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ECOLOGY AND CONSERVATION OF THE ENDEMIC SCORPIONS' GENUS *Didymocentrus* IN CENTRAL CUBA

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Introduction

The West Indies or Caribbean Islands comprise one of the most important biodiversity hotspots on the planet. Particularly, this region stands out by its high number of single-island endemic species. Scorpions are a perfect example of this outstanding biodiversity: more than 150 species (96% endemic) had been reported to this region until 2015, which represents nearly 10% of the world's scorpion fauna, and still new species are being discovered each year. The Cuban archipelago comprises by far the largest island of the Caribbean and also harbors one of the richest and most unique biotas of the world, with endemism levels frequently exceeding 90% in many groups. This island shelters also the most diverse scorpion fauna of the region and constitutes the country with more species relative to land surface of the world: 55 species, 91% endemic (Teruel & Kovařík 2012, Teruel 2013). This values are hardly approached by a few regions, such as Hispaniola, Baja California Peninsula, Madagascar and Australia (Teruel & Kovařík 2012). Moreover, four out of the five endemic scorpion genera of the Insular Caribbean occur in Cuba, being three of them exclusive to this island. Particularly, the burrowing scorpions of the family Scorpionidae (subfamily Diplocentrinae) comprise 14 species in four genera in this country, all endemic and with restricted distribution ranges. However, the conservation status of Cuban endemic scorpions has received very little attention, to the point that only six out of the 55 species (11%) were evaluated under the category of Vulnerable (Vales *et al*. 1998). But even this assessment could be by far underestimating the real conservation status of those six species, which due to their reduced geographic range could qualify for a higher category of threat following the IUCN criteria.

The Neotropical burrowing scorpion genus *Didymocentrus* comprises 11 species distributed in Central America and the West Indies. Particularly, four species endemic to the central region of Cuba constitute the only representation of this genus in the Greater Antilles. According to the scarce information available in the literature, these scorpions seem to be habitat-specific and highly sedentary (Teruel & Rodríguez 2008). Also, their populations are severely fragmented into metapopulations, restricted to isolated patches of native vegetation with apparently little likelihood of genetic exchange. But the main threatening factors affecting these species and their associated habitats have not ceased. Urgent actions are required to mitigate the accelerated human-induced habitat loss by deforestation, forest fires, increasing agriculture, urbanization, and introduction of alien invasive species. Based on the limited distribution of *Didymocentrus* in Cuba, all known species fulfil the IUCN criteria for the category of Endangered or Critically Endangered. However, additional detailed and updated information is required to make an accurate evaluation of their conservation and propose management actions to guarantee their long-term survival.

Furthermore, scorpions have been historically seen by people as dangerous animals and they are intentionally killed everywhere no matter the species they belong to, how armless or beneficial they could be, or how much threatened their populations and habitat could be. Sensitizing people from local communities with direct incidence on endemic scorpions and their habitats is crucial to guarantee their long-term conservation. Also, National Action Plans of Cuba have never included scorpions, despite their key role keeping the balance in natural ecosystems. But most of these

problems arise from ignorance and the lack of adequate promotion of basic knowledge and the importance to preserve them.

Objectives:

1) To generate updated information on the distribution and habitat requirements of *Didymocentrus armasi* and *D. trinitarius*, the two species of greatest concern due to their highly reduced range.
2) To predict new potentially suitable habitat for target species using GIS-based technology and the information gathering during the field-work phase of the project.
3) To assess the conservation status of all Cuban *Didymocentrus* species using both historical records from the literature and the information gathered for two of them during this project.
4) To start a community-based campaign in central Cuba to promote the knowledge and conservation of Cuban endemic scorpions, making emphasis in the target species.

Study area

The field-work phase of the project was implemented in south-central Cuba, from Trinidad to Cienfuegos cities (Fig. 1), where the target species occurs. This area comprises a strip of nearly 50 km and about 5 km wide varying from lowland coastal and subcoastal ecosystems to the low hills making up the southern slope of the Guamuhaya Massif. Vegetation in this area is composed mainly by secondary scrubland and grassland, although patches of native semi-deciduous forest and dry microphylous scrubland persist in some places. This area has very particular edaphic and climatic conditions, and harbors a specific array of vascular plants, which led important specialists to classify it as an independent phytogeographic district ("Casildense"), characterized by several local endemic plant species (Borhidi 1991).

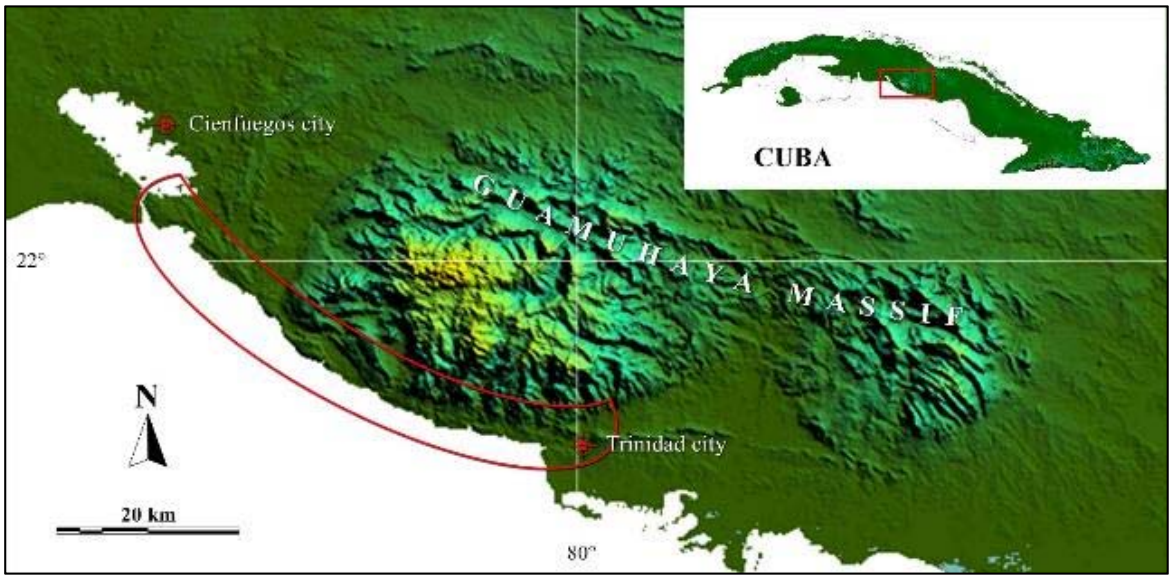

Figure 1. Map of south-central Cuba depicting the area (red contour) where the field-work phase of the project was implemented.

Field work

This project included a one-year phase of field work. First, I implemented an intensive program of field trips searching for *Didymocentrus* populations. The scorpions were actively searched both during day by turning over rocks and digging into their burrows or at night using a portable ultraviolet (UV) lamp (Fig. 2). I georeferenced each location with *Didymocentrus* using a GPS coupled to a cellphone. I gathered other important biotic variables (sympatric scorpion species, vegetation type, canopy coverage) and abiotic variables (temperature, relative humidity, light intensity, type of predominant rocks). Also, all threats both natural and anthropogenic directly affecting target species and their associated habitats were carefully listed and characterized for each population assessed.

For more detailed ecological observations, I implemented some plots 224 m^2 (14 x 16 m) in native semi-deciduous forest on karstic areas. I carried out overnight surveys during the rainy season of 2015. These surveys included samplings every hour since one hour before sunset to one hour after the sunrise. I walked slowly around the plots using a portable UV lamp to detect the scorpions. Each individual was recorded and I marked their burrow's entrances with a metallic numbered label. I placed portable weather stations within each plot to record abiotic variables during the sampling period. Once confirmed a scorpion occupying a single burrow and after properly tagged, its activity was followed overnight by recording its presence or absence at the burrow's entrance. All other scorpion species co-occurring with *Didymocentrus* were identified and characterized.

Figure 2. Working with the target species *Didymocentrus trinitarius* in south-central Cuba.

This phase allowed filling important gaps in the distribution of *Didymocentrus* in south-central Cuba. Collection of both specimens and ecological data in intermediate localities between *D. armasi* and *D. trinitarius* produced very interesting results. Indeed, what was considered two species until now certainly constitutes a single species with phenotypic characters varying progressively from "*armasi*" to "*trinitarius*", forming a chain or cline in the East-West sense. Thus extreme populations of this cline are in fact the most different morphologically, which led to the description of a population from Cienfuegos as a different species (*D. armasi*) in the past (Teruel & Rodríguez 2008). This interesting finding brings new light onto the conservation status of this species, mainly because it extends its distribution range and the number of known populations. We will make the formal taxonomic arrangement according to the International Code of Zoological Nomenclature by publishing it in a peer reviewed journal during the next year. This implies placing *D. armasi* as a junior synonym of *D. trinitarius*, which will be the only species of this genus occurring in south-central Cuba, known from near 30 localities along a narrow subcoastal strip of more than 80 km long and about 6 km wide (Fig. 3). Therefore, in all analyses of ecological niche modeling and assessment of conservation status made here, populations of south-central Cuba were treated as a single taxon: *D. trinitarius*. However,

further genetic analysis would be useful to assess population genetic structure and corroborate such a hypothesis.

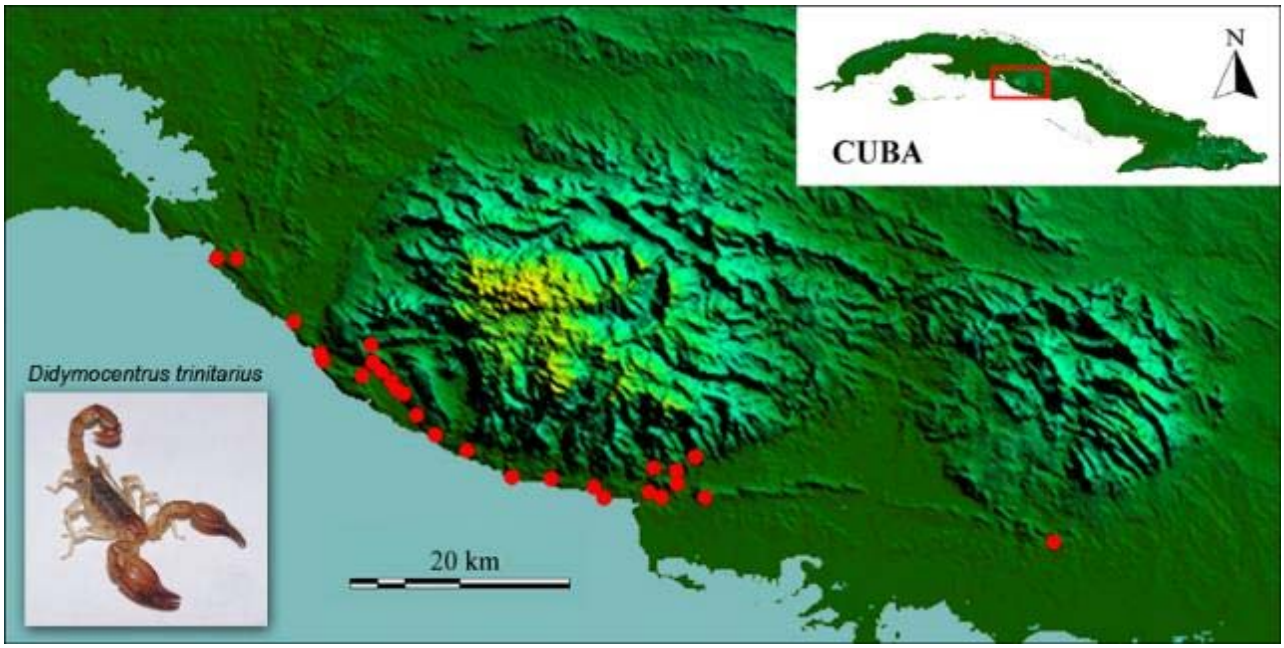

Figure 3. Distribution of the target species *Didymocentrus trinitarius* in south-central Cuba.

I found the species inhabiting exclusively limestone areas covered by relatively well-preserved primary semi-deciduous forest (Fig. 4). It shelters inside burrows dug by the scorpions directly in the forest soil or inside limestone crevices (Fig. 5). Other endemic scorpion species co-occurring with *D. thirnitarius* are: *Rhopalurus junceus*, *Microtityus trinitensis* and *Centruroides stockwelli* (Buthidae), and *Heteronebo bermudezi morenoi* (Scorpionidae) (Fig. 6). The study of daily activity patterns during last six months showed that the species is strictly nocturnal: it commences its activity about one hour after sunset and stop it about one hour before sunrise (always 0 lux) (Fig. 7). Individuals position themselves at the entrance of their burrows with only the pedipalps extended forward (Fig. 5) awaiting mainly hard-bodied insects (e.g., beetles) and millipedes, which according to remains found in the immediate vicinity of burrow entrances, they constitute the most frequent prey. They are highly sensitive to light, being full moon nights the ones with lowest levels of surface activity, particularly in areas without dense canopy coverage. Thus I presume that deforestation could be a factor affecting negatively the occurrence of *Didymocentrus*, mainly because reduction in canopy coverage enhance penetration of moonlight up to the soil and loss of humidity by evaporation during the day.

Figure 4. Subcoastal semi-deciduous forest: typical habitat of the target species *Didymocentrus trinitarius*.

Figure 5. Foraging position of the target species *Didymocentrus trinitarius* at the entrance of their burrows: in the soil (above) and in rock crevices (below); with white light (left) and UV light (right).

Figure 6. Endemic scorpion species co-occurring with the target species *Didymocentrus trinitarius.*

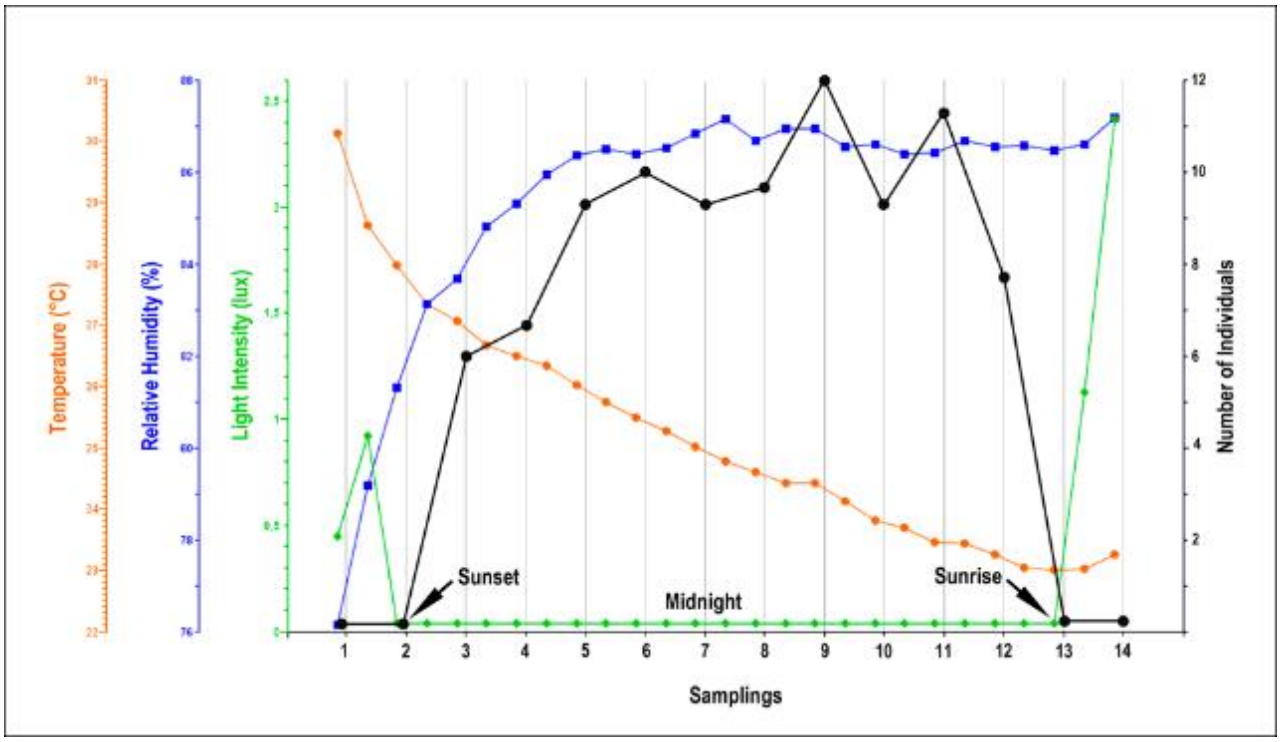

Figure 7. Mean daily activity pattern of the target species *Didymocentrus trinitarius* in the sampled plots.

Ecological niche modeling

I used GIS-based analyses of ecological niche to predict new potentially suitable habitats for the occurrence of all three Cuban *Didymocentrus* species. Ecological niche was modeled with the MaxEnt software (Phillips et al., 2006). As predictors I used altitude and uncorrelated bioclimatic variables such as maximum temperature of the warmest month, annual temperature range, mean temperature of wettest quarter, mean temperature of coldest quarter, annual precipitation, precipitation seasonality, precipitation of warmest quarter, and precipitation of coldest quarter. For *D. trinitarius* I used both records from the literature and those obtained during the field-work phase of this project (21 records); for *D. jaumei* and *D. sanfelipensis* I used historical records only (5 records each) (Fig. 8).

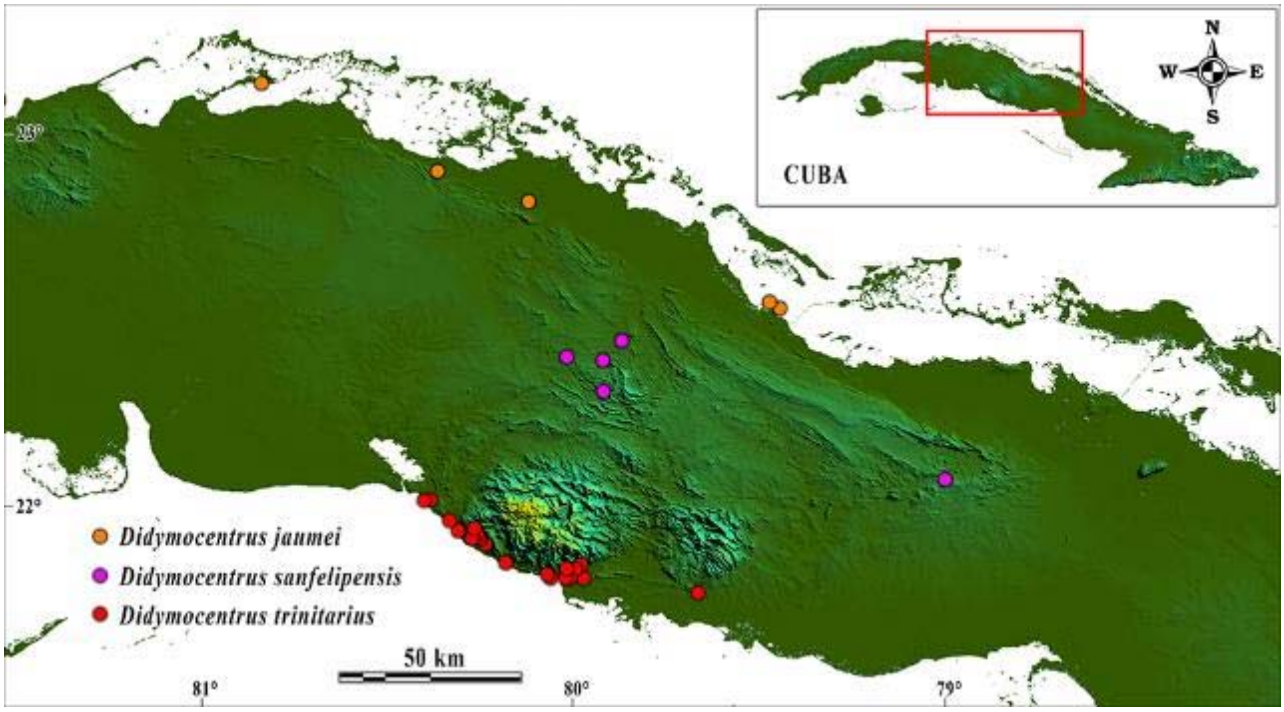

Figure 8. Current distribution of *Didymocentrus* species in central Cuba, including data from the literature and from this work.

Ecological niche models showed few potential new areas with suitable habitat for the occurrence of both *D. trinitarius* and *D. sanfelipensis* (Fig. 9). The distribution records of *D. trinitarius* suggest that the species is restricted to semideciduous forest on karstic soil along the southern coast of central Cuba, which was faithfully reflected in the resulting models. *Didymocentrus sanfelipensis* is known so far from a specific type of soil (serpentine) with a very particular vegetation type called "cuabal" (dry serpentine thorny scrub-woodland), with high level of plant endemism. The models resulting from historical records of *D. sanfelipensis* showed that all potential areas with suitable habitat for the species were indeed restricted to some patches of serpentine soil located in inland central Cuba. On the other hand, the models resulting from historical records of *D. jaumei* showed a wide range of new potential areas across the northern coast of central Cuba (Fig. 9). But the low number of records of both *D. jaumei* and *D. sanfelipensis* could impose some bias in the results. Also, ecological niche modeling did not include some important variables such as type of soil, coverage of primary vegetation and interaction with other species, which could be decisive factors for the occurrence of target species. Therefore, future efforts should be focused in an intensive ground-truthing to delimitate the real distribution boundaries of these last two species. Historical distribution of these scorpions must be surveyed in order to identify the remaining viable populations and their conservation status. Finally, genetic analysis including as much *Didymocentrus* populations as possible would be very useful in delimitating species boundaries and conservation units.

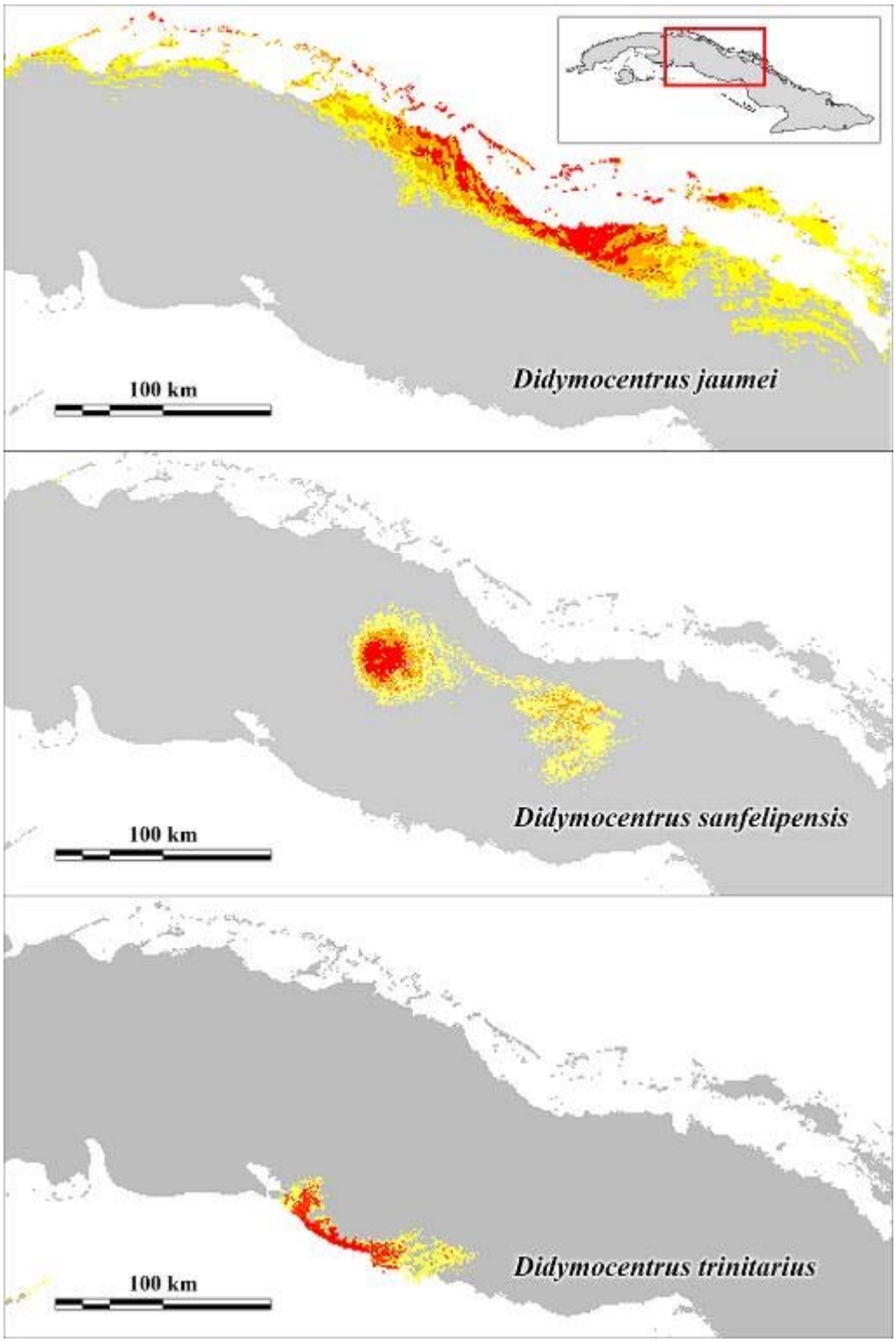

Figure 9. Ecological niche models of Cuban *Didymocentrus* species.

Table 1. Number of records used in the models and values of training and test AUC, the average ± standard deviation is showed.

Species	Number of records	Training AUC	Test AUC	Estimate current area (km^2)
Didymocentrus jaumei	5	0.963 ± 0.02	0.960 ± 0.03	5230
Didymocentrus sanfelipensis	5	0.996 ± 0.05	0.968 ± 0.05	1460
Didymocentrus trinitarius	21	0.998 ± 0.03	0.997 ± 0.05	413

Umbral: Minimum training presence.

Assessment of conservation status

Because of the difficulty in obtaining some demographic parameters (e.g., number of mature individuals) for *Didymocentrus*, and the lack of information other than a few historical records for two of the species (*D. jaumei* and *D. sanfelipensis*), I assessed their conservation status based on their geographic range, i.e., the IUCN criterion B (IUCN, 2012; IUCN Standards and Petitions Subcommittee, 2014). I calculated both the Area of Occupancy (AOO) and the Extent of Occurrence (EOO) using MapInfo Professional (ver. 10.5) (Pitney Bowes Software, 2010). Due to the small size, specific ecological requirements and poor dispersal abilities of burrowing scorpions in the genus *Didymocentrus*, for calculation of the AOO I used a reference scale grid of 1 km cells (1 km2). I calculated the EOO using the minimum convex polygon. Because of the long history of forest depletion in Cuba during the last centuries (> 80%), I assumed the IUCN criterion Bb(iii), referring to continuing decline in the effective "area extent and/or quality of habitat", as fully applicable to *Didymocentrus* species.

For *D. trinitarius* I used both records from the literature and those obtained during the field-work phase of this project; for *D. jaumei* and *D. sanfelipensis* I used historical records only. According to the IUCN, "*The term location defines a geographically distinct area in which a single threatening event can rapidly affect all individuals of the taxon present. The size of the location depends on the area covered by the threatening event and may include part of one or many subpopulations. Where a taxon is affected by more than one threatening event, location should be defined by considering the most serious plausible threat.*" This last situation is particularly applicable to *D. trinitarius*, the species with more records; the scarce records of *D. jaumei* and *D. sanfelipensis* are widely separated and each one of them constitute independent locations; even the two closest records of *D. jaumei* (3 km apart) correspond to separate keys. The most serious plausible threats for *D. trinitarius* are the forest fires (Fig. 10) and the human-induced deforestation for charcoal production.

Figure 10. Forest fires: one of the most serious plausible threats for the target species *Didymocentrus trinitarius.*

The final assessment resulted in *D. trinitarius* with a total of 10 locations comprising 21 records, an AOO of 21 km^2 and an EOO of 189 km^2; *D. jaumei* with 5 locations comprising 5 records, an AOO of 5 km^2 and an EOO of 205 km^2; and *D. sanfelipensis* also with 5 locations comprising 5 records, an AOO of 5 km^2 and an EOO of 865 km^2. The proportion of records within protected areas was 10 (48%) for *D. trinitarius*, 4 (80%) for *D. jaumei* and 1 (20%) for *D. sanfelipensis*. According to these results *D. trinitarius* qualifies for the category of **Endangered** [B1, B2ab(iii)], and both *D. jaumei* and *D. sanfelipensis* qualify for the category of **Critically Endangered** [B2ab(iii)]. This information will be crucial for the inclusion of these and other endemic scorpions in the National Action Plan of Cuba.

Most *Didymocentrus* subpopulations are severely fragmented into metapopulations, restricted to isolated patches of native vegetation surrounded by a heavily disturbed matrix of unsuitable habitat, with very low likelihood of genetic exchange. Therefore, further genetic analysis including as much subpopulations as possible will be crucial to know its population genetic structure, allowing a more accurate delimitation of species boundaries and the identification of conservation units.

Educational work

I developed the awareness phase of the project during the last six months, involving mainly the key local communities with direct incidence on target species and most institutions in the region related to nature conservation. I made special emphasis on *Didymocentrus* species and the current conservation status of their populations and habitats, working toward the creation of positive public attitudes through their knowledge, as a weapon to diminish the historical aversion. I gave awareness-raising talks to local community people, workers from protected areas and Biology undergraduates from the most important University of central Cuba (Universidad Central "Marta Abreu" de Las Villas) (Fig. 11). It is interesting to note that most people in Cuba are aware of at most three scorpion

species, and simply ignore the existence of the remaining 52. They also ignore that Cuba is among the leading countries in the world in terms of scorpion diversity and endemism, being more than 90% of Cuban species exclusive to this island. During my talks I made emphasis on endemic habitat-specific species such as the burrowing scorpions in the genus *Didymocentrus*, and on their critical conservation status because of irresponsible human activities. I also highlighted the importance of scorpions to keep the balance in natural ecosystems and the practical use of habitat-specific species as indicator taxa that can offer an early alert of disturbance in the forests they inhabit. Indeed, I trained rangers from some protected in regards to scorpion monitoring and identification (Fig. 12) so they can be included in the Action Plans as key species for guaranteeing the adequate management of natural ecosystems. I also made a public presentation at regional symposium for biodiversity conservation, on the diversity and conservation of scorpions from south-central Cuba.

Figure 11. Awareness-raising activities and public presentations.

Figure 12. Training of rangers from protected areas.

Most people see scorpions as dangerous creatures capable of inflicting painful stings, however, the sting of a burrowing scorpion can be hardly distinguished from that of a fire ant. This makes of *Didymocentrus* excellent candidates to be used as flagship species to promote the conservation of all Cuban endemic scorpions. They proved to be very tame when handling during education activities (Fig. 13), especially with children. But continuation is the key for success regarding environmental education, and this project together with those supported by The Rufford Foundation have allowed me to start with a long-term program for the study and conservation of Cuban endemic scorpions.

Figure 13. Handling the target species *Didymocentrus trinitarius.*

One of the most significant achievements of this projects is the creation of a thematic group for the conservation of endemic species with children from a coastal community near Cienfuegos. This region harbors several endemic species of plants and animals, including many local endemics. I will supervise this thematic group as representative of the Cienfuegos Botanical Garden and with help of a local museum in charge of a local community program. With support of future projects, I plan to

develop this initiative with children as leading actors to promote the conservation of local endemic species, including scorpions.

Finally, I produced posters with quality photographs promoting the knowledge and conservation of Cuban endemic scorpions, making emphasis in the burrowing scorpions genus *Didymocentrus* (Appendix). These were distributed in the most important institutions related to environment conservation, universities, headquarters of protected areas and schools of south central Cuba. In future projects I plan to extend my conservation message to other areas of this region harboring important *Didymocentrus* populations.

Budget

I was able to complete most objectives originally proposed thanks to the partial funding of both the MBZ and The Rufford Foundation (RSG). The RSG provided the equivalent to $ 2485 in equipment for office and field work (e.g., laptop computer, UV lamps, headlamps, digital camera, weather stations, etc.). Such equipment comes from a successfully accomplished project (ending date June 2015) on the conservation of the Cuban endemic scorpion genus *Tityopsis* (project reference 15393-1). This decision was made after the previous consent of both The Mohamed bin Zayed Species Conservation Fund (MBZ) and the RSG's boards. The MBZ provided the equivalent to about 50% of the total budget required for this project (Table 2).

Table 2. Budget summary.

Activity/Item	**Cost (USD)**	**MBZ**	**RSG**
Field work	1265	1265	–
Education	620	620	–
Presentation at symposium	60	60	–
Training	40	40	–
Printing	350	350	–
Tax for bank transfer and currency exchange	165	165	–
Equipment	2485	–	2485
Total	**4985**	**2500**	**2485**

General remarks

I already uploaded a second application to the MBZ to continue working with the burrowing scorpions' genus *Didymocentrus*. If this proposal is successful I plan to use again part of the equipment initially purchased with the funds of the RSG for the *Tityopsis* project. This way the RSG logo would appears also in every material resulting from this second project.

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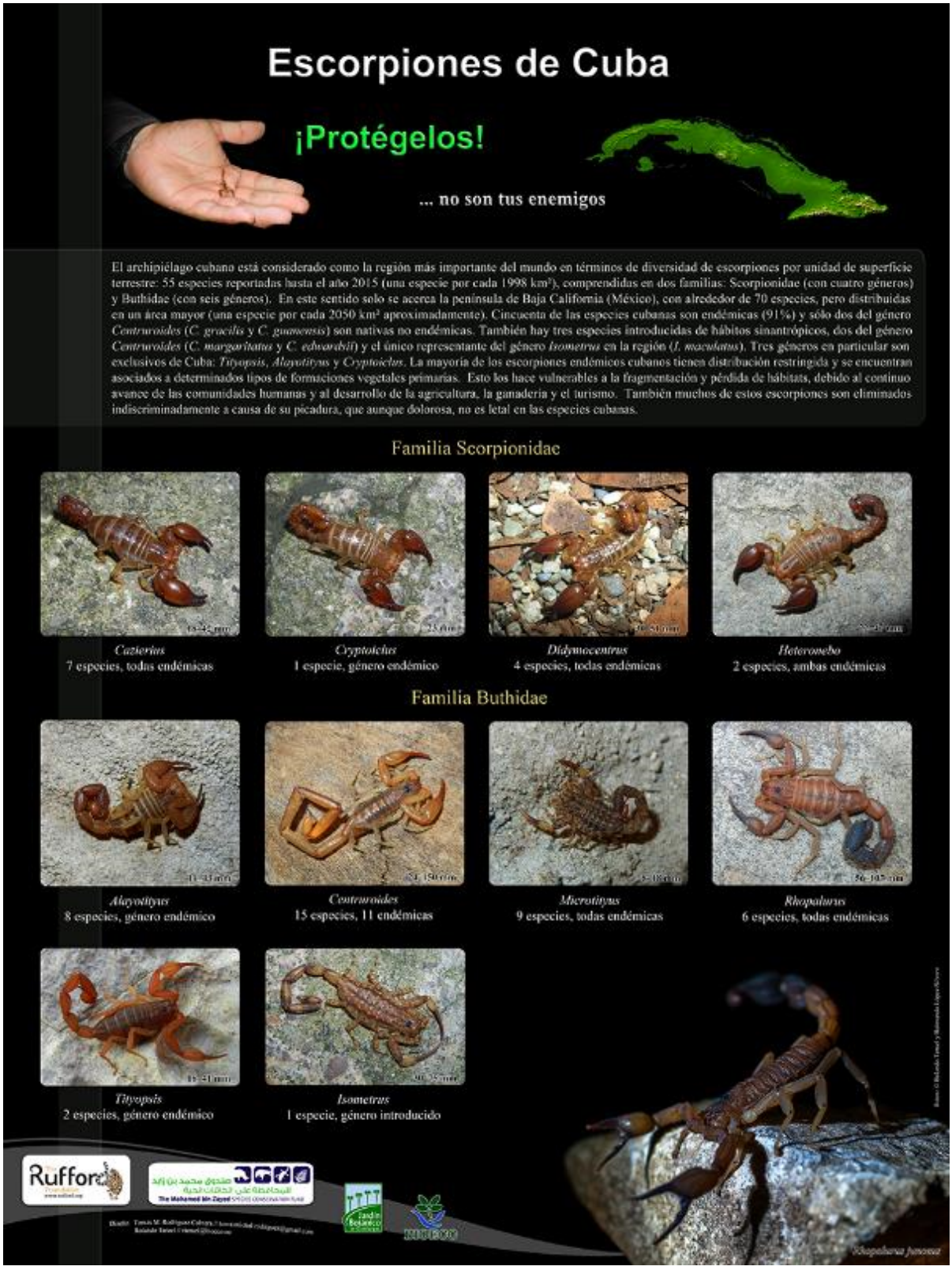
Appendix. Educative material produced during the project.



Poster "Sorpions of Cuba" (24 x 32 in).

Poster “Scorpions of south-central Cuba” (24 x 32 in).

Poster "Scorpions of the genus *Didymocentrus*" (20 x 24 in).

Field guide “Scorpions from south-central Cuba”.