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Accuracy assessment of datasets on the geographic distribution of *Aotus* spp. using a new Georeferencing Reliability Index

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Studies on species distribution models evaluate the reliability and discrimination capacity of the models, while the accuracy of the spatial component of the data is often disregarded. The objective of our work was to design and validate an index, the Georeferencing Reliability Index (GRI), to measure and compare quality of different databases containing presence data of *Aotus* species. The database of *A. lemurinus* showed the highest georeferencing accuracy (GRI = 0.608) and that of *A. zonalis* the lowest (GRI = 0.167). Results indicated that there is poor-quality spatial information data for *Aotus* spp. Therefore, the distribution areas of all species should be more accurately established to evaluate whether they are at conservation risk. In addition, the index can be used to select the most accurate spatial data for constructing a species distribution model. Finally, we strongly believe that the GRI may provide accurate, up-to-date information essential for wildlife management programs.

Introduction

The geographic distribution of a species is defined as all locations in geographic space where it can be detected (Soberon *et al*. 2000), resulting from the interplay of intrinsic and extrinsic factors (Cabrera & Willink 1973, Benito de Pando 2008). Data for estimating the distribution area of a species are collected primarily through censuses or sample surveys which are expensive, time-consuming and not always applicable due to either climatic, geographical or political reasons, among others. This led to the development of methods for species distribution modelling based on available information, using collection sites and sight records for the species under consideration as spatial attributes (Brito *et al*. 2011, Desrochers *et al*. 2011, Vidal-García & Serio-Silva 2011, Hao *et al*. 2012, McKinney *et al*. 2012, Norman *et al*. 2012, Somodi *et al*.

2012). Indeed, the assessment of data quality depends on the model. Unfortunately, despite the abundance of specimens in museum collections worldwide, there are few records of sufficiently high quality to be included in biogeographic analyses (Soberon *et al*. 2000, Lobo & Hortal 2003, García-Milagros & Funk 2010, Newbold 2010). Therefore, in order to avoid misleading conclusions, both quantity of available records and quality of spatial data are paramount issues in the field of biogeography (Bauzer-Medeiros & Pires 1994, Alhqvist *et al*. 2000, Beard 2001, Elzinga *et al*. 2001, Jager & King 2004, Boakes *et al*. 2010, Lobo & Tognelli 2011, Rocchini *et al*. 2011).

The Geographic Information System (GIS) allows for the development of studies at a regional scale, such as the mapping of natural resources, plants and animals. Species distribution models (SDMs) are tools that combine these different information sources. SDMs take into account the quantity and quality of the species records and of the model-based variables, as well as the precision and accuracy of the data (Elith & Leathwick 2009, Rodriguez-Castañeda *et al*. 2012, Wisz *et al*. 2013). In general terms, the software generating SDMs is quite robust so that the resulting model is not affected by small variations in the accuracy of the spatial component of a database (Visscher 2006, Graham *et al*. 2008, Buisson *et al*. 2010). Consequently, when researchers generate thematic and SDM maps, they usually retrieve data from the original dataset without evaluating the quality of the georeferences (Elith & Leathwick 2007, López-Arévaloa *et al*. 2011, Pliscoff & Fuentes-Castillo 2011, Campos & Jack 2013, Shanee *et al*. 2013).

Several problems may arise when the geographic location of specimens from museum collection records is transcribed into coordinates, i.e., some localities on museum tags are more accurate than others. This emphasizes the importance of assessing the accuracy of each record and of the overall dataset used to construct a map. Aiming at developing data documentation standards to be used among networking collections, August *et al*. (1996) encouraged collectors to provide information on the latitude and longitude of the collection site on a regular basis. Moreover, to rank the accuracy of the coordinate determinations, they created the Coordinate Precision Index (CPI), with values ranging from 1 (coordinate data using the GPS technology) to 9 (no available locality data). However, the index is seldom used when determining which records are included in a species distribution map.

Currently, some authors have proposed methods to study and compare the accuracy and other attributes of the spatial component between, for example, maps and distribution models (Finn 1993, Pontius 2000, Wieczorek *et al*. 2004, Guo *et al*. 2008). They show advantages and disadvantages depending upon the specific dataset (Table 1). However, no example is provided to show their potential use in the context of a species or genus.

From this standpoint a new approach for assessing the quality of a georeferenced dataset is needed. This situation applies to the geographic distribution of most biota. In particular, primates represent a good model because they show a worldwide distribution, include a high proportion of threatened species and their collections are often incomplete and inaccurately georeferenced. In addition, the number of primate species at risk of extinction is increasing rapidly due to heavy deforestation (IUCN 2011). Moreover, only a few distribution maps of primates have been made using these methods (Thorn *et al*. 2007, Ortiz-Martínez *et al*. 2008, Boubli & Lima 2009, Mercado & Wallace 2010, Vidal-García & Serio-Silva 2011, Mantilla-Meluk & Giménez-Ortega 2011). The SDMs appear as a viable alternative to provide missing information on primates from many neotropical areas where censuses and samplings are difficult to implement. Indeed, the SDMs generate higher resolution maps which contribute to better decisions regarding conservation planning.

The owl monkey (*Aotus* spp.) is a nocturnal primate widely distributed through Central and South American tropical rainforests, from Panamá to Paraguay and northern Argentina (Defler & Bueno 2007) for whom geographic data are notably scarce and available information suggests that some populations are declining (IUCN 2011). Hershkovitz (1983) reconstructed the genus' geographic distribution using presence records from a few localities, with biomes and major rivers as references for delimiting the

Table 1. Comparison of some evaluation methods for species distribution models.

Method	Example of use (species/taxon)	Description	Advantages	Disadvantages
AMII (Average Mutual Information Index; *see* Finn 1993)	None	For comparison of maps, it evaluates prediction model accuracy by measuring the agreement between patterns. Based on the Normalized mutual information (NMI).	It provides a function that compares maps obtained using different methodologies.	Index values may be overestimated. It cannot differentiate the worse-than-random model from the best-than-random model.
CPI (Coordinate Precision Index; *see* August *et al*. 1996)	Mammals	For mammal databases. The collector classifies the accuracy of the geographic data into many categories.	Fast, simple and easy to apply. It can be included in specimen museum tags.	The collector must indicate the degree of accuracy of the geographic coordinates. Only the collector can assign categories. It evaluates individual records rather than the entire database.
Error Comparison (*see* Pontius 2000)	None	For analyzing quantification error *versus* location error in a comparison between maps.	Simple	It does not take into account original records. It compares between maps, considering one of them the true map.
Point-Radius method (*see* Wieczorek *et al*. 2004)	Mammals, birds, malaria	For georeferenced localities from collection data. It calculates uncertainties inherent to each record.	It is fast, simple and yields consistent results.	It depends on the available sources for georeferencing, does not assess a pool of records and assumes that uncertainty is equally distributed around a central point.
Probability distributions of spatial uncertainties (Guo *et al*. 2008)	None	For georeferenced localities from collection data. It calculates uncertainties inherent to each record through a probability density function.	It is fast, simple and yields consistent results, providing a probability density function around the point.	It depends on the available sources for georeferencing and does not assess a pool of records.
GRI (Georeferencing Reliability Index)	Primates (*Aotus* sp.)	This study	It is fast, simple and very useful when working with data from museum collections and the literature. It can evaluate an entire database and allows comparison between datasets. *A posteriori*.	It may lead to misinterpretations because the collector does not assign the categories. The number of records are not considered.

area occupied by each *Aotus* species. Later, other researchers used the geographic distribution of the *Aotus* species proposed by Hershkovitz with small modifications depending on whether they considered some populations as species or subspecies (Ford 1994, Plautz *et al*. 2009, Menezes *et al*. 2010). In addition, although some field studies produced maps containing updated information, they covered limited and scattered geographic areas (Cornejo *et al*. 2008, Defler 2010). Recently, Alvarez-Gonçalvez *et al*. (2013) generated an integral map in an attempt to provide a broader picture of the current biogeography of *Aotus* spp.

In order to address this knowledge gap, our objective was to design and validate an index to measure and compare the quality of different databases containing georeferenced presence/absence data of *Aotus* (Cebidae, Platyrrhini) species. We believe that it may be used as a valuable tool for estimating the reliability of databases created some years ago and may allow insight into the accuracy of species distribution maps generated by SDMs from different types of sources.

Material and methods

We used the following steps to develop the index: (1) Definition of categories according to the reliability of the geographic coordinates of the collecting sites, and assignment a score to each one; (2) construction of a dichotomous key for standardizing the assignment of different categories to records; and (3) development of the Georeferencing Reliability Index (GRI). For validation purposes, we first tested the GRI with hypothetical data before applying it to actual data on the geographic distribution of the genus *Aotus*.

Index development

Georeferencing quality categories and score assignment

We established seven georeferencing reliability categories (GRC) based on the classification proposed by Benito de Pando (2008):

- GRC 1: coordinate data obtained using the GPS technology (systematic sampling), with an accuracy of a few meters (within the error of the GPS);
- GRC 2: coordinate data obtained using the GPS (random sampling), with the same accuracy as that for GRC 1;
- GRC 3: coordinate data obtained from a polygon or a point of a high-resolution map, with an accuracy below 100 m;
- GRC 4: coordinate data obtained from a location plotted by hand on a high-resolution map, with an accuracy below 4 km^2;
- GRC 5: coordinate data taken from a UTM (Universal Transverse Mercator) grid, with a resolution greater than 4 km^2;
- GRC 6: coordinates obtained from toponymic data;
- GRC 7: other sources.

These categories are ranked from higher (GRC 1) to lower (GRC 7) coordinate accuracy, with georeferencing reliability scores (GRS) ranging from 6 to 0, respectively. Thus, the more reliable a category is (e.g. coordinates from the GPS), the higher the GRS will be.

Dichotomous key

We created a dichotomous key as a tool to unequivocally assign each latitude/longitude record from a database to one of the categories described above (Table 2). This allowed us to give a georeferencing reliability score (GRS) to each georeferencing reliability category (GRC).

Georeferencing Reliability Index

For each database, we calculated the normalized average of the georeferencing reliability scores (GRS) to compute the Georeferencing Reliability Index (GRI) using the following formula:

$$\mathrm{GRI} = \frac{\sum_{i=0}^{n} \mathrm{GRS}_i}{6n} \quad (1)$$

where, $\sum$GRS is the sum of the georeferencing

Table 2. Dichotomous key for assigning georeferencing reliability categories (GRC) to records, used to calculate the georeferencing reliability score (GRS).

A	Reliable species identification	B
A´	Unreliable species identification	Record not considered
B	Systematic sampling	C
B´	Random sampling	D
C	Presence record obtained using GPS	GRC 1 = 6 points
C´	Presence record not obtained using GPS; coordinates accurate to arcmins or collection site within 4 km^2 from coordinates given	GRC 3 = 4 points
C´´	Presence record not obtained using GPS; coordinates neither accurate to arcmins, nor collection site within 4 km^2 from coordinates given	E
D	Presence record obtained using GPS	GRC 2 = 5 points
D´	Presence record not obtained using GPS; coordinates accurate to arcmin/min or collection site within 4 km^2 from coordinates given	GRC 3 = 4 points
D´´	Presence record not obtained using GPS; coordinates neither accurate to arcmins, nor collection site within 4 km^2 from coordinates given	E
E	Sampling points located on a map	F
E´	Sampling points not located on a map	G
F	High-resolution map (resolution < 4 km^2)	GRC 3 = 4 points
F´	High- or medium-resolution map; sampling points plotted by hand (resolution > 4 km^2)	GRC 4 = 3 points
F´´	Low-resolution map	GRC7 = 0 points
G	Coordinates of the records given in UTM coordinates (resolution > 4 km^2)	GRC 5 = 2 points
G´	Coordinates of the records not given in UTM coordinates	H
H	Location of the record defined by toponymy, making reference to a city or locality	I
H´	Location of the record defined or not by toponymy, but making reference to a large region	GRC 7 = 0 points
I	Approximate coordinates can be obtained from a gazetteer	GRC 6 = 1 points
I´	Approximate coordinates cannot be obtained from a gazetteer	GRC 7 = 0 points

reliability scores in the database, n is the number of records in the database, and $6n$ is the maximum value for the sum of the georeferencing reliability scores that can be obtained if all the records in the database are ranked as GRC 1 (GRS = 6).

The index ranges between 0 and 1, indicating minimum and maximum georeferencing reliability of a database, respectively.

GRI analysis based on hypothetical cases

We built two hypothetical databases to assess the validity of the index: one containing a majority of highly accurate records, and the other containing records with geographic coordinates obtained from toponymic information (Table 3). As explained above, we first assigned a score to each record and then calculated the GRI for each database using Eq. 1. For the first database the index was calculated as:

Table 3. Records for two hypothetical databases with the corresponding categories and scores. GRC = georeferencing reliability category, GRS = georeferencing reliability score.

Record	Source of spatial data	GRC	GRS
Database 1			
1	Random (GPS)	2	5
2	UTM grid	5	2
3	Random (GPS)	2	5
4	Random (GPS)	2	5
5	Random (GPS)	2	5
6	Point on high-resolution map	3	4
7	Random (GPS)	2	5
Database 2			
1	Toponymic	6	1
2	Toponymic	6	1
3	Toponymic	6	1
4	UTM grid	5	2
5	Toponymic	6	1
6	Point plotted by hand on high-resolution map	4	3
7	Point on high-resolution map	3	4

$$GRI = (5 + 2 + 5 + 5 + 5 + 4 + 5)/(6 \times 7) = 0.738,$$

and for the second database the index was calculated as:

$$GRI = (1 + 1 + 1 + 2 + 1 + 4 + 4)/(6 \times 7) = 0.333.$$

These results reveal that the index proposed by us is able to characterize high- and low-quality databases and allows their comparison.

Results

Following development of the GRI, we applied the index to databases that included specimens of all 10 species currently assigned to the genus *Aotus* (Hershkovitz 1983, Ford 1994, Defler & Bueno 2007). Each dataset recorded the presence or absence of specimens in one species. We compiled their geographic location from museum collections, the literature and consultation with experts (Alvarez-Gonçalvez *et al*. 2013). Overall, we collected data of 322 owl monkeys from different locations, which were not evenly distributed since smaller countries had equal or greater numbers of records than larger countries. Data had a highly variable degree of accuracy due to the diverse sources of information, e.g. only 243 of the records were georeferenced (Alvarez-Gonçalvez *et al*. 2013). This provided a testing ground for quality assessment of the data sets with the GRI, which was obtained as explained above. Table 4 lists the values of the GRI for each species and the genus.

Table 4. Localities where the presence of different *Aotus* species was recorded and their corresponding GRI values.

Species	Number of localities with presence	GRI
A. azarae	99	0.569
A. brumbacki	11	0.333
A. griseimembra	27	0.253
A. lemurinus	17	0.608
A. miconax	20	0.588
A. nancymae	36	0.565
A. nigriceps	13	0.474
A. trivirgatus	9	0.278
A. vociferans	47	0.557
A. zonalis	43	0.167
Genus *Aotus*	322	0.464

We obtained GRI values lower than 0.5 for each data set due to the poor accuracy of most geographic locations. According to the index, the database of *A. lemurinus* showed the highest georeferencing accuracy (GRI = 0.608) and that of *A. zonalis* the lowest (GRI = 0.167).

Discussion

Studies on species distribution models measure the reliability and discrimination of the model's capacity rather than the accuracy of the spatial component of data (Lobo *et al*. 2008, Liu *et al*. 2009). A revision of the available bibliography involving the use of SDMs reveals that very little attention has been directed at evaluating the accuracy of spatial information for each record in the dataset. However, as shown in Table 1, some researchers such as August *et al*. (1996) provided useful tools (e.g. the Coordinate Precision Index) to evaluate the spatial components of the data. Although their method involves the classification of records into several categories, it does not allow evaluating the entire database. In contrast, the GRI certainly can be used to assess the accuracy of the geographic coordinates for not only each record but also a whole dataset. In addition, some categories of the Coordinate Precision Index must be assigned by the collectors themselves, and may be ambiguous when using literature sources and old databases. For this reason, we decided not to consider such categories in our paper.

Assessment of the quality of the spatial components of the data is particularly important for primate collections in museums, since most of the locations of the specimens were registered before the implementation of the GPS. The lack of a standardized, objective procedure to select good-quality data is a matter of concern for researchers who attempt to set conservation priorities. Indeed, adequate assessment of the conservation status of a species, which relies on the best available scientific evidence, is a starting point for making decisions about the implementation of efficient conservation measures.

Species distribution models are sensitive to sample size and to the quality of spatial data. In the particular case of *Aotus* species, the index indicated that data provided poor spatial information, either because of their limited number or because of their low accuracy. Our analyses revealed that the distribution areas of all *Aotus* species should be more accurately established to consider whether they are at conservation risk. In determining the geographic distribution of the genus *Aotus*, the index indicated that there were differences in accuracy among species data sets. For example, the number of records of *Aotus zonalis* is comparable to that of *A. vociferans* (n = 43 *vs*. n = 47, respectively) but they provide spatial information of lower quality (GRI = 0.557). This emphasizes the importance of taking into account not only the quantity of records but also the quality of their spatial component. Despite the fact that the *Aotus* species under consideration are not listed by the IUCN as data deficient (DD) and considering our previous explanation, the low values of GRI obtained suggests that more attention is needed to improve the quality of the data. This may be common for many researchers who, like us, have to face the issue that the location of the records (obtained from diverse sources and collected over a long time period) was determined using different methods providing different levels of accuracy.

It is important to point out that the index does not assess the spatial quality of a database, not of individual records independently of the number of record considered. Since the accuracy of a map strongly depends upon the quality of the data used to construct it, the GRI can be considered as an additional tool for evaluating the usefulness of maps and models and the conclusions drawn from their results.

In the present work, we developed the georeferencing reliability index (GRI), which proved to be useful for assessing the reliability of museum records, for comparison between databases containing the same or different numbers of records, and to detect spatial information gaps (*see* the case of *A. zonalis* and *A. vociferans* mentioned above). The GRI emerges as a complementary and useful tool, providing up-to-date information for wildlife management programs focused on threatened species, since more urgent efforts and resources need to be put on at-risk species with lower GRI values.

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