; 15
	Pterocles coronatus	Crowned sandgrouse	–	LC	1; 7; 9; 11; 12; 13; 14; 15; 16; 18; 20
	Pterocles exustus	Chestnut-bellied sandgrouse	–	LC	5; 7; 8; 9; 10; 11; 20
	Pterocles gutturalis	Yellow-throated sandgrouse	–	LC	Outside
	Pterocles lichtensteinii	Lichtenstein's sandgrouse	–	LC	1; 7; 9; 12; 13; 14; 16; 20
	Pterocles orientalis	Black-bellied sandgrouse	–	LC	12; 13; 15
	Pterocles quadricinctus	Four-banded sandgrouse	–	LC	5; 8; 10
	Pterocles senegallus	Spotted sandgrouse	–	LC	1; 9; 11; 12; 13; 14; 15; 16; 18; 20; 21
Mammalia	*Crocidura tarfayensis*	Tarfaya shrew	Sahara	DD	12
	Ctenodactylus vali	Val's gundi	Sahara	DD	13
	Ictonyx libyca	Libyan striped weasel	Sahara	LC	5: 7; 8; 10; 11; 12; 13; 15; 16; 18; 20
	Jaculus jaculus	Lesser Egyptian jerboa	–	LC	5; 7; 8; 10; 11; 12; 13; 14; 15; 16; 18; 20
	Jaculus orientalis	Greater Egyptian jerboa	–	LC	15; 20
	Vulpes zerda	Fennec fox	Sahara	LC	5; 7; 8; 9; 10; 11; 12; 13; 14; 15; 16; 17; 18; 20; 21
Reptilia	*Acanthodactylus aegyptius*	Egyptian fringe-fingered lizard	Sahara	NE	18; 20
	Acanthodactylus aureus	Golden fringe-fingered lizard	Sahara	NE	12
	Acanthodactylus boskianus	Bosc's fringe-toed lizard	–	NE	1; 5; 7; 8; 9; 10; 11; 12; 13; 14; 15; 16; 18; 20; 21
	Acanthodactylus dumerili	Duméril's fringe-fingered lizard	Sahara	NE	8; 9; 10; 11; 12; 13; 14; 15
	Acanthodactylus longipes	Long fringe-fingered lizard	Sahara	NE	7; 11; 12; 13; 14; 15; 16; 18; 20
	Acanthodactylus opheodurus	Arnold's fringe-fingered lizard	–	LC	Outside
	Acanthodactylus scutellatus	Nidua fringe-fingered lizard	–	NE	7; 9; 11; 13; 14; 15; 16; 18; 20; 21
	Acanthodactylus taghitensis	Taghit's fringe-toed lizard	Sahara	DD	12
	Agama boueti	Bouet's agama	Sahel	LC	5; 7; 8; 9; 10; 11; 12
	Agama boulengeri	Boulenger's agama	Sahara	LC	11
	Agama spinosa	Spiny agama	–	LC	1; 20
	Agama tassiliensis	Tassili agama	Sahara	LC	7; 9; 14; 16
	Cerastes cerastes	Desert horned viper	–	NE	1; 7; 9; 11; 12; 13; 14; 15; 16; 18; 20
	Cerastes vipera	Sahara sand viper	–	LC	7; 8; 9; 10; 11; 12; 13; 14; 15; 16; 18; 20
	Chalcides boulengeri	Boulenger's feylinia	Sahara	NE	12; 13; 14; 15; 16; 18
	Chalcides delislei	De l'Isle's wedge-snouted skink	Sahel	LC	1; 5; 7; 8; 9; 10; 11; 12; 21
	Chalcides humilis	Ragazzi's bronze skink	Sahara	NE	1; 20

(*continued on next page*)

Table 3 (*continued*)

Class	Taxa	Common name	END	CS	Flagship hotspot
	C halcides sepsoides	Wedge-snouted skink-	Sahara	LC	18; 20
	Chalcides sphenopsiformis	Duméril's wedge-snouted skink	Sahara	LC	12
	Dasypeltis sahelensis	Sahel egg eater	Sahel	NE	5; 7; 8; 10; 11; 12
	Echis coloratus	Palestine saw-scaled viper	–	NE	1; 20
	Echis pyramidum	Egyptian saw-scaled viper	–	LC	5; 7; 8; 9; 10; 11; 12; 14; 21
	Eryx jaculus	Javelin sand boa	–	NE	18; 20
	Leptotyphlops algeriensis	Beaked thread-snake	Sahara	NE	7; 11; 12; 16
	Leptotyphlops boueti	Bouet's worm snake	Sahel	NE	8; 10
	Leptotyphlops cairi	Two-coloured blind snake	Sahara	NE	20; 21
	Leptotyphlops macrorhynchus	Beaked blind snake	–	NE	18; 20
	Leptotyphlops nursii	Nurse's blind snake	–	NE	Outside
	Mauremys leprosa	Mediterranean turtle	–	NE	12; 13; 15
	Mesalina rubropunctata	Red-spotted lizard	Sahara	NE	7; 9; 11; 12; 13; 14; 18; 20
	Philochortus lhotei	Lhote's shield-backed ground lizard	Sahel	NE	7; 14
	Pristurus adrarensis	Adrar semaphore gecko	Sahara	DD	11
	Pseudotrapelus sinaitus	Sinai agama	–	NE	20
	Ptyodactylus guttatus	Sinai fan-fingered gecko	–	NE	20
	Ptyodactylus hasselquistii	Yellow fan-fingered gecko	–	NE	20
	Ptyodactylus oudrii	Oudri's fan-footed gecko	–	LC	12; 13
	Ptyodactylus ragazzi	Ragazzi's fan-footed gecko	–	NE	5; 7; 8; 9; 10; 11; 14; 15; 21
	Ptyodactylus siphonorhina	Sinai fan-fingered gecko	Sahara	NE	5; 8; 9; 10; 11; 21
	Scincopus fasciatus	Peters' banded skink	Sahel	DD	5; 7; 8; 9; 10; 12; 13; 15; 21
	Scincus albifasciatus	Senegal sandfish	Sahara	NE	8; 10; 11; 12; 13
	Scincus scincus	Sandfish skink	–	NE	9; 13; 14; 15; 16; 18; 20; 21
	Stellagama stellio	Starred agama	–	LC	20
	Stenodactylus petri	Egyptian sand gecko	Sahara	NE	1; 7; 9; 11; 12; 13; 14; 15; 16; 18; 20
	Stenodactylus stenodactylus	Elegant gecko	Sahara	NE	1; 7; 9, 11; 12; 13; 14; 15; 16; 18; 20
	Trapelus boehmei	Desert agama	Sahara	LC	11; 12; 13
	Trapelus mutabilis	Desert agama	Sahara	NE	7; 9; 13; 14; 15; 16; 17, 18; 20
	Trapelus pallidus	Pallid agama	–	NE	20
	Trapelus schmitzi	Schmitz' agama	Sahara	DD	14; 16
	Trapelus tournevillei	Sahara agama	Sahara	LC	13; 15
	Tropiocolotes algericus	Algerian sand gecko	Sahara	NE	12; 13; 15
	Tropiocolotes bisharicus	Bishari pigmy gecko	Sahara	NE	1
	Tropiocolotes steudeneri	Algerian sand gecko	Sahara	NE	1; 7; 14; 16; 18; 20; 21
	Typhlops etheridgei	Mauritanian blind snake	Sahara	DD	11
	Typhlops vermicularis	European blind snake	–	NE	20

sharing similar characteristics (Batt, 2009) that can be used in multi-species-target campaigns, extending the benefits of future marketing campaigns to a wider range of biodiversity (Veríssimo et al., 2014).

The identification of flagship fleets considered all taxonomic groups together. The alternative strategy, analysing each taxonomic group individually, would likely inflate the importance of traits inside each taxonomic group that do not necessarily represent attractiveness in the real world. In the Sahara-Sahel, for instance, the area of occupancy for amphibians is a pointless variable due to the general desert environment of the region where few waterbodies are available to find them. Taxonomy-based analyses may also deflate the importance of traits that are commonly selected as attractive in real world situations identifying flagships (see Section 4.3 below). Pooling taxonomic groups onto the analysis allowed the statistics finding which are the most variable traits and how many fleets can be defined based on their intrinsic traits, thus not biasing (inflating or deflating) traits by taxonomic group and answering the need to identify flagship species objectively and independently of the taxonomic group to which they belong to (Santarém and Paiva, 2015; Veríssimo et al., 2014). Moreover, by pooling all taxa indiscriminately of their taxonomic group, we increased the chances of targeting higher number of different audiences at the same time, which may benefit a wider range of biodiversity (Di Minin et al., 2013; Hausmann et al., 2016).

The use of GIS approach allowed mapping the location of flagship hotspots, which may guide the implementation of flagship-based conservation initiatives. The methodology can be extrapolated to other biomes and the spatial approach here used constitutes a novel method that should be further explored in ecotourism-based research (Santarém et al., 2018).

4.2. *Potential methodological improvements for future works*

The method here used to identify flagship hotspots contains some potential caveats. Including variables associated with the perceptions of local people about flagships may improve flagship identification. For instance, species unlinked with human-wildlife conflicts may be acknowledged as important flagships, while crop-damaging species or species that kill humans may be difficult to promote as flagships with positive symbolic value (Barua et al., 2010). The ecological and economic roles (e.g. pollination and food provision, respectively), and population size (as a proxy for rareness) may also catalyse conservation actions efficiently (Barua et al., 2011; Ebner et al., 2016; Veríssimo et al., 2009).

Supervised machine-learning methods (Kotsiantis, 2007) can be used as alternative to the clustering method here applied to identify flagships. Based on a training set of successful flagship species together with species with low public appeal, models are trained to classify any species as flagship or not. Still, knowledge about the species under analysis must be available for effective method application (Smith et al., 2012).

Given the general paucity in the availability of accurate biodiversity distribution data in the Sahara-Sahel (Brito et al., 2014), the mapping of flagship hotspots was based in IUCN species distribution polygons. IUCN polygons depict the species full extent of occurrence and naturally include non-occurrence areas within the range, which probably inflated the rate of false presences (e.g. Graham and Hijmans, 2006) and introduced omission and commission errors (Macdonald et al., 2017). In contrast, the most remote areas of the Sahara-Sahel or the areas subjected to long-term local conflicts are likely under sampled

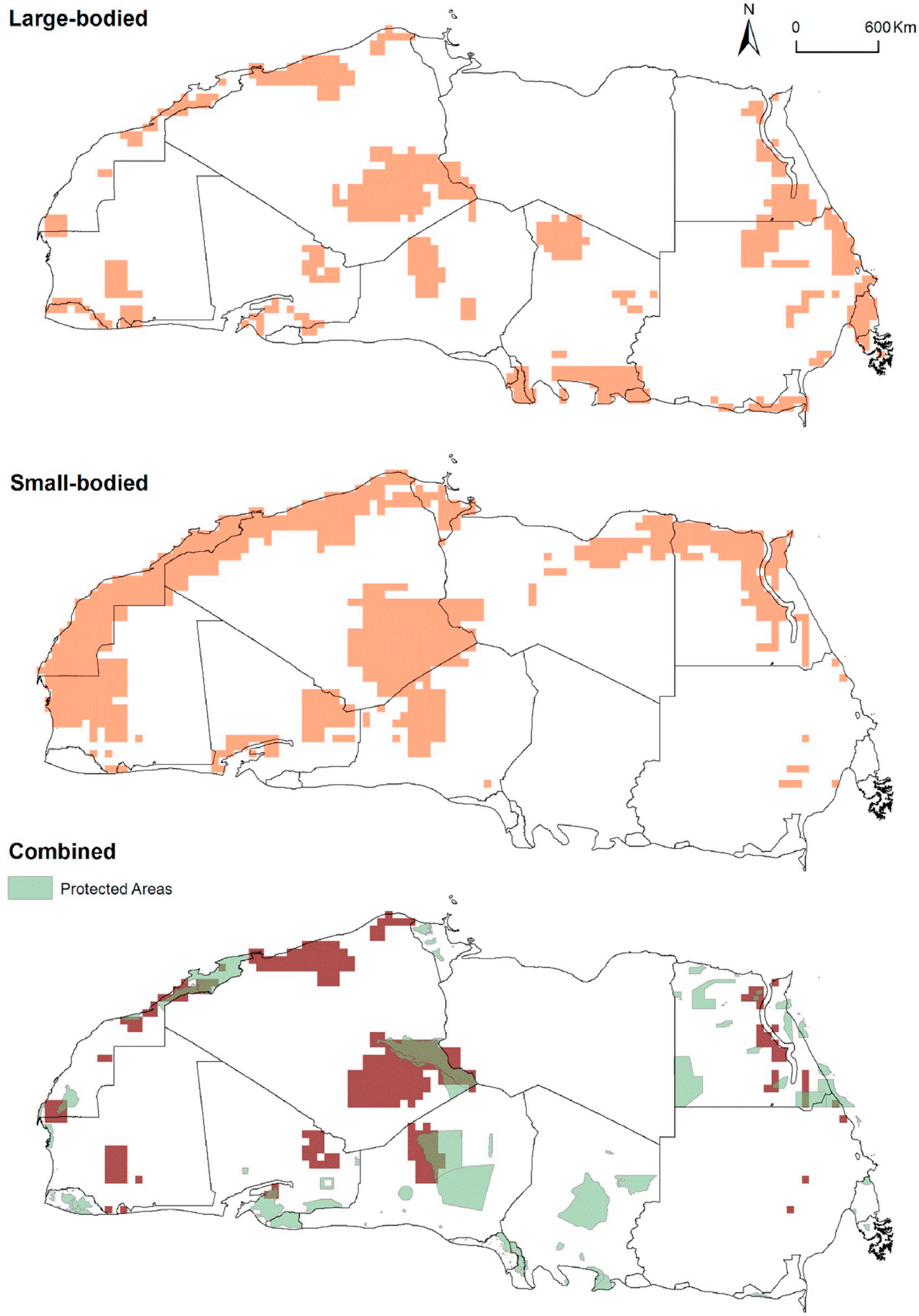

Fig. 3. Flagship Hotspots of large-bodied flagship fleets (above), small-bodied flagship fleets (centre), and both fleets combined (bottom) in the Sahara-Sahel. Areas with higher flagship richness are depicted in orange (above and centre) and dark red (bottom). The extent of Flagship Hotspots covered by current protected areas network (UNEP-WCMC and IUCN, 2018) is indicated by the Protected Areas polygons in the combined map. See Fig. S1 for the names of the areas. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

(Brito et al., 2016), which probably impacted the accuracy of the final mapped results. For instance, the combined map also demonstrates a completely absence of flagship hotspots in Libya and Chad and a poor representation in Sudan (Fig. 3). Additional research in these regions may dictate a different pattern, particularly in the data deficient Sudanese mountainous areas (Siddig, 2014), which may follow the general trend of flagship hotspots to be located in mountains (see Fig. 3 and Fig. S1 together). Although these constraints may cause some bias for the identified flagship hotspots due to deficient data, these effects were diluted when applying a coarse spatial resolution (pixel size of

0.5°). Still, future developments should target the use of accurate distribution data, for instance by deriving species ranges from ecological niche-based models. Additionally, the spatial and temporal dynamics of many flagships, such as migrating birds or hibernating reptiles, should be contemplated in future developments, as these influence the likelihood of species observation and consequently the location of flagship hotspots.

4.3. Factors relevant for assessing flagship species in deserts

When identifying flagship species, there are species traits that are highly related. For instance, endemic species tend to display unique adaptations to deserts and large species are generally heavy (see correlations in axes XX and YY in Fig. 1, respectively). These relationships helped to systematically build inferences on what characteristics are relevant for flagship appealing when applying statistical methods, as we did here.

Adaptations to deserts were relevant features in defining flagships in Sahara-Sahel (Fig. 1, Table 2), a finding similar to what was found in a study developed in Seychelles (Veríssimo et al., 2009), where species with unusual characteristics were selected by respondents. International tourists and ecotourism operators often prefer species with unique adaptations to the local environment as they turn out to be regional mottos where they live and hence can raise funds more efficiently than others without particular adaptations (Root-Bernstein and Armesto, 2013; Veríssimo et al., 2009).

Similarly, endemism stands out as an important feature for desert flagship species. Endemism was selected by local communities as an important feature for potential Brazilian flagships (Veríssimo et al., 2014), although tourists did not find it an important trait for Indian flagships (Takahashi et al., 2012). Rarity is also an attractive trait to the public that is willing to pay additional fees for ecotourism and conservation projects targeting endemic species (Veríssimo et al., 2009). This is an encouraging result for endemic-rich areas, such as Sahara-Sahel, composed by several developing countries where flagship-based ecotourism can have a positive role (Brito et al., 2014, 2016).

Body size and weight helped defining flagship species in Sahara-Sahel. Fascination with large animals is widely reported as a key-element in defining flagship appeal (Macdonald et al., 2015, 2017) and large and heavy animals are also preferred by international NGOs when implementing flagship-based conservation programmes (Clucas et al., 2008). However, even small-sized flagships are acknowledged by specific target groups of tourists (Ebner et al., 2016; Macdonald et al., 2017), which is relevant to the heterogeneous pattern we found between the identified flagship fleets in the Sahara-Sahel (fleet A – large-bodied flagships and fleet B – small-bodied flagships; Fig. 2, Table S1). Hence, even the smallest animals can be used in flagship marketing campaigns if they exhibit traits that make them appealing flagships (Smith et al., 2012). For instance, the small-bodied flagships fleet is composed by species that display many unique adaptations to deserts, such as the reptiles of genera *Acanthodactylus*, *Cerastes*, and *Scincus*, which may be preferred by specialized audiences in deserts (e.g. desert ecotourists and conservationists) and targeted for specialized desert marketing campaigns (Santarém et al., 2018).

Likelihood of extinction was also found to be highly associated to species with flagship characteristics in the Sahara-Sahel. This kind of 'last chance to see' tourism is typical for various ecotourism destinations with rapidly changing habitats (Lemelin et al., 2012) and as a phenomenon it is supported by many studies (e.g. Batt, 2009; Clucas et al., 2008; Ebner et al., 2016; Macdonald et al., 2015), which contrasts with the unimportance found in some works (e.g. Macdonald et al., 2017 and Smith et al., 2012). Notwithstanding, non-threatened species may still be suitable for flagship marketing campaigns, as common species may be promptly chosen as regional ambassadors by local communities when compared to infrequently encountered rare species (Takahashi et al., 2012). This has implications for Sahara-Sahel species, as many of them are not threatened or have not been yet evaluated (Brito et al., 2016).

4.4. Factors potentially relevant for defining flagship species in other biomes/scales

Several species traits were identified as less important in defining flagship species in the Sahara-Sahel but may be relevant in other biomes (e.g. tropical jungles) or other scales of analysis (e.g. local, national). Although area of occupancy was one of the least important variables in this study (a pattern consistent with findings of other works), still, it is widely accepted that species with narrow ranges can reinforce local allegiance and influence people's willingness to pay for conserving low distributed animals, while large-ranged species help promoting global priority regions (Barua et al., 2011; Bowen-Jones and Entwistle, 2002; Root-Bernstein and Armesto, 2013; Veríssimo et al., 2009, 2013). Thus, distribution patterns should be contextualized when identifying flagship species in different biome/scale contexts, as conservation problems may vary accordingly.

Despite we were unable to find a grouping pattern by diet, carnivores are generally preferred by international ecotourists and wider audiences, as people not facing wildlife damages generally revere them (Clucas et al., 2008; Macdonald et al., 2017). However, other feeding habits may be preferred by specific audiences and thus this needs to be further contextualized in order to consider different preferences.

Body patterns were not important for many people from different regions of the world in a global assessment (Macdonald et al., 2015). However, striking colour patterns have been found as an important attribute of flagship appealing in other taxonomic groups, namely invertebrates (Barua et al., 2012). Unusual colour patterns may attract specific audiences as well, and thus deserve to be contextualized, as people from different context may differ in their preferences towards colouration and body patterns (Macdonald et al., 2015).

Visibility traits followed similar results in bird flagships assessments (Veríssimo et al., 2009). This contrasts with the recommendations to use such feature in wildlife tourism, where diurnal activity pattern and predictable activity are considered influential to observers' preferences (Reynolds and Braithwaite, 2001). However, some specialized tourist segments may prefer rare and difficultly observable species in Africa (Di Minin et al., 2013), which opens an opportunity to broadening flagship marketing campaigns in the Sahara-Sahel.

It has been claimed that utilitarian values are not important to general tourists (Veríssimo et al., 2009), whereas local people put high value in the usefulness of species (Takahashi et al., 2012; Barua et al., 2012). International knowledge of species within the Sahara-Sahel is practically null (Brito et al., 2014), but there is an opportunity to explore this trait further once more scientific knowledge is raised. The use of poisons from desert species for medical research and cultural believes, and locally religious representations (e.g. old Animal-Gods in Egypt) can raise the profile of some neglected species, thus contributing to attract funds to its conservation through ecotourism initiatives.

The criteria here used serve as a set of guidelines for what attributes should be used to identify flagship fleets that resonate with different audiences. Both tourists and locals need to be considered when assessing such features (Macdonald et al., 2017; Smith et al., 2009). Considering both audiences motivates them to support flagship conservation projects, with implications to broader biodiversity (Barua et al., 2012; Takahashi et al., 2012).

4.5. Sahara-Sahel flagship fleets

The variability contained in the most important variables helped shaping fleets. The cluster algorithm grouped several species sharing similar characteristics with flagship appealing into nine flagships fleets, which potentially allows promoting many Sahara-Sahel species in multi-flagships campaigns, highlighting the benefits of using flagship fleets to preserve more than just only the most popular species (Veríssimo et al., 2014). From the fleets here identified, large- and small-bodied flagships, retaining many endemic species (e.g. *Addax nasomaculatus* in fleet A and *Acanthodactylus aureus* in fleet B; Table 3; Table S1), play a key role in the development of strategic marketing campaigns in Sahara-Sahel. Despite the shocking on-going extinction of Sahara-Sahel species (from which several of them were identified as flagships), the world is neglecting reversal conservation measures that would prevent their collapse (Durant et al., 2014; Brito et al., 2018). Hence, these two flagship fleets in particular can be used by local governments to raise the profile of currently overlooked species and to attract international conservation donors, as even less popular species might raise funds in special occasions (Hausmann et al., 2016; Macdonald et al., 2017; Veríssimo et al., 2017). Other ecotourism segments can be attracted as well, which may diversify and enhance tourism operations targeting alternative flagship species (Lindsey et al., 2007; Walpole and Leader-Williams, 2002).

Other identified fleets may be suitable for particular initiatives, for instance groups H and I are constituted by several bird species, thus being optimal for specific birdwatching and NGO's - BirdLife International - conservation campaigns, or for other segments of the society not specialized in desert biodiversity (Di Minin et al., 2013; Root-Bernstein and Armesto, 2013). Birds were poorly represented in the two most suitable fleets for flagship campaigns (fleets A and B) because there are few endemic birds in the Sahara-Sahel with adaptations to desert conditions (Table S1). However, they might be strong flagship species in other regions rich in endemic birds (e.g. in tropical islands; Veríssimo et al., 2009). No single amphibian was identified as suitable flagships for conservation marketing and ecotourism promotion campaigns (fleets A and B), as only two of them are endemic to the region (Table S1) and none displays adaptations to local conditions (Brito et al., 2016). Amphibians were investigated as candidate flagships in other works (e.g. Bride et al., 2008), presenting restricted opportunities for generalist audiences not primarily interested in observing regional desert endemic species and for amphibian-enthusiasts that wish to observe more species of this taxonomic group in the Sahara-Sahel. However, amphibians may be strong flagships for conservation and ecotourism stakeholders in other regions of the world, where amphibian richness is higher than in arid regions and where amphibian species display several adaptations to local conditions (e.g., in India; Kanagavel et al., 2017).

4.6. Flagship hotspots in the Sahara-Sahel

This was the first study mapping flagship hotspots that may attract ecotourists to these regions and that are able to fund conservation programmes targeting flagship species (Santarém and Paiva, 2015; Walpole and Leader-Williams, 2002). Overall, hotspots for large-bodied flagships were mostly fragmented, while hotspots for small-bodied flagship tend to be spatially continuous. This pattern reflects the high regional fragmentation levels of large animal populations (Brito et al., 2014, 2018; Durant et al., 2014) and highlights the need for designing corridors connecting these fragmented patches to protect large-bodied animals (Brito et al., 2016). Although total species richness is larger along the Sahel (Brito et al., 2016), the combined map of hotspots for both flagship fleets suggests that the central Sahara accumulates the highest flagship richness (Fig. 3) and that flagship-based observation initiatives probably should be prioritized in this region. Despite the prediction that the Sahel should offer more animal encounters than the Sahara due to local total species richness, it is here demonstrated that the Saharan mountains and waterbodies maximize flagship richness, and that these places may be optimal for flagship-targeted marketing campaigns.

The location of flagship hotspots is broadly coincident with priority conservation areas identified in Sahara-Sahel (Brito et al., 2016). Still, more than half of the flagship hotspots are not currently protected (Fig. 3), which urges the development of protecting schemes towards this unique desert biodiversity, as species occurring in areas of high conservation priority display added value for their conservation marketing (Macdonald et al., 2017). Flagship hotspots in Mauritania, Mali, Niger, and Egypt are particularly poorly protected. By identifying the areas concentrating more flagships, we complement the urgency of preserving these regions and provide local governments with an additional tool to raise funds through flagship species marketing campaigns (Santarém et al., 2018). As most of the species of large- and small-bodied flagship fleets correspond to the most threatened species in the Sahara-Sahel, ecological corridors and transboundary mega conservation areas should be prioritized if these species are to be saved (Brito et al., 2016).

5. Conclusions

Evaluating flagship species potential for biological conservation and ecotourism development is an increasing important focus area in many parts of the world, and flagship marketing remains a key fundraising tool for international agencies (e.g. IUCN and United Nations) and NGOs, local governments, and the scientific community. The approach developed here is scalable and replicable worldwide, and the used criteria serve as a set of guidelines for what attributes could and should be used to identify flagship fleets that resonate with different audiences. The methodology has implications for the preservation of several species, as it allows the identification of flagship fleets for conservation marketing and ecotourism promotion in a systematic way. By doing so, flagship-rich regions (flagship hotspots) located in low-income countries can attract international donors able to fund conservation campaigns, hence benefiting even the less popular and charismatic species.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.biocon.2018.10.017.

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