Revista Brasileira de Entomologia 59 (2015) 260–264

REVISTA BRASILEIRA DE
Entomologia
A Journal on Insect Diversity and Evolution

www.rbentomologia.com

Short Communication

Beta-ionone attracts *Euglossa mandibularis* (Hymenoptera, Apidae) males in western Paraná forests

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ARTICLE INFO

Article history:
Received 6 March 2015
Accepted 29 May 2015
Available online 4 July 2015
Associate Editor: Eduardo A.B. Almeida

Keywords:
Atlantic Forest
Biogeography
Euglossini
Euglossina
Mixed Ombrophylous Forests

ABSTRACT

Males of *Euglossa mandibularis* were consistently captured in scent traps baited with β-ionone in areas of Mixed Ombrophylous Forests or transition between this latter physiognomy and Montane Semideciduous Forest at Parque Nacional do Iguaçu, Paraná state, Brazil. Geographic records for the species and sampling effort (including or not β-ionone among the offered compounds) along Atlantic Forest biome are presented and discussed. We also discuss seasonal and geographic variation in collection of scents by orchid bees.

Among all the astonishing interactions between bees and plants, a fantastic example is the collection of aromatic compounds by male orchid bees (Hymenoptera, Apidae, Euglossina). Some 60 synthetic chemical compounds, most present in orchid flowers, have already been recognized as biologically active attractants of these Neotropical bees (Gerlach and Schill, 1991; Roubik and Hanson, 2004). These substances have been widely used to attract orchid bees in inventories of local faunas (Sydney et al., 2010) but, despite the significant increase in the knowledge on euglossine richness and distribution, determined mainly by the use of this method of collection (Nemésio, 2012), its contribution is limited by the lack of standardization in the use of scent baits for ecological studies on euglossine taxocenoses (e.g. Nemésio, 2012). Other possible limitation is the geographical and temporal variation in the attractiveness of the compounds (Ackerman, 1989; Nemésio, 2012), and the fact that some species have never been – or were only eventually – attracted to any employed substance (Nemésio and Silveira, 2004).

Euglossa (*Euglossella*) *mandibularis* Friese 1899 is one of the best-known cases. Despite being quite abundant in some localities (e.g. Soares et al., 1989), males of *E. mandibularis* have never been collected in systematized orchid bee assessments (Moure, 1995; Peruquetti et al., 1999; Nemésio and Silveira, 2004). Assuming that commonly employed compounds do not attract these bees, however, seems not to be a closed issue. Ramírez et al. (2002: 72) stated that 1,8-cineol, eugenol and vanillin attract this species but no additional information related to the localities where the bees came from was presented. Hinojosa-Díaz and Engel (2014), in their extensive taxonomic revision, revised the attractants for *Euglossella* in the *viridis* and *mandibularis* species group and did not confirm this information.

But there is some anecdotal evidence of the attraction of *E. mandibularis* to β-ionone baits in some previously published papers: a personal communication of Dr. Dieter Wittmann to Dr. André Nemésio (Nemésio, 2009:11,136) and personal observations by Dr. Simone Cappellari (Cappellari et al. (2009:724,725). It is interesting to note that both observations were carried out in Rio Grande do Sul state but, unfortunately, no additional and detailed data was presented. Truylio and Harter-Marques (2007) presented for the first time substantial information on the task. Data on local, sampling method and the number of collected males were presented (three males in β-ionone traps in Rio Grande do Sul state). An important question, however, should be considered. The collection of euglossine males was not the main focus of them, since their leading objective was to study the entire local bee fauna at the Parque Estadual de Itapuã (municipality of Viamão, Rio Grande do Sul state, Brazil). Probably this is why the information on the attractiveness of β-ionone to *E. mandibularis* was overlooked in the comprehensive and rigorous literature review in Nemésio's (2009) monograph.

Here we report the collection of males of *E. mandibularis* in traps baited with β-ionone in southern Brazil. The distribution of

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http://dx.doi.org/10.1016/j.rbe.2015.05.003
0085-5626/

the species and sample effort on surveying orchid bees along the distribution of *E. mandibularis* is also discussed.

Fieldwork was carried out in the Parque Nacional do Iguaçu, one of the largest remnants of the Atlantic Forest domain, encompassing ca. 185,000 ha in western Paraná state (IBAMA, 1999). Six sample sites were located in areas of Mixed Ombrophylous Forests and transition between this latter physiognomy and Montane Semideciduous Forest, at altitudes between ca. 440 and 730 masl, in the municipalities of Céu Azul and Matelândia. At each sample point, traps (we used the model provided by Gonçalves et al., 2014, with some modifications) baited with β-ionone, benzyl acetate, eucalyptol, eugenol, methyl salicylate, methyl trans-cinnamate and vanillin were offered to bees in four sampling days between November 2013 and January 2014.

Fourteen males of *E. mandibularis* Friese were collected, distributed in four of the sample sites, all of them in β-ionone traps and only in December 2013. Voucher specimens are deposited at the Universidade Federal da Integração Latino-Americana (UNILA) and label information are presented within quotation marks: two males, "BR, PR, Céu Azul, PNI 3A, Arm. β-ionona, 25°4′9.4″ 53°39′35.5″, 8/XII/2013, 729m, Zanella leg."; three males, "BR, PR, Céu Azul, PNI 3C, Arm. β-ionona, 25°4′28.0″ 53°39′33.6″, 8/XII/2013, 693m, Zanella leg."; seven males, "BR, PR, Céu Azul, PNI 3B, Arm. β-ionona, 25°4′22.4″ 53°39′30.2″, 8/XII/2013, 697m, Zanella leg."; two males, "BR, PR, Matelândia, PNI 2C, Arm. β-ionona, 25°18′32.9″ 53°52′6.8″, 8/XII/2013, 439m, Zanella leg.".

Additional distribution data was compiled from published papers on euglossine taxonomy, local inventories of bees and floral biology. The CRIA – Species Link (http://splink.cria.org.br) database was also consulted (see Appendix 1). The delimitation of ecoregions follows Olson et al. (2001).

Euglossa mandibularis is recorded in a wide area of southeastern and southern Brazil, southern Paraguay and in the provinces of Corrientes and Misiones, Argentina (Nemésio, 2009; Moure et al., 2012; Hinojosa-Díaz and Engel, 2014; see Appendix 1 and Fig. 1). Jürgens et al. (2009) mentioned its occurrence near Manaus, Amazonia, but it is probably a misidentification and must be checked. Hinojosa-Díaz and Engel (2014) presented a record for Espírito Santo state, but as no municipality was assigned to the specimen, we did not include this information on the distribution map.

Interestingly, however, this bee species had not been previously collected in any specific survey employing scent baits within its known occurrence area. But it was not for lack of trying, since several surveys of local orchid bee faunas were undertaken in the probable area of occurrence of the species (Fig. 1). In Fig. 1, it is important to distinguish between surveys where β-ionone was employed (open squares) or not (open circles). A detailed list of the surveys carried out in the Brazilian Atlantic Forest and surrounding areas included in our database is presented in Table 1.

It is possible to observe that assessments were carried out in at least six locations where *E. mandibularis* is known to occur, besides the use of a reasonable set of substances to attract orchid bees: (i) Viçosa region, Minas Gerais state (Fig. 1, site 1): 1,8-cineole, benzyl acetate, eugenol, methyl salicylate and vanillin (Peruquetti et al., 1999); (ii) Ubatuba region, São Paulo state (Fig. 1, site 2): 1,8-cineole, β-ionone, β-myrcene, amyl acetate, benzyl acetate, benzyl benzoate, methyl benzoate, eugenol, ethyl butyrate, methyl cinnamate, phenethyl alcohol, linalool, methyl salicylate and vanillin (Rocha-Filho and Garófalo, 2013); (iii) Sete Barras (Fig. 1, site 3): 1,8-cineole, β-ionone, eugenol, methyl salicylate, vanillin (Mattozo et al., 2011); (iv) Antonina, Paraná state (Fig. 1, site 4): 1,8-cineole, eugenol, methyl salicylate and vanillin (Mattozo et al., 2011); (v) Blumenau, Santa Catarina state (Fig. 1, site 5): 1,8-cineole, eugenol, vanillin (Krug, 2010); (vi) Nova Petrópolis region, Rio Grande do Sul state (Fig. 1, site 6): 1,8-cineole, skatole and vanillin (Wittmann et al., 1988). Among the aforementioned surveys, β-ionone was offered to bees only in Ubatuba and Sete Barras (both in the ecoregion "Serra do Mar Coastal Forests"), without any success in attracting males.

The main question is why males of *Euglossa mandibularis* were attracted to β-ionone baits in areas of western Paraná (Fig. 1, site 7) and in two sites in eastern Rio Grande do Sul (São Francisco de Paula, Cappellari et al., 2009, Fig. 1, site 8; Viamão, Truylio and Harter-Marques, 2007, Fig. 1, site 9)? It is outstanding these sites are

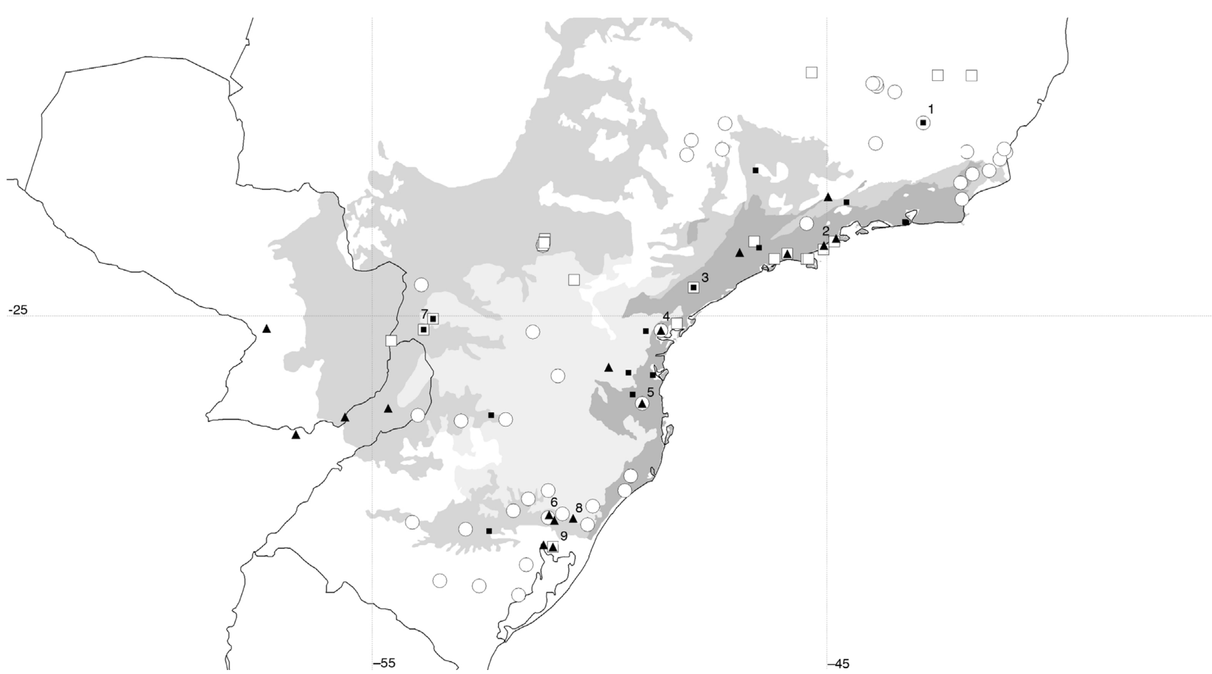

Fig. 1. Geographic distribution of *Euglossa mandibularis* and assessments of orchid bees carried out along its distribution and adjacencies. Solid squares: specimens directly examined; solid triangles: information obtained from published papers or web databases; open squares: euglossine assessments where β-ionona was used as attractant; open circles: euglossine assessments where β-ionona was not employed.

Table 1
Surveys of euglossine males carried out along Atlantic Forest and adjacencies considered in this study.

Location	Methodology	Number of scents	Time spent (months)	Use of β-ionona	Reference
Barroso, MG	Traps	3	12		Pires et al. (2013)
Belo Horizonte, MG (four fragments)	Hand net	5	12		Nemésio and Silveira (2007)
Catas Altas, MG	Hand net	5	12		Nemésio (2008)
Caratinga, MG	Hand net	17	1	Yes	Nemésio and Paula (2013)
Dionísio, MG	Hand net	13	11	Yes	Nemésio and Silveira (2006)
Marliéria, MG	Traps	16	15	Yes	Peruquetti et al. (1999)
Viçosa, MG	Traps	5	17		Peruquetti et al. (1999)
Campos dos Goytacazes, RJ	Traps	7	12		Aguiar and Gaglianone (2011)
Casimiro de Abreu, RJ	Traps	7	12		Ramalho et al. (2009)
Santa Maria Madalena. RJ (nine fragments)	Traps	6	23		Tonhasca et al. (2002)
São Francisco do Itabapoana, RJ (two fragments)	Traps	7	13		Aguiar and Gaglianone (2008)
São Francisco do Itabapoana, RJ (two fragments)	Traps	5	25		Aguiar and Gaglianone, 2012
São José do Ubá (four fragments)	Traps	5	25		Aguiar and Gaglianone (2012)
Silva Jardim, RJ (four fragments)	Traps	7	12		Ramalho et al. (2009)
Trajano de Moraes, RJ (three fragments)	Traps	5	25		Aguiar and Gaglianone (2012)
Cajuru, SP	Insect nets	3	12		Rebêlo and Garófalo (1997)
Guatapará, SP	Insect nets	4	12		Castro et al. (2013)
Ilhabela, SP	Insect nets/traps	3/14[a]	24	Yes	Cordeiro et al. (2013)
Mairiporã, SP	Insect nets/traps	3/14[a]	19	Yes	Cordeiro et al. (2013)
Mogi das Cruzes, SP	Insect nets/traps	3/14[a]	19	Yes	Cordeiro et al. (2013)
Patrocínio Paulista, SP	Insect nets	3	12		Silveira et al. (2011)
Pindamonhangaba, SP	Insect nets	3	12		Uehara-Prado and Garófalo (2006)
Salesópolis, SP	Insect nets/traps	3/14[a]	19	Yes	Cordeiro et al. (2013)
São Sebastião, SP	Insect nets/traps	14	9	Yes	Cordeiro et al. (2013)
Sertãozinho, SP	Insect nets	3	12		Rebêlo and Garófalo (1997)
Sete Barras, SP	Insect nets	5	8	Yes	Mattozo et al. (2011)
Ubatuba, SP (Picinguaba and Ilha Anchieta)	Insect nets	3/14[a]	24	Yes	Rocha-Filho and Garófalo (2013)
Antonina, PR	Insect nets/traps	4	12		Mattozo et al., 2011
Céu Azul, PR	Traps	7	3	Yes	Unpublished data
Foz do Iguaçu, PR	Insect nets/traps	7	9	Yes	Unpublished data
Guarapuava, PR	Traps	3	14		Dias and Buschini (2013)
Guaraqueçaba, PR	Insect nets	8	14	Yes	Giangarelli et al. (2014)
Londrina, PR	Insect nets	5	12		Santos and Sofia (2002)
Londrina, PR	Insect nets	5	12		Sofia et al. (2004)
Londrina, PR (three fragments)	Insect nets	3	6		Sofia and Suzuki (2004)
Londrina, PR (four fragments)	Insect nets	5	3	Yes	Watzel et al. (Pers. comm., 2009)
Matelândia, PR	Traps	7	3	Yes	Unpublished data
Palotina, PR	Traps	3	9		Gonçalves et al. (2014)
Telêmaco Borba, PR	Insect nets	8	18	Yes	Giangarelli et al. (2014)
Blumenau, SC	Insect nets/traps	3	27		Krug (2010)
Concórdia, SC	Insect nets/traps	3	27		Krug (2010)
Maracajá, SC	Insect nets/traps	6	12		Essinger (2005)
Porto União, SC	Insect nets	6	13		Krug and Alves-dos-Santos (2008)
Urussanga, SC	Insect nets/traps	6	12		Essinger (2005)
Rio Grande do Sul state (15 areas in 15 municipalities)	Insect nets	3	4[b]		Wittmann et al. (1988)

[a] Number of attractants varied between first and second year of collection.
[b] Time spent in the entire study; individual areas were sampled for one or a few days.

located in the "Araucaria Moist Forest" ecoregion or surrounding areas. Regarding the occurrences in western Paraná, fieldwork was carried out in a typical area of Mixed Ombrophylous Forest, municipality of Céu Azul, and a transition area between Araucaria Forest and Montane Seasonal Semideciduous Forest in the municipality of Matelândia. With respect to the occurrences in Rio Grande do Sul, the study site at São Francisco de Paula was also located in a typical Mixed Ombrophylous Forest area (Cappellari et al., 2009) and, in the case of the occurrence in Viamão, the authors described the study site as located on "the slope of a hill, in a continuous stretch of forest with trees not too high" (Truylio and Harter-Marques, 2007). In both cases, it is safe to assume that no sites were placed in Dense Ombrophylous Forest.

Some attempts to explain why some species collect or not certain particular compounds can be found in the literature. Geographic and seasonal variations within species for fragrance preferences are known (Ackerman, 1989; Armbruster, 1993), with examples comprising both small (e.g. *Eulaema cingulata* (Fabricius, 1804) in coastal areas of São Paulo state; Rocha-Filho and Garófalo, 2014) and broad geographic scales (e.g. the discussion on *Euglossa cordata* (Linnaeus, 1758) preference by Farias et al., 2007). Otherwise, a particularly important result was presented by Ramírez et al. (2010) pointing that male *Euglossa* aff. *viridissima* maintain most of the individual compounds of their fragrance phenotypes across distant populations in disparate habitats, but a few major (abundant) compounds can be present or absent from perfume bouquets. As suggested by Ackerman (1989) age or genetic difference among populations or differences in the availability and use of these resources by different populations could explain this trend. Spatial structuring of male euglossine populations by resource distribution in combination with preferences changing with natural fragrance availability and use could also explain site-to-site and season-to-season variation in bait preferences by these bees (Armbruster, 1993).

Even though sampling was restricted to a single rainy season, it is outstanding that all males were collected in December 2013. Since *E. mandibularis* is not generally attracted to scent lures, a more comprehensive evaluation of a seasonal pattern of activity in the species throughout its distribution is rather difficult. However, observations carried out in the Viçosa region suggest the species is active only during the rainy season, when *Solanum latiflorum* Bohs is blooming (Soares et al., 1989; Peruquetti et al., 1999; these authors treated the plant species as *Cyphomandra calycina* Sendtn).

One can try to understand this restriction considering the particularities of the region concerned, since changes in the preferences for aromatic compounds seem to be related to climatic seasonality (Abrahamczyk et al., 2012). Moreover, considering the relation between *E. mandibularis* and β-ionone in a more comprehensive way, a pronounced climatic seasonality is also a feature of the other two locations (São Francisco de Paula and Viamão).

This climatic circumstance mainly affects the orchid bees via the turnover of the aromatic substances provided by the plants, and changes in the preferences for aromatic compounds would be a response to this scenario (Abrahamczyk et al., 2012). Data on the phenology of plants of the Mixed Ombrophylous Forest support a highly seasonal pattern of flowering, with periods of high and low flowering activity, as consequence of the climatic seasonality (Liebsch and Mikich, 2009).

Abrahamczyk et al. (2012) also suggested that the ability to change the aromatic preference between seasons could be interpreted as an adaptation enabling some species to colonize climatically strongly seasonal habitats, what might be particularly important in the case of Mixed Ombrophylous Forest, apparently a harsh habitat for euglossine bees (see Wittmann et al., 1988). To our knowledge, three previous assessments were carried out in this phytophysiognomy, all of them suggesting a rather low species richness: (i) Krug and Alves-dos-Santos (2008); Porto União (Santa Catarina state); attractants: benzyl benzoate, benzyl salicylate, eucalyptol, eugenol, methyl salicylate and vanillin; number of specimens/species attracted: none; (ii) Dias and Buschini (2013); Guarapuava (Paraná state); attractants: eucalyptol, eugenol and vanillin; 35 males of two species (*Eulaema nigrita* Lepeletier, 1841 and *Euglossa fimbriata* Moure, 1968); (iii) Giangarelli et al. (2014); Telêmaco Borba (Paraná state); attractants: benzyl acetate, benzyl benzoate, eucalyptol, eugenol, methyl cinnamate, methyl salicylate and vanillin; 92 males of three species (*Eufriesea violacea* (Blanchard, 1840), *Euglossa* sp. and *Eulaema nigrita*). Besides these three systematized inventories, Wittmann et al. (1988) have not collected any euglossine bee when sampling Mixed Ombrophylous Forest areas in Rio Grande do Sul state (see Fig. 1 of Wittmann et al., 1988). And it is still quite interesting to compare the distribution of *Euglossa mandibularis* to this low species richness scenario in the Araucaria Forest. Although widely distributed in southeastern and southern Brazil, southern Paraguay and northeastern Argentina, this species seems to surround the Mixed Ombrophylous Forest, with known records only on the outskirts of the ecoregion (but note that β-ionone was not included in any of these assessments).

Eltz et al. (2005) suggested that innate preferences broadly define the spectrum of attractive odors collected by males, whereas learning refines quantitative aspects, e.g. avoids over collecting from abundant sources by negative feedback. However, it is interesting to consider if a negative feedback scenario would also be frequent in highly seasonal environments with temporally structured resource availability. This could be lead to potential constraints on the choice of compound sources and also implicate a significant delay in separate collections of a particular substance. The test of predictions of this hypothesis and possible links between chemical ecology and the remarkably low richness of orchid bees in highly seasonal environments remains to be studied.

However, we cannot entirely dismiss the possibility that the collection of β-ionone by males of *E. mandibularis* in the locations shown here and reported in the literature (Truylio and Harter-Marques, 2007; Cappellari et al., 2009) represents only fortuitous associations, even if we consider the geographic range of the locations. In order to improve understanding of issues as presented here, we strongly suggest the utilization of (i) β-ionone, (ii) compounds known to be present in flowers of plant species pollinated by *E. mandibularis* (e.g. Sazima et al., 1993; Cappellari et al., 2009), and even (iii) attractants of *Euglossella* species elsewhere (see Table 2 of Hinojosa-Díaz and Engel, 2014) in orchid bee assessments carried out along the known distribution of *Euglossa mandibularis*.

Conflicts of interest

The authors declare no conflicts of interest.

Acknowledgements

Gabriel A.R. Melo, curator of DZUP, who kindly provided access to specimens of *Euglossa mandibularis* under his responsibility. Ismael Hinojosa-Díaz for taking a few questions on the attractiveness of specific compounds to *E. mandibularis*. Marcio Oliveira (INPA) who kindly donated some attractants, which enabled the realization of the first collections of orchid bees in the region of Foz do Iguaçu. We acknowledge James H. Cane (USDA-ARS) for being kind as to read the manuscript. Instituto Chico Mendes de Conservação da Biodiversidade (ICMBio) allowed us to sample the areas through license #41140-1. We also acknowledge Rafael Xavier who was very helpful in solving all problems regarding our access to different areas in the Parque Nacional do Iguaçu.

Appendix 1. List of localities with known records of *Euglossa mandibularis*

Specimens deposited at DZUP and UNILA were directly studied; reference to published papers follows the indirect records (countries appear in capitals, state/provinces in bold and municipalities in italics; localities, when available, appear after a "/"; relevant notes appear in brackets).

ARGENTINA. **Corrientes**. *Ituzaingó* (Hinojosa-Díaz and Engel, 2014); **Misiones**. *Dos de Mayo* (Hinojosa-Díaz and Engel, 2014). BRASIL. **Espírito Santo** (Hinojosa-Dìaz and Engel, 2014 [as no municipality was assigned to the specimen, we did not include this register in the presented distribution map]). **Minas Gerais**. *Passa Quatro* (Friese, 1925 [as *Euglossa aenescens* Friese, 1925; see Moure et al., 2012]); *Poços de Caldas*/Morro São Domingos (DZUP); *Viçosa* (DZUP). **Paraná**. *Antonina* (Mattozo et al., 2011); *Céu Azul*/Parque Nacional do Iguaçu (UNILA); *Matelândia*/Parque Nacional do Iguaçu (UNILA); *Piraquara*/Mananciais da Serra (DZUP). **Rio de Janeiro**. *Itatiaia* (DZUP); *Rio de Janeiro*/Alto da Boa Vista (DZUP); *Rio de Janeiro*/Floresta da Tijuca (DZUP). **Rio Grande do Sul**. *Nova Petrópolis* (Nemésio, 2009); *Porto Alegre*/Campus UFRGS (species link, CRIA); *Santa Cruz do Sul*/Cinturão Verde (DZUP); *Santa Maria do Herval* (species link, CRIA); *São Francisco de Paula* (Cappellari et al., 2009); *Viamão*/Parque Estadul de Itapuã (Truylio and Harter-Marques, 2007). **Santa Catarina**. *Blumenau*/Parque Nacional da Serra do Itajaí (Krug, 2010); *Corupá* (Hinojosa-Díaz and Engel, 2014); *Joinville* (DZUP); *Mafra* (Hinojosa-Díaz and Engel, 2014); *Rio dos Cedros*/Alto Rio dos Cedros (DZUP); *Rio Vermelho* (DZUP); *Seara*/Nova Teutônia (DZUP). **São Paulo**. *São Paulo*/Vila Ema (DZUP); *Ubatuba*/E.E. Instituto Agronômico (Sazima et al., 1993); *Ubatuba*/Picinguaba (Gonçalves et al., 2012); *Sete Barras*/Fazenda Morro do Capim (DZUP); *Salesópolis*/Estação Ecológica da Boracéia (Wilms, 1995); *Cotia*/Reserva Florestal de Morro Grande (Aguilar, 1998). PARAGUAY. **Cordillera**. *San Bernardino* (Cockerell, 1917 [as *Euglossa mandibularis bernardina* Cockerell, 1917; see Moure et al., 2012]. **Itapúa**. *Puerto Cantera* (Hinojosa-Díaz and Engel, 2014 [the authors (p. 89) present "Puerto Cantera?"; we decided to include the coordinates corresponding to the municipality of Puerto Cantera in the presented distribution map].

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