New insights on *Bidens herzogii* (Coreopsideae, Asteraceae), an endemic species from the Cerrado biogeographic province in Bolivia

Novedades en el conocimiento de *Bidens herzogii* (Coreopsideae, Asteraceae), una especie endémica de la provincia biogeográfica del Cerrado en Bolivia

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Abstract

The morphological limits among some Coreopsideae genera in the Asteraceae family are complex. An example is *Bidens herzogii*, a taxon first described as a member of the genus *Cosmos*, but recently transferred to *Bidens*. The species is endemic to Eastern Bolivia and it grows on the Cerrado biogeographic province. Recently collected specimens, analysis of herbarium specimens, and revisions of literature lead us to propose new data on morphological description and a chromosome counts for the species, a tetraploid, where $x = 12$, $2n = 48$. Lastly, we provide data on geographic distribution and niche modeling of *B. herzogii* to predict areas of endemism in Eastern Bolivia. This area is already known for this pattern of endemism, and the evidence generated can be used to direct conservation efforts.

Key words: Bolivian Chiquitanía, Niche modeling, Western Cerrado.

Resumen

Los límites morfológicos entre algunos géneros de la familia Asteraceae tribu Coropsideae son complejos. Un ejemplo es *Bidens herzogii*, especie descrita en principio como *Cosmos herzogii*, pero recientemente transferida al género *Bidens*. La especie es endémica del este de Bolivia, en la provincia biogeográfica del Cerrado. Colecciones recientes, análisis de ejemplares de herbario y la revisión de literatura, nos llevan a la necesidad dar a conocer nuevos datos sobre la descripción morfológica de *B. herzogii* y un conteo cromosómico para la especie, un tetraploide, donde $x = 12$, $2n = 48$. Por último, a partir de datos sobre su distribución geográfica y un modelo de su nicho ecológico es posible predecir áreas de endemismo en el este de Bolivia. Esta región del país es reconocida por este patrón y la evidencia aquí generada puede ser útil para dirigir esfuerzos de conservación.

Palabras clave: Cerrado Occidental, Chiquitanía boliviana, Modelación de nicho.
Introduction

The tribe Coreopsideae, Asteraceae, is a monophyletic lineage with 24 genera and 600 species (Panero & Funk 2002, Panero 2007, Crawford et al. 2009). The tribe has a cosmopolitan distribution, although its greatest diversity is found in the Americas. Two diverse genera of Coreopsideae are *Bidens* L. and *Cosmos* Cav. which are frequently confused, and as a consequence several synonymies exist between them (e.g. Hemsley 1881, Sherff 1929, 1932, Melchert 1975, 1990, 2010a-b, Melchert & Turner 1990). A recent case is the proposal of Hind (2013) to transfer *Cosmos herzogii* Sherff to *Bidens*. Based on this work and on a recent systematic study of *Cosmos* (Vargas-Amado et al. 2013; Castro-Castro et al. 2014, Castro-Castro 2015) and field work we support this last decision. *Bidens herzogii*, the new combination, is endemic to Eastern Bolivia and it grows on the Cerrado or Cerradense Occidental biogeographic provinces (Morrone 2001 and Navarro & Ferreira 2009, respectively). This region is distinguished by its unique flora, singular abiotic characteristics, and several biological endemisms (Suárez 2000, Wood et al. 2011, Pozo et al. 2013, Fig. 1A).

Nevertheless, after a revision of herbarium material and live plants in the field, and confronting our observations with previous analyses of *Bidens herzogii* (Sherff 1934, Hind 2013), we note important morphological variations and measurement ranges of stems, roots, inflorescences, heads, florets, and achenes, that here we would like to provide. At the same time, we discuss on morphological boundaries between *Cosmos* and *Bidens* and the infrageneric taxonomic relationship of *B. herzogii* based on morphology and the first chromosome count for the species. Finally, based on our biogeographic work, we detect that potential geographical distribution of *Bidens herzogii* could predict key similar areas for potential conservation and reveal patterns of endemism and species richness in the Bolivian Cerrado.

Methods

*Bidens herzogii* was collected in the type locality and other sites nearby. Extensive sampling captured much of its morphological, ecological, and geographic variation. Vouchers were deposited at USZ, IBUG and MEXU. The morphological data was complemented with the revision of specimens at BOLV, G, IBUG, MEXU, and USZ (herbarium acronyms following Thiers 2013).

For chromosome counts, mitotic metaphase cells from root tips were observed. The root tips were obtained from three individuals obtained from the type locality and cultivated under greenhouse conditions (see in specimens examined for analyzed material). Root tips were pretreated with 0.002 M 8-hydroxyquinoline for 5 h at 5–10°C. Then, the material was hydrolyzed in 5 N HCl at room temperature for 25 min and washed in distilled water. The root-tips were squashed and stored at -20°C for 3 days. The slides were subsequently dried at room temperature and then stained with 1% acetorcein. Mitotic metaphase figures were photographed with a Zeiss Axiostar microscope and AxioCam ICc1 digital camera equipped with Axiovision 4.8 software.

Geographic information attached to herbarium specimens and the localities obtained from the field work were used for niche modeling, implemented in MaxEnt (Phillips et al. 2006) and following the protocols described by Cruz-Cárdenas et al. (2012). We used 19 climatic variables from WorldClim dataset (Hijmans et al. 2005) and eight occurrence points of *Bidens herzogii*. There are various regionalization proposals for Bolivia (Olson et al. 2001, Morrone 2004, Flores-Baltazar 2013, Ledezma-Kravarovic 2013). According to Flores-Baltazar (2013),
the Chaco and the Chiquitania are two different biogeographic provinces and *Bidens herzogii* has been collected in both of them. Unfortunately, the author did not offer a digital mask. Alternatively, Morrone (2004) recognized only the Chaco biogeographic province and provided a mask. All points of occurrence are located at the Chaco province (Morrone 2004). In order to define the potential range of *B. herzogii*, we employed the maximum sensitivity test plus specificity suggested by Liu et al. (2005). According to this criterion, greater probability values represent the potential area of the species. The area obtained was divided into three categories, based on areas of potential distribution with medium, high and very high occurrence probabilities. This procedure was achieved dividing by three the range of probability values of the species (J.L. Villaseñor-Ríos, pers. com., 2013).

**Results**

Notes on morphological description and chromosome count

*Bidens herzogii* (Sherff) D.J.N. Hind, Kew Bulletin: 68. 2013. Fig. 1.

Suffrutescent herb, (30-)50-130 cm (Fig. 1B), xylododium 7.5-15 cm long, 3.5-7 cm wide, with rhizome extending horizontally and connecting nearby subterranean branches. Stems erect, terete, glabrous, 0.3-2 cm wide, with marked nodes on more mature branches, internodes 1-2 cm. Petiole 2-5.5 cm long. Leaves opposite, 1-3 pinnatisect, membranaceous, light green, concolorous, glabrous, ovate to deltoid in general outline, (4-)7.5-13.5 cm long, (3.5-)5-7.5 cm wide. Primary segments opposite, entire, deeply and irregularly lobate or serrate, lanceolate to ovate, attenuate, acuminate, (0.7-)1-5.5 cm long, 0.3-1.8 cm wide; margins entire or 1-9 dentate, teeth 1-2 mm (Fig. 1C). Inflorescence corymbiform, (1-)2-5(-9) heads. Peduncles thin, glabrous, 2.5-8(-15) cm long. Capitula radiate, (2.5-)3-4.5 cm wide across extended rays (Fig. 1D). Involucral campanulate, 0.3-0.6 mm wide. Phyllaries biseriate; outer series (8-)14-22, green, foliaceous, (4-)5-7.5 mm long, 0.5-0.8 mm wide, linear, sigmoid, extended or reflexed, glabrous, lustrous, with 1(-3) inconspicuous resiniferous ducts on abaxial face, obtuse; inner series 12-22, scarious, membranaceous, translucent, pale yellow, hyaline margins, with 5-8 fine resiniferous and conspicuous ducts on abaxial face, 8-10 mm long, 2-2.2 mm wide, lanceolate, acute (Fig. 1E). Receptacle flat, convex when dry, palaceous, 2-4 mm diameter. Paleae translucent yellow, 8-10 mm long, 1-2 mm wide, persistent, resembling inner phyllaries. Ray florets 6-12 (frequently deciduous), uniseriate, sterile, yellow (brown when dry), lanceolate limb, obtuse, entire or 2-lobulate, (1.3-)2.3-2.8 cm long, 0.3-0.8(-1) cm wide, with 3-8 conspicuous ribs, glabrous, tube 3 mm long, 0.5 mm wide, glabrous. Disk florets (16-)26-32, hermaphrodite, yellow; corollas tubular, occasionally urceolate in peripheral florets in material from Santiago [Castro-Castro et al. 3701 (USZ, IBUG, MEXU)], 0.8-11 mm long, 1.5-2.2 mm wide, glabrous, 5-lobed; lobes triangular, erect, acute, glabrous, 1.5 mm long, 1 mm wide. Frequently, outer disk florets tend to a ray form, anthers are reduced or absent and gynoecium is normal (Fig. 1E). Anthers 5, brownish yellow, 2.5-3 mm, sagittate, appendices acute; filaments laminar, glabrous. Pollen orange. Style 1.2-1.5 cm, brownish yellow; style branches 1.8-2.1 mm, penicillate, papillose. Achenes tetragonal to flattened, fusiform, falcate, 4 thick ribs alternating with 4 thin ribs, (9-)1.2-1.8 cm long, 1.6-1.8 mm wide, greenish brown to black at maturity, glabrous, muricate; carpodium annular; pappus awns 2-3, 2-2.2 mm, each awn with 6-8 retrorse barbs, persistent (Fig. 1F). Chromosome number 2n = 48 (Fig. 2).

Figure 1. Bidens herzogii. A. Habitat, B. habit, C. leaf variation, D. capitulum, from above, E. capitulum, lateral view and F. fruiting capitulum. Based on Castro-Castro et al., 3701 and 3702 (IBUG, USZ, MEXU).
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Specimens examined

**BOLIVIA. Santa Cruz.** Prov. Chiquitos, NO de Roboré, 18°14’14’S, 59°42’18”W, 1,053 m, 3-May-2008 (fl, fr), *Wood et al. 24685* (K, USZ!). Santiago de Chiquitos. Chochis, zone of pass across Chochis range climbing up from Chochis-Matacuzal trail, 18°03’S, 59°34’48”W, 18-March-2005 (fl, fr), *Wood et al. 21908* (BOLV!, K, LPB!, USZ!); Cerro Chochis, on the meseta at the summit, 18°07’S, 60°00’W, 1,200 m, 22-February-2006 (fl, fr), *Wood 22243* (K, USZ!); Cerca de La Antena, 3-4 km de Santiago de Chiquitos, arriba de San Juanama, 18°20’5”S, 59°07’42”W, 697 m, 9-April-2008 (fl, fr), *Wood et al. 24315* (K, USZ!); Camino de Santiago de Chiquitos a Soledad-Aguas Calientes, poco antes de llegar a Soledad, 18°21’S, 59°36’W, 3-December-2003 (fl, fr), *Wood et al. 20152* (BOLV!, K, LPB!, USZ!); Serranía de Santiago, camino a La Cueva y a la altura de El Arco, 18°40’S, 59°15’W, 800 m, 13-November-1997 (fl, fr), *Mamani & Jardim 1288* (USZ!); Sendero El Arco-Las Cuevas de Juan Miserandino, Cerro San Miserato, 18°20’34.9”S, 59°33’30”W, 820 m, 12-May-2013 (fl, fr), *Castro-Castro et al. 3701* (USZ!, IBUG!, MEXU!; material used for chromosomal counts); Sendero Soledad, camino entre El Arco de Soledad y el Río Soledad, alrededores de las rocas El Búho y La Tortuga, 18°22’11’S, 59°35’16.8”W, 574 m, 13-May-2013 (fl, fr), *Castro-Castro et al. 3702* (USZ!, IBUG!, MEXU!); summit of Cerro San Miserate, Chiquitos, 900 m, May-1907 (fl), *Herzog 496* (G!).

Potential geographical distribution of *Bidens herzogii*

*Bidens herzogii* is endemic to the Cerrado biogeographic province, in Eastern Bolivia. Its geographic range is restricted to the central part of Santa Cruz de la Sierra Department (Fig. 3). It grows on rocky fields with thin alluvial soils accumulated in the rock crevices. The area is dominated by xeric scrubs and were evident *Astrocaryum arenarium* Barb. Rodr., *Deuterocohnia longipetala* (Cárdenas) D.R. Hunt, *Echinopsis calochlora* K. Schum., *Hippeastrum* spp., *Mimosa auriculata* Benth., *Paepalanthus chiquitensis* Herzog, *Pitcairnia chiquitana* R. Vásquez & Ibish, *Smilax campesiris* Griseb., *Vellozia variabilis* Mart. ex Schult. f., and several species of Poaceae (Fig. 1a).

The herbarium vouchers analyzed and the field observations were recorded from the Chiquitos and Cordillera provinces. But the modeling analysis extended its potential distribution to the José Miguel de Velasco and Ñuflo de Chávez provinces (Fig. 3). The area comprised 2,805 km² with occurrence values of 44.8-62.5%, 62.6-80.2% and 80.3-100%, for median, high and very high probabilities, respectively. The median probability area included 1,693 km², of which 60% was located at Puerto Suárez and a significant part of San Matías municipalities (Fig. 3B). Meanwhile, the high probability area extended across 882 km².
km², with 32% of its area located at the Roboré municipality. This area harbored the majority of herbarium records. Finally, the very high probability covered 229 km² and 8% of them belonged to the Concepción and San Matías municipalities (Fig. 3A).

First, we used the 19 climatic variables of WorldClim to create a potential distribution model of *Bidens herzogii*. However, only seven climatic variables were employed in the final analysis after the mean test. These variables were isothermality, temperature seasonality, temperature annual range, annual precipitation, precipitation of wettest month, precipitation of wettest quarter and precipitation of warmest quarter (Fig. 4). Thus, only seven climatic variables predicted the presence of *Bidens herzogii*.

Usually, *Bidens herzogii* grows on sites with media isothermality (67 and 68%, Fig. 4A), some seasonal temperature (Fig. 4B), and relatively lower temperatures than the rest of Eastern Bolivia (18.5°C and 19.4°C, Fig. 4C). In addition, annual precipitation varies between 1,069-1,201 mm (Fig. 4D-G). According to Navarro (2011), these climatic conditions persist throughout the Chiquitanía region, where the climate is markedly seasonal, with a time of intense rainfall, and mostly humid the rest of the year.

**Discussion**

Morphological boundaries between *Cosmos* and *Bidens* and the infrageneric taxonomic relationship of *B. herzogii*

The boundaries between *Bidens* and *Cosmos* are complex in some cases and their separation requires a combination of characters. A reliable character to separate both genera is the filament indument of the stamens. In *Cosmos*, the filaments are pubescent whereas these are glabrous in all known taxa of *Bidens*. Other useful morphological characters identified by Castro-Castro *et al.* (2014) are indicated in the Table 1.

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**Figure 3.** Potential and known geographic distribution of *Bidens herzogii* in eastern Bolivia.
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**Figure 4.** Relevant climatic variables predicting the potential distribution of *Bidens herzogii* in eastern Bolivia. A. Isothermality (in percent), B. temperature seasonality (standard deviation X 100), C. temperature annual range (in °C), D. annual precipitation (in mm), E. precipitation of wettest month (in mm), F. precipitation of wettest quarter (in mm) and G. precipitation of warmest quarter (in mm). The area of potential distribution is shown in blue and herbarium records as black dots.
Many chromosomal changes are common evolutionary processes in Coreopsideae (Crawford et al. 2009, Watanabe 2014). The basic chromosome number in the tribe is \( x = 12-14 \), but Crawford et al. (2009) considered \( x = 16 \) with an important chromosome reduction to \( x = 12 \) in three clades. One clade groups the genera *Chrysanthellum* Richard, two lineages of *Coreopsis* L., *Glossocardia* Cass., *Isostigma* Less., *Henricksonia* B.L. Turner and *Heterosperma* Cav. A second clade includes the genera *Fitchia* Hook, *Narvalina* Cass., *Oparanthus* Sherff, *Petrobium* R. Br. and *Selleophytum* Urb. The third clade comprises *Bidens*, *Coreocarpus* Benth., two lineages of *Coreopsis*, *Cosmos* and *Thelesperma* Less.

Around 60% of *Bidens* species, for which the chromosomal numbers are known, have \( x = 12 \) or multiples, but deviations from this value exist (\( x = 10, 11, 17, 18 \); Watanabe 2014). On this basis, it is possible to hypothesize that \( x = 12 \) is the basic number for the genus. A similar scenario occurred in *Cosmos*, in which both dysploidy and polyploidy has been associated with its evolution and diversification. Melchert (1968) found a correlation between morphological and chromosomal data and identified three main species complexes within the genus. A major evolutionary dichotomy occurred with the ancestor that gave rise to the two perennial complexes. In the suffruticose species of *Cosmos* sect. *Mesinenia* Sherff, \( x = 11 \) (\( n = 11, 22, 33 \)). In contrast, all other perennials in *Cosmos* sect. *Discopoda* (DC.) Sherff, \( x = 12 \) (\( n = 12, 24, 36 \)). In annual species of *Cosmos* sect. *Cosmos*, \( x = 12 \) (\( n = 12, 24 \)).

In *Bidens*, there also exists a wide chromosome series \( 2n = 20, 22, 24, 34, 36, 48, 96 \) (Panero 2007, Watanabe 2014). *Bidens herzogii* is a tetraploid, as the somatic chromosome number was \( 2n = 48 \) (Fig. 2). The chromosomal counts agreed with other data for *Bidens* species from South America (Solbrig et al. 1972, Powell et al. 1974, Turner et al. 1979, Keil et al. 1988, Grombone-Guaratini et al. 2006, Crawford et al. 2009, Watanabe 2014).

Based on infragenic classification proposed by de Candolle (1836) and Sherff (1937), *Bidens herzogii* can be included in *Bidens* section *Psilocarpaea* DC. It is the largest section

**Table 1. Morphological boundaries between the genera *Cosmos* and *Bidens*.**

<table>
<thead>
<tr>
<th>Character</th>
<th><em>Cosmos</em></th>
<th><em>Bidens</em></th>
</tr>
</thead>
<tbody>
<tr>
<td>Habit</td>
<td>upright herbs</td>
<td>trailing or climbing herbs</td>
</tr>
<tr>
<td>Stem</td>
<td>terete</td>
<td>tetrangular or terete</td>
</tr>
<tr>
<td>Leaves</td>
<td>opposite</td>
<td>alternate or opposite</td>
</tr>
<tr>
<td>Phyllaries</td>
<td>glabrous, 5-8(-10) per series, with</td>
<td>mostly pubescent or glabrous, 4-22</td>
</tr>
<tr>
<td></td>
<td>conspicuous resiniferous ducts on</td>
<td>per series, may or may not have</td>
</tr>
<tr>
<td></td>
<td>the abaxial face</td>
<td>inconspicuous resiniferous ducts on</td>
</tr>
<tr>
<td></td>
<td></td>
<td>the abaxial face</td>
</tr>
<tr>
<td>Capitulum</td>
<td>heterogamous</td>
<td>heterogamous or homogamous</td>
</tr>
<tr>
<td>Ray florets</td>
<td>sterile</td>
<td>fertile or sterile</td>
</tr>
<tr>
<td>Stamen filament</td>
<td>pubescent</td>
<td>glabrous</td>
</tr>
<tr>
<td>Achenes</td>
<td>tetragonal, with a single longitudinal groove</td>
<td>3-4-angled or dorsally flattened</td>
</tr>
<tr>
<td></td>
<td>on each side</td>
<td>with 2-4 grooves on each side</td>
</tr>
<tr>
<td>Pappus awns</td>
<td>retrorsely barbed</td>
<td>antrorsely or retrorsely barbed</td>
</tr>
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</table>
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of *Bidens*, comprises much of the American species, and includes annual and perennial herbs and shrubs, with simple or segmented leaves, discoid or radiate heads, tetragonal and aristate achenes. Sherff (1937) and Kim *et al.* (1999) argued that this section does not represent a natural lineage and future studies may indicate the advisability of splitting this section into several smaller groups.

Potential distribution of *Bidens herzogii* and its implications for the conservation

The herbarium records and potential projected distribution of *Bidens herzogii* coincided in the Chiquitanía region, in the plains identified as Occidental Cerradense by Navarro & Ferreira (2009). Navarro (2011) remarked that La Chiquitanía constitutes a natural region in Southeastern Bolivia, and extends into northern Paraguay and Western Brazil at the boundaries of the Amazon River and La Plata River basins. The region is part of the Brazilian Precambric Shield, also known as the “Cratón de Guaporé” (Suarez 2000, Montes de Oca 2001) and it is distinguished by its unique flora, singular abiotic characteristics, and several biological endemism (Suarez 2000, Wood *et al.* 2011, Pozo *et al.* 2013).

**Conclusions**

We propose that the potential geographical distribution of *B. herzogii* (Figs. 2-3), could predict key areas for others restricted plants and indicate potential areas for conservation. Species distribution models estimates the spatial distributions of species requiring attention, due to its rarity or limited known occurrences. According to Hernández *et al.* (2006), out of four modeling methods, Maxent was the best in producing useful results with sample sizes as small as 5, 10 and 25 occurrences. The accuracy of models is greater for species with small geographic ranges and limited environmental tolerance. Our results indicate that reasonable models can be generated for some rare species like *Bidens herzogii* and it should encourage conservationists to add distribution modeling tools to their research programs.

For example, the Noel Kempff National Park and the Tucavaca Natural Protected Area, in Santa Cruz department (SERNAP 2013, Robinson *et al.* 2002), could direct their efforts in order to protect new areas or extend their geographic limits, considering the potential distribution of *B. herzogii* and by modeling the distribution of other associated species restricted to the region based on methods used in our work. This proposal coincides with Pozo *et al.* (2013) in the identification of conservation hotspots areas in Eastern Bolivia, containing high environmental heterogeneity, high plant diversity and endemism. Finally, we recommend its application for defining conservation priorities in Eastern Bolivia.

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