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CALANOIDS (CRUSTACEA: COPEPODA) REPORTED FOR CHILEAN INLAND WATERS

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Abstract

Calanoid copepods in Chilean inland waters are the main group in zooplanktonic assemblages. They are represented by three genera: *Boeckella, Parabroteas* and *Tumeodiaptomus*. The genus *Boeckella* has three widespread species: *B. gracilipes,* distributed in practically all inland freshwaters, mainly between 33-44° S; *B. poopoensis,* that inhabits saline lakes of northern Chile (14-27° S); and *B. michaelseni,* that inhabits inland freshwaters between 44-54° S. *Tumeodiaptomus* is represented by *T. diabolicus,* that is dominant between 32-42° S. Finally, *Parabroteas* has one species, *P. sarsi* that is abundant mainly in shallow ponds between 44-54° S. Different assemblages of calanoid species characterize northern (*Boeckella occidentalis, B. poopoensis,* and *B. gracilipes*) central (*Tumeodiaptomus diabolicus, B. gracilipes,* and *B. bergi*), and southern (*T. diabolicus, B. gracilipes*, and *B. michaelseni*) Chile.

Keywords: *Boeckella, Tumeodiaptomus, Parabroteas*, freshwaters, Chile.

Calanoideos (Crustacea: Copepoda) reportados para aguas interiores chilenas

Resumen

Los copépodos calanoideos en aguas continentales chilenas se caracterizan por ser el grupo principal en los ensambles zooplanctónicos. Están representados por tres géneros: *Boeckella, Parabroteas* y *Tumeodiaptomus*. El género *Boeckella* está representado por tres especies de amplia distribución geográfica: *B. gracilipes*, que se encuentra entre los 18 y 44° S, *B. poopoensis* principalmente en lagos salinos del norte de Chile (14-27° S) y *B. michaelseni* que se encuentra entre 44-54° S. *Tumeodiaptomus*, representado por *T. diabolicus*, está distribuido entre 32-42° S. Finalmente, *Parabroteas*, con solo una especie, *P. sarsi*, ha sido reportada en lagunas poco profundas entre 44-54° S. Hay diferentes especies para la zona norte (*Boeckella occidentalis, B. poopoensis*, y *B. gracilipes*) central (*Tumeodiaptomus diabolicus*, *B. gracilipes, B. bergi*), y sur (*T. diabolicus*, *B. gracilipes*, y *B. michaelseni*) de Chile.

Palabras clave: *Boeckella, Tumeodiaptomus, Parabroteas*, aguas dulces, Chile.

Introduction

Calanoid copepods are abundant in Chilean continental waters and have been reported from central and southern regions (Soto & Zúñiga, 1991; De los Ríos & Soto, 2006; Villalobos, 2006). Also, they are abundant in zooplanktonic assemblages in northern Chile, were the salinity is the

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main regulating factor for zooplankton community structure (De los Ríos & Crespo, 2004; De los Ríos, 2005). In southern Chile, there are numerous shallow ponds with different conductivity gradient and trophic status (Soto *et al.,* 1994; De los Ríos *et al.,* 2008a, 2008b), and calanoid copepods are abundant in conditions of oligotrophy or high conductivity (Soto & De los Ríos, 2006). The most representative widespread species is *Boeckella gracilipes,* that was reported for widely distributed shallow water bodies between 18-51° S (Villalobos & Zúñiga, 1991; Bayly, 1992a, 1992b; Villalobos, 2006; Valdovinos, 2008), although it is abundant mainly between 33-44° S (Bayly, 1992; Menu-Marque *et al.,* 2000). Other widespread species are *Tumeodiaptomus diabolicus,* reported between 32-42° S (Soto & Zúñiga, 1991; Villalobos *et al.,* 2003); and *B. poopoensis,* that inhabits mainly saline lakes of northern Chile (De los Ríos & Crespo, 2004) and neighboring countries (Menu-Marque *et al.,* 2000; De los Ríos & Contreras, 2005). In extreme southern Chile, the representative species are *B. michaelseni* and *Parabroteas sarsi*, both frequent south of 44° S; the first species is dominant in large lakes and shallow ponds, whereas the second species is dominant mainly in shallow ponds (De los Ríos, 2008).

We provide herein a list of the calanoid copepods reported for Chilean inland waters based on a revision of the available literature, and we analyzed their geographical distribution.

Material and methods

Distributional patterns for this study were obtained from the literature (Mrázek, 1901; Brehm, 1935a-d, 1936, 1937; Loeffler, 1961; Thomasson, 1963; Zúñiga, 1975; Zúñiga & Domínguez, 1977, 1978; Zúñiga & Araya, 1982; Andrew *et al.*, 1985; Araya & Zúñiga, 1985; Soto & Zúñiga, 1991; Villalobos & Zúñiga, 1991; Bayly 1992a, 1992b; Schmid-Araya & Zúñiga, 1992; Campos *et al.*, 1994a, 1994b; Villalobos, 1999; De los Ríos & Crespo, 2004; De los Ríos, 2005; Soto & De los Ríos, 2006). We compiled the localities where the species have been reported and their valid names (Bayly, 1992a, 1992b; Menu-Marque *et al.,* 2000; De los Ríos, 2008) and represented them on maps (Figures 1-13).

Results and discussion

Thirteen calanoid species are reported from Chilean inland waters. For detailed geographic information for species see appendix:

List of Chilean inland waters calanoids

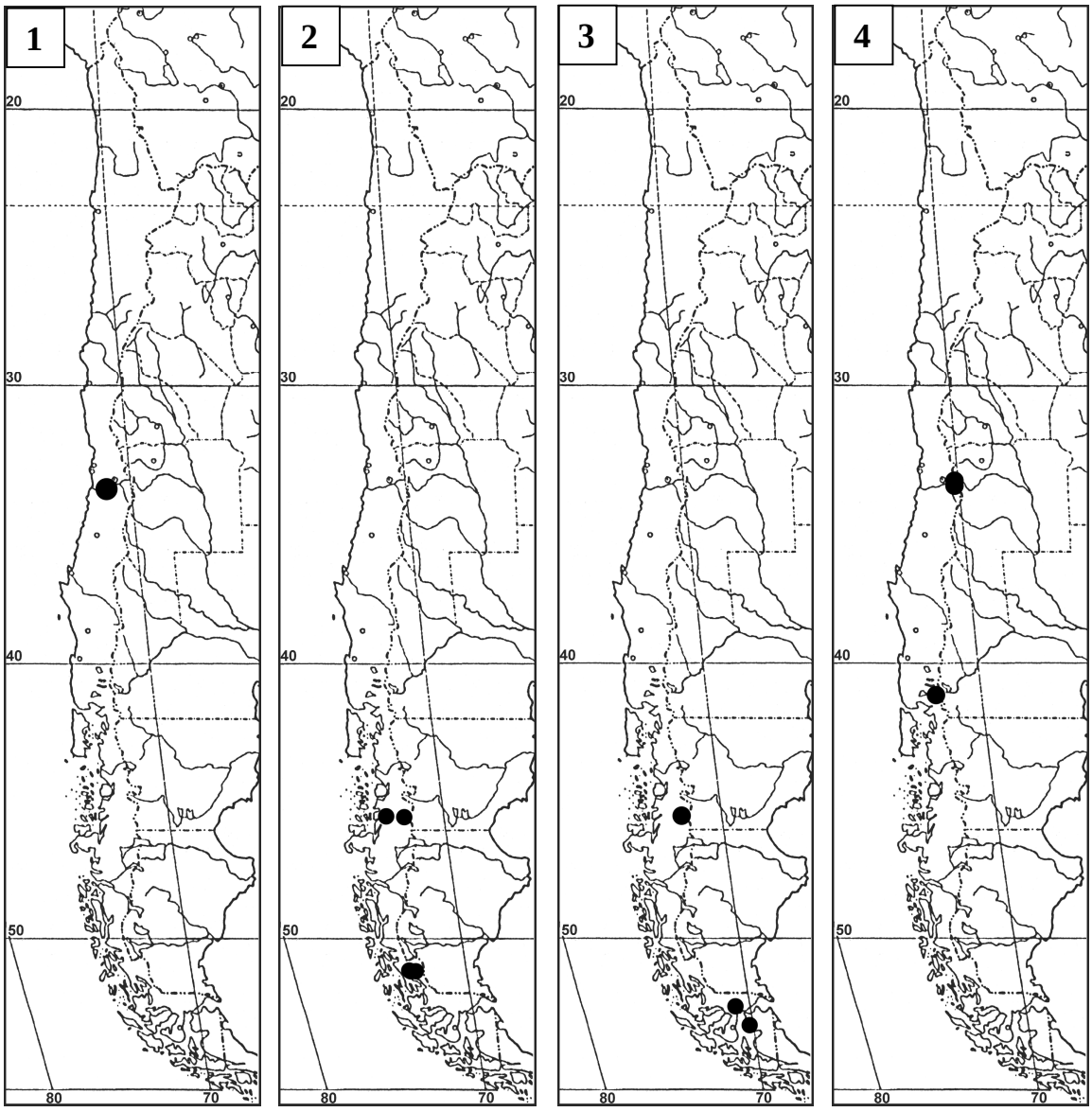
Genus *Boeckella* Guerne & Richard, 1889

Boeckella bergi Richard, 1897 (Figure 1)

B. brasiliensis (Lubbock, 1855) (Figure 2)

B. brevicaudata (Brady, 1875) (Figure 3)

B. gibbosa (Brehm, 1935) (Figure 4)



Figures 1-4. Geographical distribution of chilean calanoid copepods: 1, *Boeckella bergi* Richard, 1897; 2, *B. brasiliensis* (Lubbock, 1855); 3, *B. brevicaudata* (Brady, 1875); 4, *B. gibbosa* (Brehm, 1935).

Figuras 1-4. Distribución geográfica de copépodos calanoídeos chilenos: 1, *Boeckella bergi* Richard, 1897; 2, *B. brasiliensis* (Lubbock, 1855); 3, *B. brevicaudata* (Brady, 1875); 4, *B. gibbosa* (Brehm, 1935).

B. gracilipes Daday, 1901 (Figure 5)

B. gracilis (Daday, 1902) (Figure 6)

B. meteoris Kiefer, 1928 (Figure 7)

B. michaelseni (Mrázek, 1901) (Figure 8)

B. occidentalis Marsh, 1906 (Figure 9)

B. poopoensis Marsh, 1906 (Figure 10)

B. poppei (Mrázek, 1901) (Figure 11)

Genus *Parabroteas* Penther, 1913

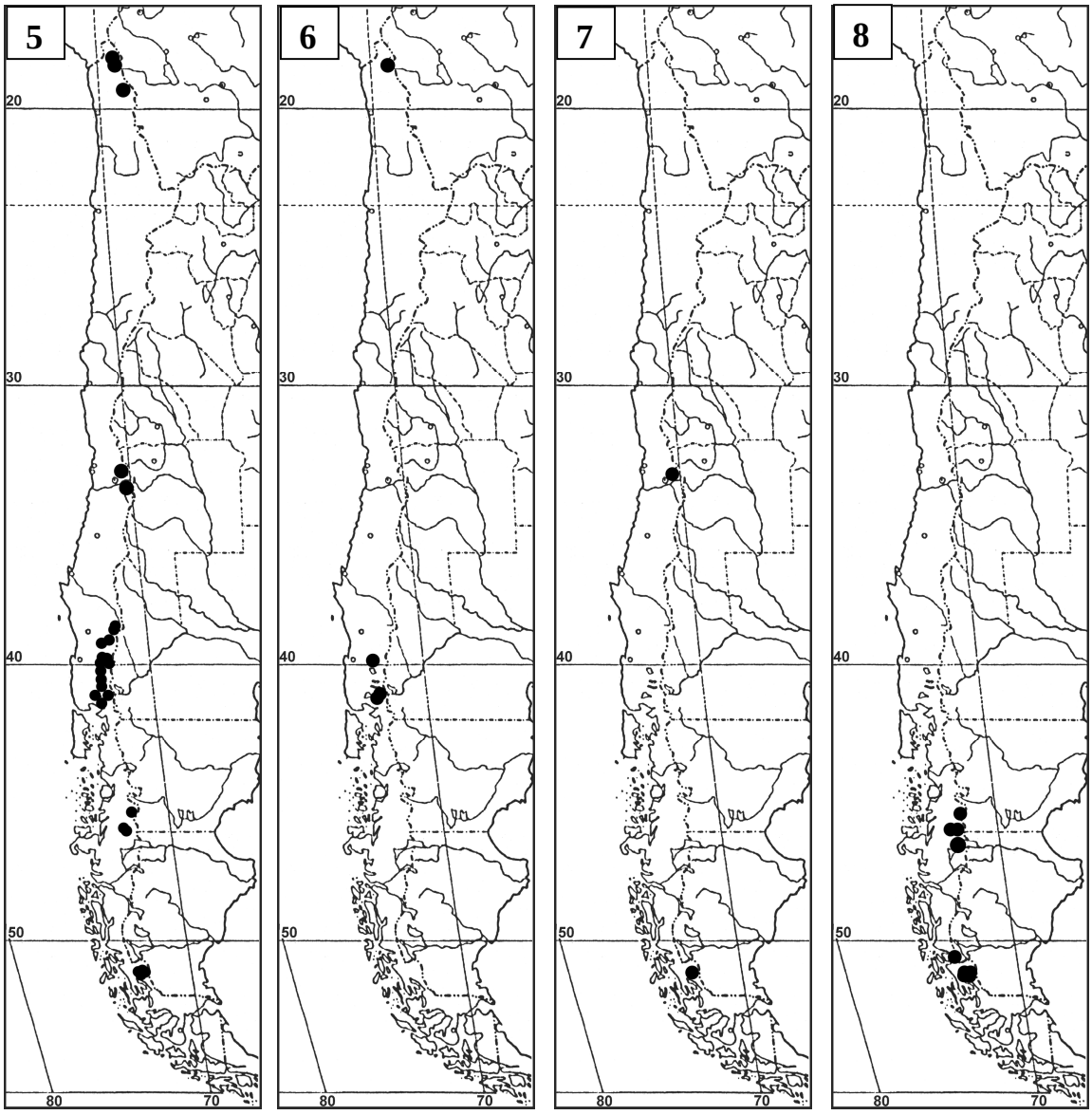
Parabroteas sarsi (Mrázek, 1901) (Figure 12)

Genus *Tumeodiaptomus* Dussart, 1979

Tumeodiaptomus diabolicus (Brehm, 1935) (Figure 13).

From the geographic reports, it is possible found geographically restricted species for a) northern Chile, such as *B. occidentalis* (Figure 9); b) central Chile, such as *B. bergi* (Figure 1); c) central Chile and southern Patagonia such as *B. gibbosa* (Figure 4) and *Tumeodiaptomus diabolicus* (Figure 13); and d) central and southern Patagonia such as *B. brasiliensis* (Figure 2), *B. brevicaudata* (Figure 3), B. *michaelseni* (Figure 8), *B. poppei* (Figure 11) and *Parabroteas sarsi* (Figure 12). Finally it is possible found widespread species such as *B. gracilipes* (Figure 5), *B. gracilis* (Figure 6), *B. meteoris* (Figure 7) and *B. poopoensis* (Figure 10), which were reported along wide geographical gradient (see appendix).

The analysis revealed the existence of a species assemblage restricted to northern Chile, mainly in saline and subsaline water bodies located in the Andes (Bayly, 1993; De los Ríos & Crespo, 2004; De los Ríos & Contreras, 2005; De los Ríos, 2005), and including *Boeckella occidentalis*, *B. poopoensis,* and the widespread species *B. gracilipes*, as reported by Menu-Marque *et al.* (2000) for neighboring areas in Argentina, Bolivia and Perú. Nevertheless, Chile has fewer species reported than Argentina and Bolivia (Menu-Marque *et al.,* 2000), probably because of the barrier role of Andean mountains that would impede species dispersal (Gajardo *et al.,* 1998; De los Ríos & Zúñiga, 2000; De los Ríos & Contreras, 2005). The most representative species can be the halophilic *B. poopoensis* that is widespread in saline waterbodies of South America (Menu-Marque *et al.,* 2000; Echaniz *et al.,* 2006a). It can tolerate a salinity level between 5-90 g/l (Hurlbert *et al.,* 1984, 1986; Bayly, 1993; Wiliams *et al.,* 1995; De los Ríos & Crespo, 2004), constituting the exclusive component in the crustacean zooplankton assemblages at salinities between 20-90 g/l (Hurlbert *et al.,* 1984, 1986; Wiliams *et al.,* 1995; Zúñiga *et al.,* 1999; De los Ríos & Crespo, 2004).



Figures 5-8. Geographical distribution of chilean calanoid copepods: 5, *Boeckella gracilipes* (Daday, 1902); 6, *B. gracilis* (Daday, 1902); 7, *B. meteoris* Kiefer, 1928; 8, *B. michaelseni* Mrazek, 1901.

Figuras 5-8. Distribución geográfica de copépodos calanoídeos chilenos: 5, *Boeckella gracilipes* (Daday, 1902); 6, *B. gracilis* (Daday, 1902); 7, *B. meteoris* Kiefer, 1928; 8, *B. michaelseni* Mrazek, 1901.

A different situation is found in central Chile (33-37° S), where the representative species is the diaptomid *Tumeodiaptomus diabolicus*, distributed in lagoons and reservoirs from middle valleys (Zúñiga 1975; Araya & Zúñiga, 1985; Schmid-Araya & Zúñiga, 1992). It is also possible to find *Boeckella gracilipes,* reported for Andean water bodies. Zúñiga (1975) proposed that *T. diabolicus*

is located at low altitude water bodies in central Chile, because it cannot tolerate cold temperatures. The presence of *B. bergi* in the Aculeo lagoon, where *T. diabolicus* should be dominant, may be caused by the introduction of argentinean silversides (Silvina Menu-Marque, *com. pers.*). Unfortunately, there are not studies about crustacean zooplankton in water bodies located between 27-33° S, and the studies between 34-38° S are restricted to three sites, so many lagoons and small reservoirs are still unknown.

The copepods south of 38° S are well studied, due to several available limnological studies (Domínguez & Zúñiga, 1979; Campos, 1984; Soto & Zúñiga, 1991; De los Ríos & Soto, 2006, 2007). The best studied water bodies are large and deep lakes located between 38-51° S, characterized by their oligotrophic or oligomesotrophic status (Soto & Zúñiga, 1991), as the Araucanian lakes located between 38-41° S (Campos, 1984). The species reported are mainly *Tumeodiaptomus diabolicus,* distributed between 38-40° S, which can coexist with *Boeckella gracilipes* (Soto & Zúñiga, 1991; De los Ríos & Soto, 2007). The latter species is dominant from 40 to approximately 45° S, and south of 45° S it is replaced by *B. michaelseni* (Menu-Marque *et al.,* 2000; De los Ríos & Soto, 2007; De los Ríos, 2008). Between 38-42° S, there are two different groups of water bodies: the coastal lagoons and wetlands, where *T. diabolicus* has been reported between 41-42° S (De los Ríos, 2003; Villalobos *et al.,* 2003) –further studies are necessary between 38-41° S to assess the potential allopatry between *T. diabolicus* and *B. gracilipes—*; and pristine mountain water bodies located within protected areas with native forest between 39-45° S (Steinhart *et al.,* 1999, 2002; De los Ríos *et al.,* 2007), not studied systematically, due to access problems (De los Ríos *et al.,* 2007). The zooplankton studies denoted the presence of *B. gracilis* in lakes at 39° S (De los Ríos *et al.,* 2007; De los Ríos & Romero, 2009), and it is probable that this species is also distributed in high mountain lakes of northern Patagonia (38-41° S).

In central and southern Patagonia between 45-53° S, there are permanent or ephemeral shallow ponds with a high number of copepods and cladoceran species (Henríquez, 2004; De los Ríos, 2005, 2008) and marked endemism (Menu-Marque *et al.,* 2000). Species reported in this area are large and robust (Menu-Marque *et al.,* 2000) and are markedly pigmented (Villafañe *et al.,* 2000). Some species can tolerate a relatively wide conductivity gradient, such as *Boeckella poppei* and *Parabroteas sarsi* (De los Ríos & Contreras, 2005; De los Ríos & Rivera, 2008). In this area it is possible to find the halophilic *B. poopoensis* (Menu-Marque *et al.,* 2000; Soto & De los Ríos, 2006; Adamowicz *et al.,* 2007) and the widespread species *B. gracilipes* and *B. michaelseni* (Menu-Marque *et al.,* 2000; De los Ríos, 2008). Further studies are still necessary to understand the species distribution, because there are species reported with low frequency, which need confirmation, such as *B. brevicaudata* and *B. gibbossa*.

The species identified herein are distributed in the South American transition zone and the Andean region (Morrone, 2004, 2006). The former includes the Atacama biogeographic province (northern Chile between 18-28° S), where only *B. occidentalis* was found. In the Andean region, many of the species reported were located mainly in the Santiago, Maule, Valdivian Forest, Magellanic Forest and Magellanic Moorland biogeographic provinces.

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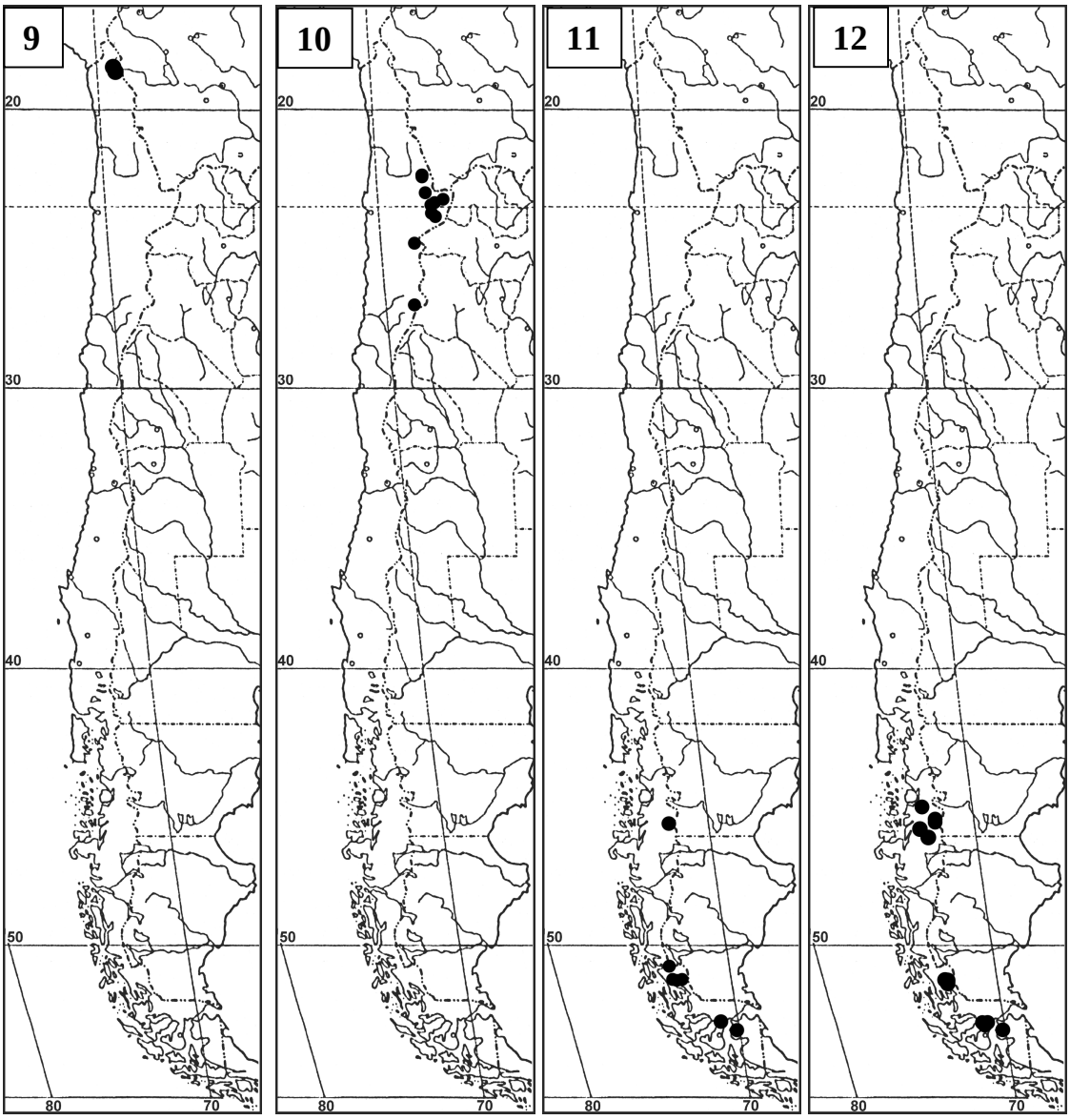

Figures 9-12. Geographical distribution of chilean calanoids copepods: 9, *Boeckella occidentalis* Marsh, 1906; 10, *B. poopoensis* Marsh, 1906; 11, *B. poppei* (Mrazek, 1901); 12, *Parabroteas sarsi* (Mrazek, 1901).

Figuras 9-12. Distribución geográfica de copépodos calanoideos chilenos: 9, *Boeckella occidentalis* Marsh, 1906; 10, *B. poopoensis* Marsh, 1906; 11, *B. poppei* (Mrazek, 1901); 12, *Parabroteas sarsi* (Mrazek, 1901).

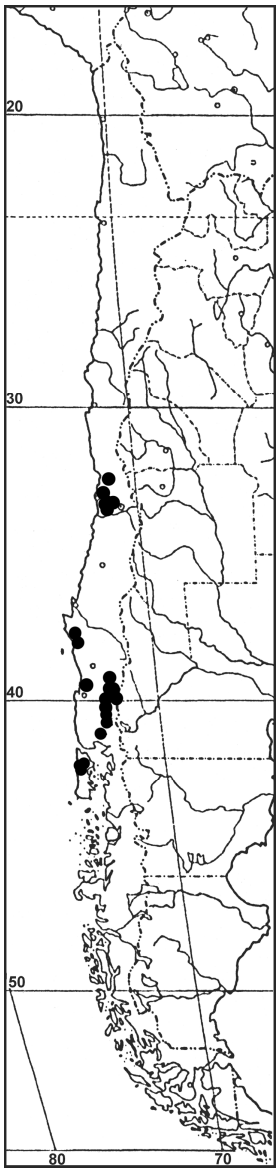

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Figure 13. Geographical distribution of Chilean calanoids copepods: *Tumeodiaptomus diabolicus* (Brehm, 1935).

Figura 13. Distribución geográfica de copépodos calanoídeos chilenos: *Tumeodiaptomus diabolicus* (Brehm, 1935).

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APPENDIX

Apéndice

Species reported for Chilean inland waters with information about their geographical coordinates and references:

Boeckella bergi Richard, 1897: Aculeo lagoon (33°50′ S; 70°56′ W) (Brehm, 1936).

B. brasiliensis (Lubbock, 1855): Balmaceda pools (45°53′ S; 71°40′ W), Monserrat lagoon (51°07′ S; 72°47′ W) (De los Ríos, 2005); Redonda lagoon (51°01′ S; 72°52′ W), Larga lagoon (51°01′ S; 72°52′ W), Jovito lagoon (51°02′ S; 72°54′ W) (Bayly, 1992b).

B. brevicaudata (Brady, 1875): Balmaceda (45°53′ S; 71°40′ W), Kon Aiken (52°50′ S; 71°10′ W) (De los Ríos, 2005); De los Patos Bravos lagoon (53°09′ S; 70°57′ W) (Mrázek, 1901).

B. gibbosa (Brehm, 1935): Pond close to Todos los Santos lake (41°08′ S; 71°56′ W) (Brehm, 1935c); Negra lagoon (33°36′ S; 70°07′ W) (Araya & Zúñiga, 1985); De los Indios lagoon (33°40′ S; 70°08′ W) (Brehm, 1936a); Lo Encañado lagoon (33°40′S; 70°08′ W) (Brehm, 1935d).

B. gracilipes Daday, 1901: Parinacota lagoon (17°12′ S; 69°34′ W) (Villalobos & Zúñiga, 1991); Cotacotani lagoon (18°14′ S; 69°13′ W), Chungara lake (18°15′ S; 69°10′ W), Del Inca lagoon (32°48′ S; 70°08′ W), Negra lagoon (33°36′ S; 70°07′ W), Panguipulli lake (39°43′ S; 72°15′ W), Neltume lake (39°47′ S; 71°58′ W), Pirihueico lake (39°50′ S; 71°49′ W) (Araya & Zúñiga, 1985); Galletue lake (38°41′ S; 71°16′ W), Icalma lake (38°49′ S; 71°17′ W) (Soto & Zúñiga, 1991); Caburgua lake (39°07′ S; 71°46′ W) (Campos *et al.*, 1987); Pichilafquen lake (39°13′S; 72°40′ W) (Thomasson, 1963); Riñihue lake (39°50′ S; 72°19′ W) (Zúñiga & Domínguez, 1977); Villarrica lake (39°18′ S; 72°06′ W), Calafquen lake (39°31′ S; 72°13′ W), Pellaifa lake (39°36′ S; 71°58′ W), Ranco lake (40°13′ S, 72°25′ W), Puyehue lake (40°40′ S; 72°28′ W), Rupanco lake (40°50′ S; 72°31′ W), Llanquihue lake (41°08′ S; 72°49′ W), Todos los Santos lake (41°08′ S; 71°56′ W) (Loeffler, 1961); Chapo lake (41°27′ S; 72°31′ W) (Soto & Zúñiga, 1991); Elizade lake (45°44′ S; 72°20′ W), La Paloma lake (45°46′ S; 72°11′ W) (Araya & Zúñiga, 1985); Cisnes lagoon (51°01′ S; 72°52′ W), Redonda lagoon (51°01′ S; 72°52′ W), Larga lagoon (51°01′ S; 72°52′ W) (Bayly, 1992a); Balmaceda pools (45°53′ S; 71°40′ W) (De los Ríos, 2005); Don Alvaro lagoon (51°01′ S; 72°52′ W), Guanaco lagoon (51°01′ S; 72°50′ W), Paso lagoon (51°02′ S; 72°55′ W) (De los Ríos, 2005); Sarmiento lake (51°03′ S; 72°47′ W) (Campos *et al.*, 1994a); Del Toro lake (51°12′ S; 72°45′ W) (Campos *et al.*, 1994b).

B. gracilis (Daday, 1902): Chungara lake (18°15′ S; 69°10′ W) (Andrew *et al.*, 1989); Riñihue lake (39°50′ S; 72°19′ W) (Zúñiga & Domínguez, 1978); Calbuco lagoon (41°16′ S; 72°32′ W) (Loeffler, 1961); Mausa (41°27′ S; 72°58′ W) (Brehm, 1937).

B. meteoris Kiefer, 1928: Cisnes lagoon (51°01′ S; 72°52′ W) (Bayly, 1992), Cajon de Plomo (33°07′ S; 70°08′ W) (Brehm, 1935c).

B. michaelseni (Mrázek, 1901): Polux lake (45°43′ S; 71°53′ W), Elizade lake (45°44′ S; 72°20′ W), General Carrera lake (45°50′ S; 72°00′ W), Chiguay lake (45°56′ S; 71°50′ W), Lynch lake (48°33′ S; 75°34′ W) (Araya & Zúñiga, 1985); Jovito lagoon (51°02′ S; 72°54′ W), Redonda lagoon (51°01′ S; 72°52′ W) (Bayly, 1992b); Isidoro lagoon (50°57′ S; 72°53′ W), Monserrat lagoon (51°07′ S; 72°47′ W), Vega del Toro pools (51°07′ S; 71°40 W) (De los Ríos, 2005). Juncos lagoon (51°01′ S; 72°52′ W), Pehoe lake (51°03′ S; 73°04′ W), Norsdenkjold lake (51°03′ S; 72°58′ W) (Soto & De los Ríos, 2006); Sarmiento lake (51°03′ S; 72°47′ W) (Campos *et al.*, 1994a); Del Toro lake (51°12′ S; 72°45′ W) (Campos *et al.*, 1994b).

B. occidentalis Marsh, 1906: Cotacotani lagoon (18°14′ S; 69°13′ W), Chungara lake (18°15′ S; 69°10′ W) (Bayly, 1992b).

B. poopoensis Marsh, 1906: Calientes I lagoon (23°08′ S; 67°25′ W), Calientes II lagoon (23°31′ S; 67°34′ W), Calientes III lagoon (25°00′ S; 68°38′ W) (Bayly, 1992b); Chiuchiu lagoon (22°20′ S; 68°40′ W) (Brehm, 1935a); Gemela Este lagoon (23°14′ S; 68°14′ W), Gemela Oeste lagoon (23°16′ S; 68°14′ W), Miscanti lagoon (23°43′ S; 67°48′ W), Miniques lagoon (23°43′ S; 67°48′ W), Capur lagoon (23°54′ S; 67°48′ W), Santa Rosa lagoon (27°05′ S; 69°10′ W) (De los Ríos & Crespo, 2004).

B. poppei (Mrázek, 1901): Balmaceda pools (45°53′ S; 71°40′ W), Isidoro lagoon (50°57′ S; 72°53′ W), Don Alvaro lagoon (51°01′ S; 72°52′ W), Guanaco lagoon (51°01′ S; 72°50′ W), Monserrat lagoon (51°07′ S; 72°47′W), Vega del Toro pools (51°07′ S; 71°40 W), Kon Aiken pools (52°50′ S; 71°10′ W), Porvenir pool (53°17′ S; 70°19′ W) (De los Ríos, 2005); Cisnes lagoon (51°01′ S; 72°52′ W), Redonda lagoon (51°01′ S; 72°52′ W), Larga lagoon (51°01′ S; 72°52′ W), Paso lagoon (51°02′ S; 72°55′ W), Jovito lagoon (51°02′ S; 72°54′ W) (Soto & De los Ríos, 2006).

Parabroteas sarsi (Mrázek, 1901): Los Palos lagoon (45°19′ S; 72°42′W), Riesco lake (45°46′ S; 72°20′ W) (Villalobos, 1999); Chiguay lagoon (45°56′ S; 71°50′ W), Elizalde lake (45°45′ S; 72°25′ W) (Araya & Zúñiga, 1985); Balmaceda pools (45°53′ S; 71°40′ W), Guanaco lagoon (51°01′ S; 72°50′ W), Don Alvaro lagoon (51°01′ S; 72°52′ W), Vega del Toro pools (51°07′ S; 71°40′ W), Kon Aikén pools (52°50′ S; 71°10′ W and 52°50′ S; 70°50′ W), Porvenir pool (53°17′ S; 70°19′ W) (De los Ríos, 2005); Redonda lagoon (51°01′ S; 72°52′ W), Larga lagoon (51°01′ S; 72°52′ W), Cisnes lagoon (51°01′S; 72°52′ W) (Soto & De los Ríos, 2006); Monte lagoon and De los Patos Bravos lagoons (53°09′ S; 70°57′ W) (Mrázek, 1901).

Tumeodiaptomus diabolicus (Brehm, 1935) (= *Diaptomus diabolicus* Brehm, 1935): Runge reservoir (33°00′ S; 71°29′ W), Peñuelas reservoir (33°10′ S; 71°29′ W) (Schmid-Araya & Zúñiga, 1992); Valdivia (39°49′ S; 73°15′ W) (Brehm, 1935b); Pichilafquen lake (39°13′ S; 72°40′ W), Calafquen lake (39°31′ S; 72°13′ W), Pellaifa lake (39°36′ S; 71°58′ W), Riñihue lake (39°50′ S; 72°19′ W), Ranco lake (40°13′ S, 72°25′ W), Puyehue lake (40°40′ S; 72°28′ W) (Loeffler, 1961); Catapilco reservoir (32°38′ S; 71°27′ W), El Peral (33°30′ S; 71°35′ W), Lanalhue lake (37°55′ S; 73°19′ W), Lleulleu lake (38°08′ S; 73°19′ W), Neltume lake (39°47′ S; 71°59′ W), Pirihueico lake (39°56′ S; 71°48′ W), Rupanco lake (40°50′ S; 72°31′ W) (Araya & Zúñiga, 1985); Rapel reservoir (Zúñiga & Araya, 1982); Sauzalito lagoon (33°00′ S; 71°32′ W); Peñuelas lagoon (33°09′ S; 71°32′ W), Orozco reservoir (33°14′ S; 71°25′ W), Casablanca

(33°18′ S; 71°24′ W), Plateado reservoir (33°04′ S; 71°39′ W), Villarrica lake (39°18′ S; 72°06′ W), Llanquihue lake (41°08′ S; 72°49′ W) (Zúñiga, 1975).