Fragmenta entomologica, 51 (1): 1-10 (2019)

eISSN: 2284-4880 (online version)
pISSN: 0429-288X (print version)

Research article
Submitted: January 15th, 2019 - *Accepted*: April 29th, 2019 - *Published*: May 31st, 2019

Entomological knowledge in Madagascar by GBIF datasets: estimates on the coverage and possible biases (Insecta)

Mattia IANNELLA, Paola D'ALESSANDRO *, Maurizio BIONDI

University of L'Aquila, Department of Health, Life and Environmental Sciences, Section of Environmental Sciences - Via Vetoio, 67100 L'Aquila, Italy
mattia.iannella@univaq.it; paola.dalessandro@univaq.it *; maurizio.biondi@univaq.it
* Corresponding author

Abstract
Although Madagascar is one of the world's most important biodiversity hotspots, the knowledge of its faunistic diversity is still incomplete, notwithstanding many field campaigns were organized since the 17th century until nowadays, leading to a huge number of vertebrate and invertebrate records. In this contribution, taking into consideration the geographic distribution by a GBIF dataset including 286,764 records referred to nine insect orders (Coleoptera, Diptera, Hemiptera, Hymenoptera, Lepidoptera, Neuroptera, Odonata, Orthoptera, Trichoptera), we tried to supply some observations on the spatial distribution and to point out some possible biases in the entomological knowledge of Madagascar. Hymenoptera, Coleoptera and Diptera were the most represented orders in the dataset, respectively. Some orders show many "coupled" sampling, with peaks of shared sampled localities between Diptera with Hymenoptera (98.07%) and Hemiptera with Coleoptera (64.21%). Considering the geographic location and the extension of the vegetation macrogroups in Madagascar, the entomological data result unevenly distributed. Current Protected Areas' (PAs) network covers about the 70% of the total of the collecting localities for the nine insect orders considered, even though some, such as Trichoptera, Odonata, and Neuroptera seem significantly less protected than others. However, the possible new PAs planned for Madagascar could greatly increase in the future the protection level for all 9 insect orders analyzed, especially for Neuroptera, Odonata and Lepidoptera. A percentage of 82.3% of the whole sampling localities falls inside the PAs themselves or within 1000 m from their borders. A similar pattern is observed for the road network: the 62.9% of the localities fall at least at 1000 m from a road, with no sampling localities observed further than 10 km from a road; statistically significant clusters were observed in evaluating these biases, coinciding with major towns or PAs.

Key words: Madagascar, Insect distribution, Global Biodiversity Information Facility (GBIF), Vegetation macrogroups, GIS analysis, Data coverage, Protected areas system, Hotspot analysis.

Introduction

Madagascar has been designated one of the world's most important biodiversity hotspots, and it is characterized by a disproportionally diverse flora and fauna (Goodman and Benstead 2003, 2005). Recent studies on the Malagasy fauna have led to a great increase in the number of known animal species and have revealed high proportions of cryptic diversity and microendemism in several animal groups (Biondi 2001; Goodman & Benstead 2005; Townsend et al. 2009; Vences et al. 2009; Wesener et al. 2011; Biondi & D'Alessandro 2013, 2016; D'Alessandro et al. 2014). However, because of the presence of diverse biota that have evolved in isolation, and the regionally pronounced and locally steep environmental gradients, getting a good knowledge of the megadiverse fauna of the Madagascar is still a far-reaching goal, especially for the invertebrates.

The first work on Madagascar's fauna, which was essentially limited to vertebrates, was published as early as 1658 by Etienne de Flacourt, the general governor of the French colony of Fort Dauphin (Tolagnaro) (Paulian & Viette 2003). The true, formal natural exploration expeditions in Madagascar started in the eighteenth century, with "naturalist travelers" (Paulian 1954) attracted by the reports of previous voyagers, generally merchants or representatives of European Countries, on Madagascan flora and fauna.

In 1833, Boisduval and Klug published general surveys of the Lepidoptera and Coleoptera of the Madagascar region, respectively. The first attempt toward a general review of Madagascar's invertebrates was made by Alfred Grandidier (1886-1902) at the turn of the nineteenth century, in "Histoire physique, naturelle et politique de Madagascar". This work included the checklist of Coleoptera and monographs of such groups as Mollusca, Myriapoda, Lepidoptera Rhopalocera, Blattodea, Mantodea, Hymenoptera Formicidae, and a few other family groups of Hymenoptera. The phase of the naturalist travelers was followed by the period of the "naturalist amateurs" (Paulian 1954; Viette 1991), from the beginning of the twentieth century, to the World War II. In this period, the activity of the Académie Malgache (AM) begun, with comprehensive publications on several insect groups in its Bulletin and Mémoires. After the World War II, the creation of the Institut de Recherche Scientifique de Madagascar (IRSM), in 1947, gave a new boost to the zoological research in the island. It favored the arrival of professional scientists who brought a modern way to do research on the field, with standardized techniques for more effective collections and more complete knowledge of the fauna, even in the less known areas, difficult to reach (e.g. Tsaratanàna, Andrigitra, Antsingy). Until the end of 1960s, the AM and IRSM supported frequent zoological expeditions. Most of the hundreds of scientific reports on the results of such expeditions were edited in Faune de Madagascar, published under the auspices of the Government of the Republique Malgache, by the Museum d'Histoire Naturelle, Paris, and in Bullétin de l'Académie Malgache, Mémoires de l'Académie Malgache, Le Naturaliste Malgache, and the Mémoires de l'Institut Scientifique de Madagascar. From 1970 to 1973, active field work was carried out in several mountain areas under the Programme n° 225 of the French Centre National de la Recherche Scientifique. Even though the main goal of the Programme was getting floristic data, it also provided important material for taxonomic entomological research.

After a period of difficult political transition, lasted until 1985, when few contributions were made on the faunal exploration of Madagascar, current public and private Madagascan Institutions dealing with environmental and conservationist issues, along with Non-Governmental Organizations, have become very active: biological sciences, which includes studies on the fauna, is the only field of the Madagascan research constantly growing (Andriamialisoa & Langrand 2003; Gaillard 2011). Recent expeditions incorporated researchers of different nationalities and specialties, under the aegis of World-Wide Fund for Nature, Muséum National d'Histoire Naturelle (Paris), Smithsonian Institution (Washington, D.C.), California Academy of Science (San Francisco), Field Museum of Natural History (Chicago), The Natural History Museum (London). Even though important collections made during these surveys are, for the most part, still waiting to be studied (Authors pers. com.; Paulian & Viette 2003), an increasing number of taxonomic papers have been published in different scientific journals and databases. Some taxonomic groups were investigated better than other, because of the major activity of their collectors.

In this context, we have considered interesting, through the analysis of a large GBIF (Global Biodiversity Information Facility) dataset referred to 286,764 presence locations of nine orders of insects, to estimate the current coverage in the knowledge of the entomofauna in Madagascar, trying to evaluate:

a) the areas with highest and lowest number of records;
b) possible significant connections with vegetation macrogroups (*sensu* Sayre et al. 2013);
c) possible significant connections with current and proposed protected areas;
d) possible existence of correlations between records and infrastructures, specifically the road network.

Material and methods

Study area

The study area considered in this research is the island of Madagascar. Its bioclimatic zones comprise humid, subhumid, montane, dry, and subarid environments with distinct geographic and vegetation formations (Sayre et al. 2013).

Datasets

We considered a GBIF dataset (GBIF 2018; access from January 2016 to October 2018) of nine orders of insects: Coleoptera, Diptera, Hemiptera, Hymenoptera, Lepidoptera, Neuroptera, Odonata, Orthoptera and Trichoptera. For each order listed, we acquired GPS points of presence sites using records of species occurrence within Madagascar; records with coordinates missing or failing to match the locality description, were excluded from our analysis. GBIF is a portal that collates digitized collection and survey data, and is the largest online provider of distribution records. Notwithstanding the distributional databases are considered as spatially biased, due to uneven effort of sampling, data storage and mobilization, GBIF, as "digital accessible information" (DAI), however, represents an important resource that allows to gather huge amounts of data also for areas where structured data are not available (Amano et al. 2016).

For our analysis, we used as "operational unit" a taxonomic level of "order", taking into account that geographic biases can potentially increase when dealing with lower taxonomic levels (family, genus, species) (Bielby et al. 2006; D'Alessandro et al. 2018).

The database consisted of a total of 286,764 records, distributed as follows: Coleoptera (71,842); Diptera (27,066); Hemiptera (22,382); Hymenoptera (148,985); Lepidoptera (8568); Neuroptera (4777); Odonata (964); Orthoptera (1021); Trichoptera (5483).

Protected areas and infrastructures

Data of both current and proposed Madagascar's Protected Areas (PAs) (Gardner et al. 2018) were downloaded from the Réseau de la Biodiversité de Madagascar repository (REBIOMA 2018). Spatial information of roads of the whole study area were obtained from the OpenStreetMaps' Humanitarian Data Exchange (HDX) dataset (OpenStreetMap 2018).

GIS analysis

Biodiversity data analysis through Geographic Information Systems (GIS) represents a fundamental technique which helps to discover different aspects of conservation and management of nature (e.g. Iannella et al. 2016; Engen et al. 2018; Iannella et al. 2018a, 2018b; Siles et al. 2018).

The distance of presence sites (point shapefiles) from each analyzed feature (PAs and roads) was calculated through the 'Extract values to points' command performed over the rasters resulting from the 'Euclidean distance' (maximum distance set to 10 km) analysis on PAs or roads layers, both performed in ArcMap 10.0 (ESRI 2010).

The point shapefiles containing distance information were used to create two distance grids over the study area, both for PAs and roads, through a spatial join. The grids were produced with the 'Generate Tessellation' tool in ArcMap 10.0 (with each element size = 500 km^2). After the spatial joining process, if a single cell contained more than one point within (thus more than a single distance value), the median distance was calculated for the cell, in order to down-weight possible outliers.

The distance grids were analyzed with a hotspot analysis ['Hot Spot Analysis (Getis-Ord GI*)'] tool in ArcMap 10.0 (ESRI 2010), to highlight possible statistically significant clusters (hot- or cold-spots) in which non-random sampling was possibly carried out in terms of low (cold-spot) or high (hot-spot) distances from a road or a PA's border. All spatial-referenced data and intermediate geoprocesses not listed above were managed in ArcMap 10.0 (ESRI 2010).

Results

The number of presence sites (GPS points) and records present in the GBIF dataset analyzed are reported in Table 1 and Fig. 1. Based on GBIF data, the best investigated groups, in terms of number of GPS points and records, are Hymenoptera (3008; 148,975), Coleoptera (989; 71842), Diptera (708; 27,066), and Hemiptera (556; 22382). Groups with the lowest number of GPS points and records are Odonata (258; 964), Orthoptera (216; 1021), and Trichoptera (227; 1159). The numbers for Neuroptera and Lepidoptera were 218; 4799 and 1076; 8568 respectively. Based on the ratio between total records/total GPS points (Table 1), it is evident that the average number of records per site results strongly variable among the nine orders considered, with the highest values for Coleoptera (72.64), Hymenoptera (49.53), Hemiptera (40.26), and Diptera (32.23) respectively, and the lowest ones for Odonata (3.74), Orthoptera (4.73), Trichoptera (5.11), and Lepidoptera (7.96) respectively.

The distribution of records within the different vegetation macrogroups of Madagascar (Fig. 2a), also reported in Table 1 and, as percentage, in Table 2, are shown in Fig. 2b. Hymenoptera have the highest number of records (148,975) and presence sites (3008), which fall with highest percentages in: 1.A.2.Fe.2-Eastern Madagascar Subhumid Forest (20.49%), 1.A.2.Fe.1-Eastern Madagascar Lowland Rainforest (19.14%) and 1.A.1.Fe.1-Madagascar Western Dry Forest (16.68%). Coleoptera, with 71,842 records distributed in 989 sites, show the highest percentage of reports in: 1.A.1.Fe.1-Madagascar Western Dry For-

Table 1 – Total number of records, total presence sites and number of records in each vegetation macrogroup for the nine insect orders considered: COL (Coleoptera); DIP (Diptera); HEM (Hemiptera); HYM (Hymenoptera); LEP (Lepidoptera); NEU (Neuroptera); ODO (Odonata); ORT (Orthoptera); TRI (Trichoptera) (see text).

Vegetational macrogroups	Orders	COL	DIP	HEM	HYM	LEP	NEU	ODO	ORT	TRI
Type 0	6796	3016	116	648	2816	32	115	5	28	20
1.A.2.Fe.5-Madagascar Evergreen Littoral Forest	6404	434	350	231	5194	65	40	42	10	38
1.A.2.Fe.1-Eastern Madagascar Lowland Rainforest	35112	2665	905	1283	28514	1319	155	99	44	128
1.A.2.Fe.2-Eastern Madagascar Subhumid Forest	76165	19649	14755	7833	30518	3486	850	129	393	552
1.A.1.Fe.2-Madagascar Tapia Forest	3703	149	62	126	2855	38	431	29	10	3
1.A.2.Fe.3-Western Madagascar Subhumid Forest	9159	1085	1786	894	4748	144	425	16	56	5
1.A.2.Fe.4-Western Madagascar Humid Forest	2009	307	45	80	1502	41	19	0	12	3
1.A.3.Ff.1-Eastern Madagascar Montane Forest	27252	3863	2390	4476	14961	1009	225	143	48	137
2.A.1.Fp.1-Madagascar Plateau Woodland & Grassland	8818	1647	1189	473	4760	145	452	117	27	8
2.A.2.Fj.1-Malagasy Montane Scrub	1799	164	24	65	1413	91	260	19	7	16
3.A.2.Fd.1-Madagascar Southwestern Coastal Bushland	4917	1472	362	475	2166	58	983	74	49	1
3.A.2.Fd.2-Madagascar Southwestern Dry Forest-Thicket	26006	9490	2161	1582	11392	221	17	62	86	29
2.A.5.Fc.4-African Temperate Moorland	2060	277	240	54	1376	63	40	10	10	13
2.B.6.Fd.2-African Temperate Vernal Pool	1942	1058	51	122	625	20	153	5	16	5
1.A.5.Wb.1-Indian Ocean Mangrove	5039	1702	483	510	2047	90	553	25	12	17
1.A.1.Fe.1-Madagascar Western Dry Forest	53867	22072	1634	2973	24851	1322	22	169	179	114
2.A.1.Fq.1-Malagasy Subhumid Woodland & Savanna	9246	2095	332	218	6374	140	14	4	26	35
Other	4460	697	181	339	2863	284	45	16	8	35
Total Records	**284754**	**71842**	**27066**	**22382**	**148975**	**8568**	**4799**	**964**	**1021**	**1159**
Total Presence sites (GPS points)	**5896**	**989**	**708**	**556**	**3008**	**1076**	**218**	**258**	**216**	**227**
Total Records/Total GPS points	**48.30**	**72.64**	**32.23**	**40.26**	**49.53**	**7.96**	**22.01**	**3.74**	**4.73**	**5.11**

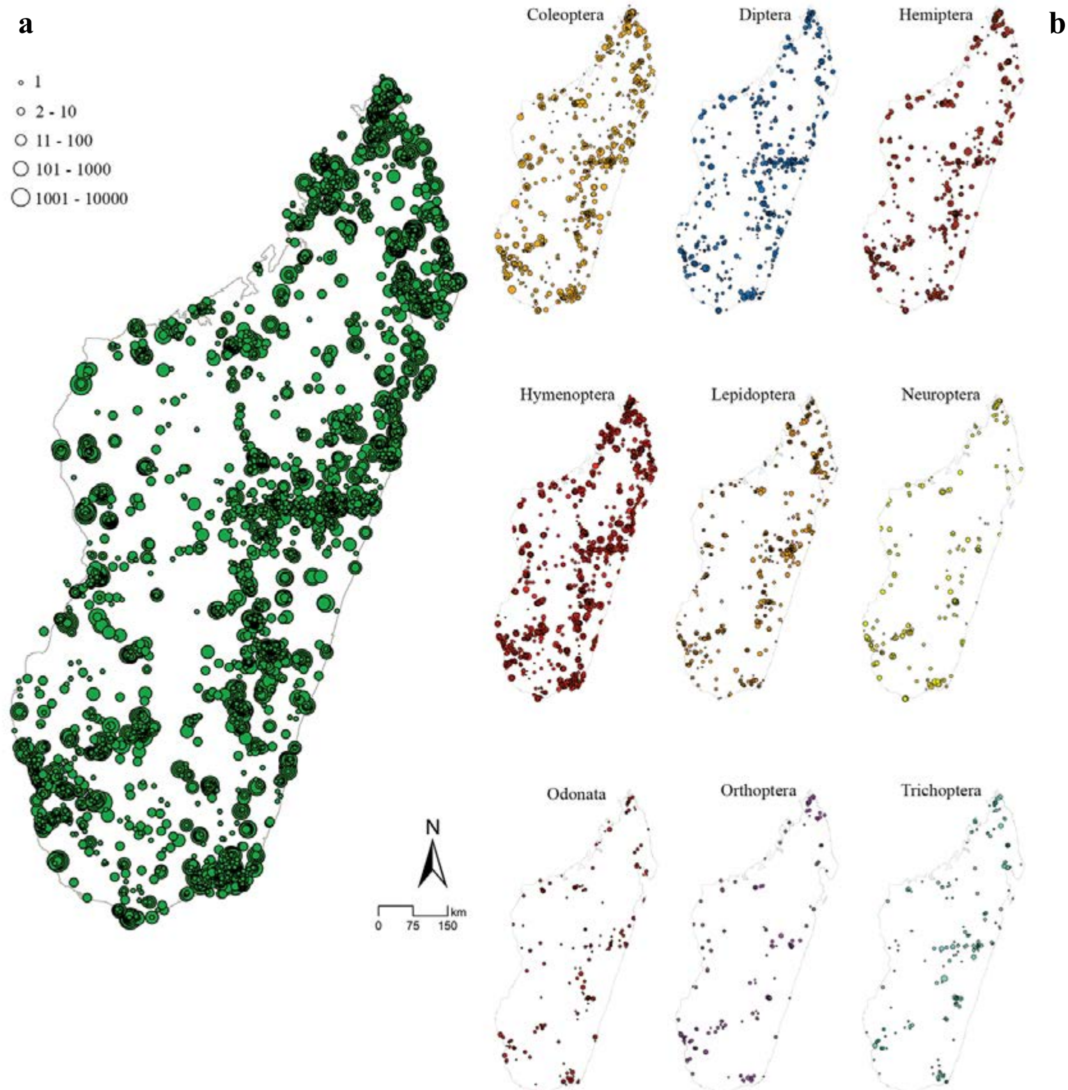

Fig. 1 – Distribution of localities for all **(a)** and each **(b)** of the nine insect orders considered in the study area. The dimension of points is proportional to the number of GPS points falling into each specific locality.

est (30.72%), 1.A.2.Fe.2 -Eastern Madagascar Subhumid Forest (27.35%) and, to a lesser extent, 3.A.2.Fd.2-Madagascar Southwestern Dry Forest-Thicket (13.21%). Another very interesting result is the close association between the Diptera, with 27,066 records distributed in 708 sites, and the macrogroup 1.A.2.Fe.2-Eastern Madagascar Subhumid Forest, which includes as many as 54.51% of the total records referring to this order.

With regard to the other orders considered, the 1.A.2.Fe.2-Eastern Madagascar Subhumid Forest plays a fundamental role also for Trichoptera (47.63% of the total records), Lepidoptera (40.69%), Orthoptera (38.49%) and Hemiptera (35.00%). The situation seems to be different for Neuroptera, which, despite showing a significant percentage of records still in the macrogroup 1.A.2.Fe.2-Eastern Madagascar Subhumid Forest, shows, as the only case among the orders considered, the highest percentage of records (20.48 %) in the 3.A.2.Fd.1-Madagascar Southwestern Coastal Bushland.

In order to highlight the importance of each macrogroup in hosting the nine insect orders both in their whole and separately (Table 2), we have: 1) considered the ratio between the total number of records (284,754) and the total area of Madagascar (587,041 km^2), resulting in 0.48 records per km^2; 2) calculated for each vegetation macrogroup an expected value of the number of records (surface in km^2 x 0.48); and 3) compared this number with the recorded values (Table 2). In accordance with the previous considerations, it comes out that some macrogroups host a significantly higher number than expected values, such as 1.A.2.Fe.2-Eastern Madagascar Subhumid Forest (+ 11.77%) and 1.A.2.Fe.1-Eastern Madagascar Lowland Rainforest (+ 10.60%), while others show significantly lower percentages than expected, such as 2.A.1.Fq.1-

Table 2 – Percentages of the presence sites in the vegetation macrogroups and deviation (Dev) respect to the expected values in the nine insect orders considered: COL (Coleoptera); DIP (Diptera); HEM (Hemiptera); HYM (Hymenoptera); LEP (Lepidoptera); NEU (Neuroptera); ODO (Odonata); ORT (Orthoptera); TRI (Trichoptera) (see text).

Vegetational macrogroups	Orders	Dev	COL	Dev	DIP	Dev	HEM	Dev	HYM	Dev
Type 0	2.17% ↑	1.50%	3.82% ↑	3.15%	0.39% ↓	-0.28%	2.63% ↑	1.96%	1.72% ↑	1.05%
1.A.2.Fe.5-Madagascar Evergreen Littoral Forest	2.04% ↓	-0.14%	0.55% ↓	-1.64%	1.18% ↓	-1.01%	0.94% ↓	-1.25%	3.17% ↑	0.98%
1.A.2.Fe.1-Eastern Madagascar Lowland Rainforest	12.33% ↑	10.60%	3.71% ↑	1.98%	3.34% ↑	1.62%	5.73% ↑	4.01%	19.14% ↑	17.41%
1.A.2.Fe.2-Eastern Madagascar Subhumid Forest	26.75% ↑	11.77%	27.35% ↑	12.37%	54.51% ↑	39.54%	35.00% ↑	20.02%	20.49% ↑	5.51%
1.A.1.Fe.2-Madagascar Tapia Forest	1.30% ↑	0.30%	0.21% ↓	-0.79%	0.23% ↓	-0.77%	0.56% ↓	-0.43%	1.92% ↑	0.92%
1.A.2.Fe.3-Western Madagascar Subhumid Forest	3.22% ↓	-2.04%	1.51% ↓	-3.75%	6.60% ↑	1.34%	3.99% ↓	-1.26%	3.19% ↓	-2.07%
1.A.2.Fe.4-Western Madagascar Humid Forest	0.71% ↑	0.49%	0.43% ↑	0.21%	0.17% ↓	-0.05%	0.36% ↑	0.14%	1.01% ↑	0.79%
1.A.3.Ff.1-Eastern Madagascar Montane Forest	9.57% ↓	-0.56%	5.38% ↓	-4.75%	8.83% ↓	-1.30%	20.00% ↑	9.87%	10.04% ↓	-0.08%
2.A.1.Fp.1-Madagascar Plateau Woodland & Grassland	3.10% ↓	-7.06%	2.29% ↓	-7.87%	4.39% ↓	-5.77%	2.11% ↓	-8.05%	3.20% ↓	-6.96%
2.A.2.Fj.1-Malagasy Montane Scrub	0.63% ↓	-0.37%	0.23% ↓	-0.78%	0.09% ↓	-0.92%	0.29% ↓	-0.72%	0.95% ↓	-0.06%
3.A.2.Fd.1-Madagascar Southwestern Coastal Bushland	1.73% ↑	1.00%	2.05% ↑	1.32%	1.34% ↑	0.61%	2.12% ↑	1.40%	1.45% ↑	0.73%
3.A.2.Fd.2-Madagascar Southwestern Dry Forest-Thicket	9.13% ↑	0.61%	13.21% ↑	4.68%	7.98% ↓	-0.54%	7.07% ↓	-1.46%	7.65% ↓	-0.88%
2.A.5.Fc.4-African Temperate Moorland	0.72% ↓	-2.94%	0.39% ↓	-3.28%	0.89% ↓	-2.78%	0.24% ↓	-3.43%	0.92% ↓	-2.74%
2.B.6.Fd.2-African Temperate Vernal Pool	0.68% ↑	0.37%	1.47% ↑	1.16%	0.19% ↓	-0.12%	0.55% ↑	0.24%	0.42% ↑	0.11%
1.A.5.Wb.1-Indian Ocean Mangrove	1.77% ↓	-0.56%	2.37% ↑	0.04%	1.78% ↓	-0.54%	2.28% ↓	-0.05%	1.37% ↓	-0.95%
1.A.1.Fe.1-Madagascar Western Dry Forest	18.92% ↓	-4.00%	30.72% ↑	7.80%	6.04% ↓	-16.88%	13.28% ↓	-9.64%	16.68% ↓	-6.24%
2.A.1.Fq.1-Malagasy Subhumid Woodland & Savanna	3.25% ↓	-10.40%	2.92% ↓	-10.73%	1.23% ↓	-12.42%	0.97% ↓	-12.68%	4.28% ↓	-9.37%
Other	1.57% ↑	1.01%	0.97% ↑	0.41%	0.67% ↑	0.11%	1.51% ↑	0.96%	1.92% ↑	1.36%

Vegetational macrogroups	LEP	Dev	NEU	Dev	ODO	Dev	ORT	Dev	TRI	Dev
Type 0	0.34% ↓	-0.33%	2.18% ↑	1.51%	0.47% ↓	-0.20%	2.49% ↑	1.82%	1.57% ↑	0.90%
1.A.2.Fe.5-Madagascar Evergreen Littoral Forest	0.69% ↓	-1.50%	0.76% ↓	-1.43%	3.96% ↑	1.78%	0.89% ↓	-1.29%	2.98% ↑	0.80%
1.A.2.Fe.1-Eastern Madagascar Lowland Rainforest	15.39% ↑	13.67%	3.23% ↑	1.50%	10.27% ↑	8.54%	4.31% ↑	2.58%	11.04% ↑	9.32%
1.A.2.Fe.2-Eastern Madagascar Subhumid Forest	40.69% ↑	25.71%	17.71% ↑	2.73%	13.38% ↓	-1.60%	38.49% ↑	23.51%	47.63% ↑	32.65%
1.A.1.Fe.2-Madagascar Tapia Forest	0.44% ↓	-0.55%	8.98% ↑	7.99%	3.01% ↑	2.01%	0.98% ↓	-0.02%	0.26% ↓	-0.74%
1.A.2.Fe.3-Western Madagascar Subhumid Forest	1.68% ↓	-3.58%	8.86% ↑	3.60%	1.66% ↓	-3.60%	5.48% ↑	0.23%	0.43% ↓	-4.83%
1.A.2.Fe.4-Western Madagascar Humid Forest	0.48% ↑	0.26%	0.40% ↑	0.18%	0.00% ↓	-0.22%	1.18% ↑	0.96%	0.26% ↑	0.04%
1.A.3.Ff.1-Eastern Madagascar Montane Forest	11.78% ↑	1.65%	4.69% ↓	-5.44%	14.83% ↑	4.71%	4.70% ↓	-5.43%	11.82% ↑	1.69%
2.A.1.Fp.1-Madagascar Plateau Woodland & Grassland	1.69% ↓	-8.47%	9.42% ↓	-0.74%	12.14% ↑	1.98%	2.64% ↓	-7.52%	0.69% ↓	-9.47%
2.A.2.Fj.1-Malagasy Montane Scrub	1.06% ↑	0.06%	5.42% ↑	4.41%	1.97% ↑	0.97%	0.69% ↓	-0.32%	1.38% ↑	0.37%
3.A.2.Fd.1-Madagascar Southwestern Coastal Bushland	0.68% ↓	-0.05%	20.48% ↑	19.76%	7.68% ↑	6.95%	4.80% ↑	4.07%	0.09% ↓	-0.64%
3.A.2.Fd.2-Madagascar Southwestern Dry Forest-Thicket	2.58% ↓	-5.95%	0.35% ↓	-8.17%	6.43% ↓	-2.09%	8.42% ↓	-0.10%	2.50% ↓	-6.02%
2.A.5.Fc.4-African Temperate Moorland	0.74% ↓	-2.93%	0.83% ↓	-2.83%	1.04% ↓	-2.63%	0.98% ↓	-2.69%	1.12% ↓	-2.55%
2.B.6.Fd.2-African Temperate Vernal Pool	0.23% ↓	-0.08%	3.19% ↑	2.88%	0.52% ↑	0.21%	1.57% ↑	1.26%	0.43% ↑	0.12%
1.A.5.Wb.1-Indian Ocean Mangrove	1.05% ↓	-1.27%	11.52% ↑	9.20%	2.59% ↑	0.27%	1.18% ↓	-1.15%	1.47% ↓	-0.86%
1.A.1.Fe.1-Madagascar Western Dry Forest	15.43% ↓	-7.49%	0.46% ↓	-22.46%	17.53% ↓	-5.39%	17.53% ↓	-5.39%	9.84% ↓	-13.08%
2.A.1.Fq.1-Malagasy Subhumid Woodland & Savanna	1.63% ↓	-12.02%	0.29% ↓	-13.36%	0.41% ↓	-13.24%	2.55% ↓	-11.10%	3.02% ↓	-10.63%
Other	3.31% ↑	2.76%	0.94% ↑	0.38%	1.66% ↑	1.10%	0.78% ↑	0.23%	3.02% ↑	2.46%

Malagasy Subhumid Woodland & Savanna (-10.40%) and 2.A.1.Fp.1- Madagascar Plateau Woodland & Grassland (-7.06%) (Fig. 2c).

The interpretation of these results can be complex, because they are probably due on one hand to a real preference of the entomofauna for some specific environmental types, but on the other hand to biases referable, for example, to non-homogenous sampling efforts in the different areas and/or for the different insect groups.

The copresence of the investigated groups was more deeply investigated by evaluating the percentage of shared sites, reported in the intersection matrix between the GPS points of the various orders (Table 3; shared sites are also visible in Fig. 1b). Orthoptera and Neuroptera show the highest levels of sharing, especially with the most representative orders like Hymenoptera, Coleoptera and Hemiptera. Single peaks can be seen also in different groups, such as Diptera with Hymenoptera (98.07%), and Hemiptera with Coleoptera (64.21%) and Hymenoptera (57.37%). The high sharing rate probably depends on the use of the same collection method (e.g. Malaise traps or pitfall traps), and/or the co-occurrence of the collection activity (e.g. over the same scientific expeditions). The low sharing of sites, like for Hymenoptera (of which the records refer mostly to Formicidae (cf. Fisher 2005) and Lepidoptera, may be explained because the sampling of some taxa requires some very specialized hunting methods, that generally does not allow to collect significant quantities of material belonging to other orders. The same considerations can be made, even if to a lesser extent, for Odonata and Trichoptera.

The surface of the current protected areas in Madagascar covers about 15% of the total area of the island. It is distributed through a long corridor along the subhumid and humid vegetation macrogroups, in the eastern side, and along the central and southern coast, in the western side (Figs 2a, 3a). A large PAs system was also established throughout the montane, subhumid, dry and humid areas in the north. Only few and small areas are protected in the central part of Madagascar, in a rather dispersed network. The proposed PAs system follows a similar distributional pattern, adding about 9% of protected surface in the south and in the north-west of the island, increasing significantly the total surface of the protected areas in the island (Fig. 3a).

Current PAs seem to provide effective protection to the set of animal groups here considered, housing 70.11% of the total records considered. The percentage in Orthoptera (76.20%), Diptera (75.79%), Coleoptera (71.29%), and Hymenoptera (70.61%) is particularly high, while it is significantly lower in Trichoptera (35.63%), Odonata (41.29%) and Neuroptera (48.82%) (Fig. 3c). The establishment of proposed PAs would result in an increase of protection. The percentage of points of presence in protected areas would rise to 85.09%, with the most significant increases for Neuroptera (+ 32.61%), Odonata (+ 27.07%) and Lepidoptera (+ 22.93%), while in other orders the increase settles between 11 and 17% (Fig. 3b).

With regard to the current PAs, the results agree with the distance analysis performed for PAs, in which the distance class 0 ÷ 1000 m (i.e. a sampling locality falls within a PA or is in a distance of at most 1 km) hosts 5501 sites (82.3%), followed by the second class (1000 ÷ 2000 m), hosting 334 sites (5.0%); sites falling 10 km or more outside the PAs' borders are 320 (4.8%) (Fig. 4a). Two main cold-spots (i.e. a statistically significant cluster of areas

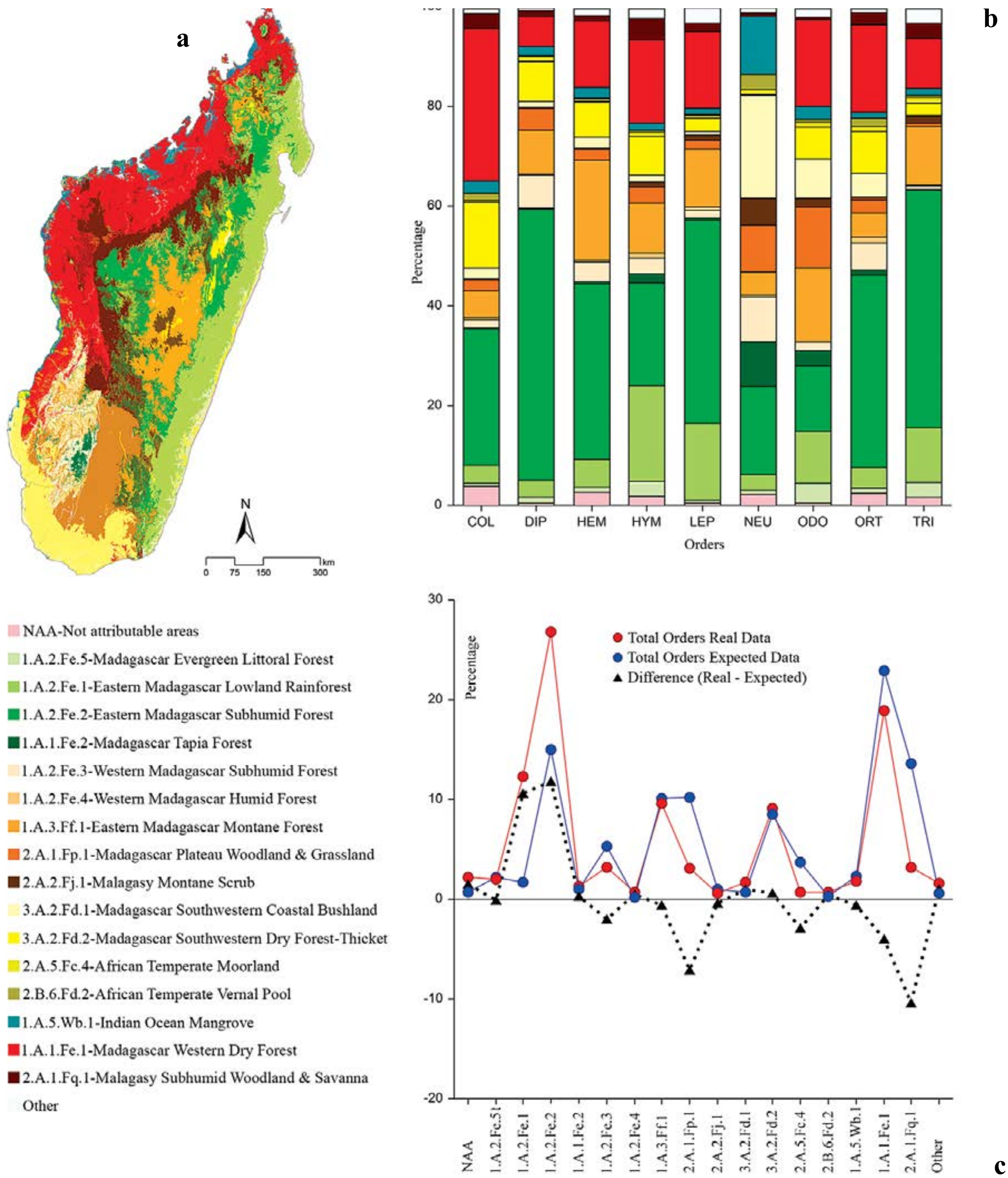

Fig. 2 – Vegetation macrogroups of the study area (from Sayre et al. 2013) **(a)** and the corresponding percentage with respect to the localities inhabited by each of the nine orders considered **(b)**; the real (red) and expected (blue) percentages of GPS points within each vegetation macrogroup for the nine insect orders considered, in black the difference real-expected **(c)**.

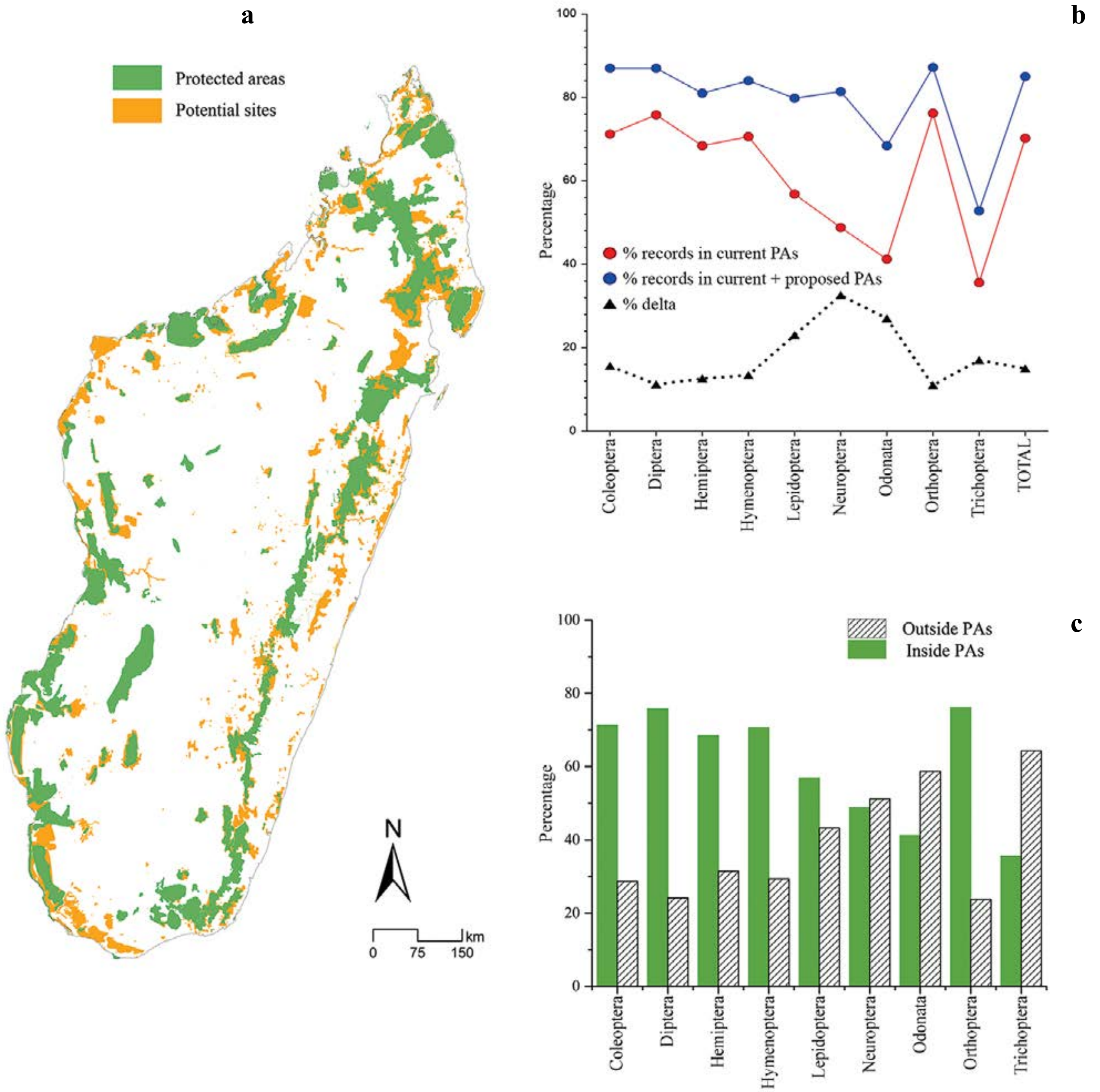

Fig. 3 – Distribution of current (green) and potential (orange) Protected Areas of Madagascar (source: REBIOMA) **(a)**; percentage of presence locations falling within current (red) and current + potential (blue) Protected Areas for the total and each of the nine orders considered. In black, the variation between the two percentages is also reported **(b)**; percentage of localities falling inside (green) and outside (dashed) current Protected Areas network **(c)**.

in which the sampling was carried out at short distances from the target feature, a Protected Area in this case) are located in the north and in the central-west Madagascar, while two wide hot-spots (i.e. a statistically significant cluster of areas in which the sampling was carried out at long distances from a Protected Area) are identified in the central-east and in the southern part of the island (Fig. 4a). In according to the distance analysis performed for roads, 4197 sampling sites (62.9%) are located within the 0 ÷ 1000 m distance range, followed by 630 sites (9.4%) of the second class (1000 ÷ 2000 m) (Fig. 4b). No sampling sites beyond the 10 km distance from roads were found. The main cold spots are in the central-east and in the southern part of the island, where also the main cities of the island occur, while the hot-spots are located in the north and in the central-west Madagascar, less urbanized (Fig. 4b). Therefore, most samplings occurred within PAs or close to roads, and, because main roads are usually outside PAs, a reversed situation is observed in the hotspot analysis of PAs' and roads' distances.

Table 3 – Correlation percentages of the common presence sites among the nine insect orders considered: COL (Coleoptera); DIP (Diptera); HEM (Hemiptera); HYM (Hymenoptera); LEP (Lepidoptera); NEU (Neuroptera); ODO (Odonata); ORT (Orthoptera); TRI (Trichoptera) (see text).

sites = 989	COL	sites = 708	DIP	sites = 556	HEM
COL	100.00%	DIP	100.00%	HEM	100.00%
DIP	19.92%	COL	27.82%	COL	64.21%
HEM	36.10%	HEM	29.24%	DIP	37.23%
HYM	28.11%	HYM	98.07%	HYM	57.37%
LEP	11.22%	LEP	10.03%	LEP	17.99%
NEU	14.26%	NEU	15.68%	NEU	29.86%
ODO	12.74%	ODO	12.71%	ODO	17.81%
ORT	16.18%	ORT	16.95%	ORT	30.04%
TRI	8.70%	TRI	9.89%	TRI	16.19%
sites = 3008	**HYM**	**sites = 1076**	**LEP**	**sites = 218**	**NEU**
HYM	100.00%	LEP	100.00%	NEU	100.00%
COL	9.24%	COL	10.32%	COL	64.68%
DIP	6.75%	DIP	6.60%	DIP	50.92%
HEM	10.61%	HEM	9.29%	HEM	76.15%
LEP	2.76%	HYM	7.71%	HYM	73.85%
NEU	5.35%	NEU	3.44%	LEP	16.97%
ODO	3.06%	ODO	5.30%	ODO	30.28%
ORT	5.45%	ORT	4.46%	ORT	49.54%
TRI	3.06%	TRI	2.70%	TRI	29.36%
sites = 258	**ODO**	**sites = 216**	**ORT**	**sites =227**	**TRI**
ODO	100.00%	ORT	100.00%	TRI	100.00%
COL	48.84%	COL	74.07%	COL	37.89%
DIP	34.88%	DIP	55.56%	DIP	30.84%
HEM	38.37%	HEM	77.31%	HEM	39.65%
HYM	35.66%	HYM	75.93%	HYM	40.53%
LEP	22.09%	LEP	22.22%	LEP	12.78%
NEU	25.58%	NEU	50.00%	NEU	28.19%
ORT	19.77%	ODO	23.61%	ODO	16.30%
TRI	14.34%	TRI	34.26%	ORT	32.60%

Discussion

The estimate of the current knowledge of the entomofauna in Madagascar shows that about 35% of the whole island is not covered by the GBIF dataset, and that a very high percentage of knowledge seems to be based on a rather limited number of areas with high values of ratio total records/total GPS points. This is particularly evident for some groups, such as Coleoptera, Hymenoptera, Hemiptera, and Diptera (ratio between 32 and 73), while for others, such as Odonata, Orthoptera, Trichoptera, and Lepidoptera, the values are much lower (between 3 and 8); this fact is probably due to the more extensive methods used in the collecting of this second group of insect orders.

Considering the geographic location and the extension of the vegetation macrogroups in Madagascar, the entomological data appear unevenly distributed. The presence of forests seems to be an important determinant of where insects were collected, in according to what was reported by D'Alessandro et al. (2014). For example, the subhumid and lowland forests in the east show much higher percentages than expected, while the woodlands and grasslands of the plateau in southern Madagascar seem to be not only poorer but also significantly underestimated (Table 2).

Generally, Protected Areas attract insect collectors within their borders, so as to significantly create bias-sampled clusters (Fig. 4a), and this also happens in Madagascar. In addition, the easiness of access to sampling sites is also an important facilitation in collecting insects, considering that a very high number of sampling localities fall near the roads (Fig. 4b). Few localities, in fact, fall outside the PAs borders, while no sampling locality observed is further than 10 km from roads. Finally, the potential extension of the system of the Protected Areas, for years planned for Madagascar, would lead to a significant percentage increase in the inclusion of areas of entomological

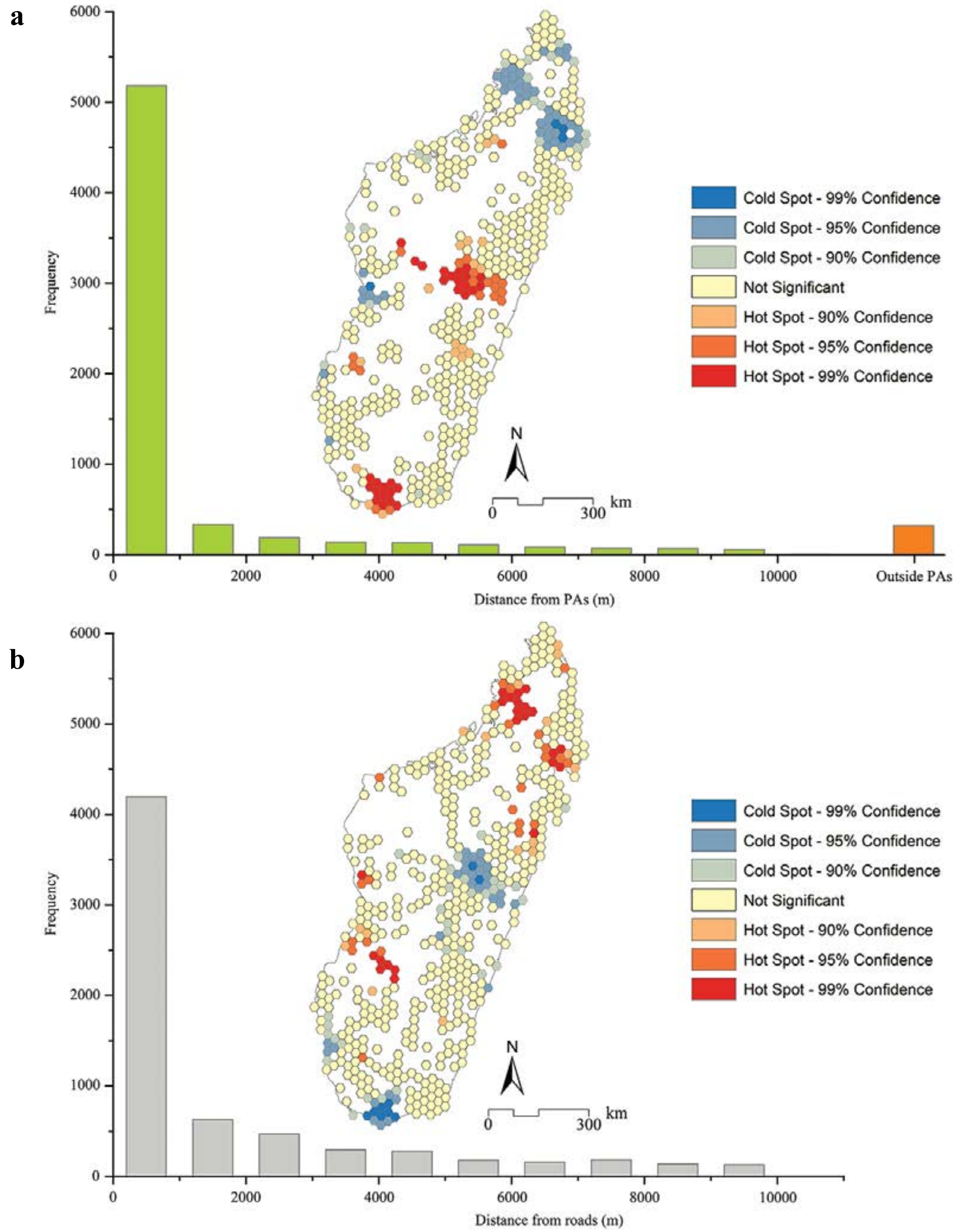

Fig. 4 – Frequency of localities falling within 10 km from the current Protected Areas system (500 meters-bin size) and the corresponding map of distances' hot- and cold-spots; a hot-spot indicates that in a certain area, the sampling localities were significantly far with respect to the PAs' boundaries (and vice-versa for cold-spots) (**a**). Ibidem for the current road network (**b**).

interest, especially for the Neuroptera, Odonata and Lepidoptera.

We can conclude that analyses on the level of entomological knowledge of a given area, even if based on partial databases, provide useful results with highly relevant nature conservation politics when performed on a very large number of records, identifying areas still in deficit of knowledge or possible biases in the data collection methods used.

References

Amano T., Lamming J.D.L., Sutherland W.J. 2016. Spatial Gaps in Global Biodiversity Information and the Role of Citizen Science. BioScience, 66: 393–400.

Andriamialisoa F., Langrand O. 2003. The history of zoological exploration of Madagascar. In: Goodman S.M., Benstead J.P. (eds), The natural history of Madagascar. The University of Chicago Press, Chicago, pp. 1–15.

Bielby J., Cunningham A.A., Purvis, A. 2006. Taxonomic selec-

tivity in amphibians: ignorance, geography or biology?. Animal Conservation, 9: 135–143; DOI: 10.1111/j.1469-1795.2005.00013.x
Biondi M. 2001. Revision of the species of *Chaetocnema* from Madagascar (Coleoptera: Chrysomelidae: Alticinae). European Journal of Entomology, 98: 233-248; DOI: 10.14411/eje.2001.040
Biondi M., D'Alessandro P. 2013. *Ntaolaltica* and *Pseudophygasia*, two new flea beetle genera from Madagascar (Coleoptera: Chrysomelidae: Galerucinae: Alticini). Insects Systematics and Evolution, 44: 1–14; DOI: 10.1163/1876312X-04401004
Biondi M., D'Alessandro P. 2016. Revision of *Diphaulacosoma* Jacoby, an endemic flea beetle genus from Madagascar, with description of three new species (Coleoptera: Chrysomelidae, Galerucinae, Alticini). Fragmenta entomologica, 48(2): 143-151; DOI: 10.4081/fe.2016.181
D'Alessandro P., Iannella M., Frasca R., Biondi M. 2018. Distribution patterns and habitat preference for the genera-group *Blepharida* s.l. in Sub-Saharan Africa (Coleoptera: Chrysomelidae: Galerucinae: Alticini). Zoologischer Anzeiger, 277: 23–32; DOI: 10.1016/j.jcz.2018.08.001
D'Alessandro P., Urbani F., Biondi M. 2014. Biodiversity and biogeography in Madagascar: revision of the endemic flea beetle genus *Neodera* Duvivier, 1891 with description of 19 new species (Coleoptera, Chrysomelidae, Galerucinae, Alticini). Systematic Entomology, 39: 710–748; DOI: 10.1111/syen.12082
Engen S., Runge C., Brown G., Fauchald P., Nilsen L., Hausner V. 2018. Assessing local acceptance of protected area management using public participation GIS (PPGIS). Journal for Nature Conservation, 43: 27–34; DOI: 10.1016/j.jnc.2017.12.002
ESRI 2010. ArcGIS Desktop: Release 10. Environmental Systems Research Institute, Redlands.
Fisher B.L., 2005. A model for a global inventory of ants: A case study in Madagascar. Proceedings of the California Academy of Sciences, 56: 86.
Gaillard J. 2011. Le système national de recherche scientifique et technique à Madagascar: état des lieux et proposition d'un cadre conceptuel pour l'élaboration d'une cadre de recherche et d'innovation. Unesco, Paris, 88 pp. Available from: www.horizon.documentation.ird.fr/exl-doc/pleins_textes/divers17-03/010060274.pdf
Gardner C.J., Nicoll M.E. Birkinshaw C., Harris A., Lewis R.E., Rakotomala D., Ratsifandrihamanana A.N. 2018. The rapid expansion of Madagascar's protected area system. Biological Conservation, 220: 29–36; DOI: 10.1016/j.biocon.2018.02.011
GBIF 2018. GBIF Occurrence Download. Web portal. URL: www.gbif.org (last accessed 30 Oct. 2018).
Goodman S.M., Benstead J.P. 2003. The natural history of Madagascar. The University of Chicago Press, Chicago, 1709 pp.
Goodman S.M., Benstead J.P. 2005. Updated estimates of biotic diversity and endemism for Madagascar. Oryx, 39: 73–77; DOI: 10.1017/S0030605305000128
Iannella M., Liberatore L., Biondi M. 2016. The effects of a sudden urbanization on micromammal communities: a case study of post-earthquake L'Aquila (Abruzzi Region, Italy). Italian Journal of Zoology, 83: 255–262; DOI: 10.1080/11250003.2016.1149235
Iannella M., Cerasoli F., D'Alessandro P., Console G., Biondi M. 2018a. Coupling GIS spatial analysis and Ensemble Niche Modelling to investigate climate change-related threats to the Sicilian pond turtle *Emys trinacris*, an endangered species from the Mediterranean. PeerJ, 6: e4969; DOI: 10.7717/peerj.4969
Iannella M., D'Alessandro P., Console G., Biondi M. 2018b. Evidences for a shared history for spectacled salamanders, haplotypes and climate. Scientific reports, 8: 16507.
UNEP-WCMC 2018. Protected Area Profile for Madagascar from the World Database of Protected Areas. URL: www.protectedplanet.net (last accessed November 2018).
Open Street Map 2018. Humanitarian OSM Team. URL: https://data.humdata.org/ dataset/ hotosm_mdg_roads (last accessed 30 Oct. 2018).
Paulian R. 1954. Cinquante années d'entomologie generale à Madagascar. Bulletin de l'Académie Malgache, numero special du Cinquantenaire: 65-70.
Paulian R., Viette P. 2003. An introduction to terrestrial and freshwater invertebrates. In: Goodman S.M., Benstead J.P. (eds), The natural history of Madagascar. The University of Chicago Press, Chicago, pp. 503–511.
REBIOMA 2018. Réseau de la Biodiversité de Madagascar. Web portal. URL: data.rebioma.net (last accessed 30 Oct. 2018).
Sayre R.G., Comer P., Hak J., Josse C., Bow J.,Warner H., Larwanou M., Kelbessa E., Bekele T., Kehl H., Amena R., Andriamasimanana R., Ba T., Benson L., Boucher T., Brown M., Cress J., Dassering O., Friesen B., Gachathi F., Houcine S., Keita M., Khamala E., Marangu D., Mokua F., Morou B., Mucina L., Mugisha S., Mwavu E., Rutherford M., Sanou P., Syampungani S., Tomor B., Vall A., Van de Weghe J., Wangui E., Waruingi L. 2013. A New Map of Standardized Terrestrial Ecosystems of Africa. Washington, DC: Association of American Geographers, 24 pp.
Siles G., Voirin Y., Bénié G.B. 2018. Open-source based geoplatform to support management of wetlands and biodiversity in Quebec. Ecological Informatics, 43: 84–95; DOI: 10.1016/j.ecoinf.2017.11.005
Townsend T.M., Vieites D.R., Glaw F., Vences M. 2009. Testing species-level diversification hypotheses in Madagascar: the case of microendemic *Brookesia* leaf chameleons. Systematic Biology, 58: 641–656; DOI: 10.1093/sysbio/syp073
Vences M., Wollenberg K.C., Vieites D.R., Lees D.C. 2009. Madagascar as a model region of species diversification. Trends in Ecology & Evolution, 24: 456–464; DOI: 10.1016/j.tree.2009.03.011
Viette P. 1991. Principales localités où des Insectes ont été recuillis à Madagascar. Faune de Madagascar, suppl. 2. Imprimerie Némont, Bar-su-Aube, France, 88 pp.
Wesener T., Raupach M., Decker P. 2011. Mountain Refugia play a role in soil Arthropod speciation on Madagascar: a case study of the endemic giant fire-millipede genus *Aphistogoniulus*. PLoS One, 6: e28035; DOI: 10.1371/journal.pone.0028035