1 **Freshwater biodiversity and conservation in mediterranean climate streams of**
2 **Chile**

3
4 ¹ Ricardo Figueroa*

5 ² Núria Bonada

6 ¹ Meyer Guevara

7 ¹ Pablo Pedreros

8 ¹ Francisco Correa-Araneda

9 ¹ María E. Díaz

10 ³ Victor H. Ruiz

11

12 ^{*1}Corresponding author: rfiguero@udec.cl Center of Environmental Sciences EULA-

13 Chile, University of Concepcion, Casilla 160-C, Concepcion, Chile

14 ²Grup de Recerca Freshwater Ecology and Management (FEM), Departament

15 d'Ecologia, Facultat de Biologia, Universitat de Barcelona (UB), Diagonal 643, 08028

16 Barcelona, Catalonia/Spain

17 ³Department of Zoology, University of Concepcion, P.O. Box 160-C, Concepción,

18 Chile

19

20

21 **Keywords:** Central Chile, diversity, endemism, fauna, flora, streams and rivers

22

23

24 **Abstract**

25

26 In Chile, mediterranean climate conditions only occur in the Central Zone (ChMZ).
27 Despite its small area, this mediterranean climate region (med-region) has been
28 recognised as a hotspot for biodiversity. However, in contrast to the rivers of other med-
29 regions, the rivers in the ChMZ have been studied infrequently, and knowledge of their
30 freshwater biodiversity is scarce and fragmented. We gathered information on the
31 freshwater biodiversity of ChMZ, and present a review of the current knowledge of the
32 principal floral and faunal groups. Existing knowledge indicates that the ChMZ has high
33 levels of endemism, with many primitive species being of Gondwanan origin. Although
34 detailed information is available on most floral groups, most faunal groups remain
35 poorly known. In addition, numerous rivers in the ChMZ remain completely
36 unexplored. Taxonomic specialists are scarce, and the information available on
37 freshwater biodiversity has resulted from studies with objectives that did not directly
38 address biodiversity issues. Research funding in this med-region has a strong applied
39 character and is not focused on the knowledge of natural systems and their biodiversity.
40 Species conservation policies are urgently required in this highly diverse med-region,
41 which is also the most severely impacted and most populated region of the country.

42

43

44

45 **Introduction**

46

47 Chile is located in southwestern South America in a region with a predominantly
48 temperate climate. Mountains dominate 80% of the country. Mediterranean climate
49 conditions (med-climate) occur only in the Central Zone, between the IV and the VIII
50 administrative regions. The Mediterranean climate region (med-region), also called the
51 Chilean Mediterranean Zone (ChMZ), is located primarily between the Aconcagua and
52 Biobío River basins (32-40°S, Fig. 1) (Di Castri, 1981) and includes the west side of the
53 Andes Cordillera, the coastal ranges, and the Central Valley (Mann, 1964). However,
54 the limits of the ChMZ are not clearly established, and the El Niño and La Niña
55 phenomena can expand or contract the area influenced by the med-climate (e.g., Di
56 Castri & Hajek, 1976; Luebert & Pliscoff, 2004, 2006).

57

58 Mesoclimate variability within the ChMZ was previously recognised by Mann
59 (1964), who distinguished between a “preclimax” area with low water availability and a
60 “postclimax” area with greater water availability. The area of the ChMZ with the
61 highest temperatures is the Central Valley. Because the coastal mountains (up to
62 2,000m.a.s.l.) act as a barrier, inland areas are sheltered from maritime influence. As a
63 result, the Central Valley is 5 to 6°C warmer than the coastal areas on the other side of
64 the mountains. However, winter frost can also occur in areas of the Central Valley near
65 the foothills of the Andes. Winter precipitation in the entire ChMZ is concentrated from
66 May through July, with a range of 300 to 1,500 mm/year from north to south (Niemeyer
67 & Cereceda, 1989). Such precipitation increases river flows and causes substantial
68 amounts of ice and snow to accumulate in the mountains from 1,500 m.a.s.l. upwards
69 (Fuentes, 1988; Clapperton, 1994). The melting of the ice and snow peaks at the end of

70 spring, maintaining permanent river flows during the entire summer. For this reason,
71 temporary rivers flowing from the Andes are relatively uncommon, whereas temporary
72 rivers are common in the coastal ranges.

73

74 Variation in med-climate conditions occurs not only in longitude (i.e., from the
75 coastal ranges to the foothills of the Andes) but also in latitude. Based on climatogram
76 analyses, Di Castri & Hajek (1976) have shown that med-climate conditions vary with
77 latitude, with a progressive decrease southwards during the dry period. South of the
78 Biobío River basin, however, two fundamental properties determine the change to
79 another climatic regime, which is the temperate climate of the Valdivian rainforest
80 (Miller, 1976). First, the influence of the westerly winds causes winter precipitation and
81 extreme summer droughts (Villagrán & Hinojosa, 1997). Second, the fragmentation of
82 the coastal ranges allows the maritime influence to extend inland, increasing
83 precipitation (Miller, 1976). The city of Valdivia in southern Chile, for example, does
84 not have the summer dry period and winter-wet period typical of a med-climate.

85

86 The ChMZ is the Chilean region with the highest human density and the most
87 fertile soils, with ~14.5% of the land used for wheat, sugar beets, oats, potatoes, oilseed
88 rape, barley, and maize production (Fuentes, 1988). This extensive agricultural use, in
89 combination with similarly important uses for livestock and industrial activities, has
90 produced strong pressure on both land use and water resources (Figueroa et al., 2007).
91 Thus, for example, 85% of the water resources of the ChMZ are used for agriculture,
92 but 70% of this water is lost to evaporation or infiltration from the open channels used
93 for irrigation (Table 1).

94

95 The orography of Chile results in a longitudinal orientation of most river basins.
96 Seven large river basins located from north to south in the ChMZ (the Aconcagua,
97 Maipo, Rapel, Mataquito, Maule, Biobío, and Itata rivers) have their headwaters in the
98 foothills of the Andes and drain the Central Valley and the coastal ranges (Fig. 1). In
99 addition, several smaller, steep river basins are located in the coastal ranges. This
100 particular distribution of river basins in the ChMZ resembles that found in the med-
101 region of California (Ball et al., 2013). Contrary to those in other med-regions of the
102 world, however, the rivers in the ChMZ have rarely been studied, and the knowledge of
103 their freshwater biodiversity is extremely scarce and fragmented. The aim of the present
104 study is to gather the available information on the freshwater biodiversity of the ChMZ
105 and to identify the gaps in this knowledge to guide further fundamental and applied
106 research in the region.

107

108

109 **Biogeography**

110

111 The principal features of the geology of the ChMZ are metamorphosed
112 sediments and igneous batholithic rocks in the Andes, sediments in the Central Valley,
113 and metamorphosed and granite deposits in the coastal ranges (Thrower & Bradbury,
114 1973). The landscape has been strongly shaped by ancient and intense tectonic activity
115 and by recent glacial events (Clapperton, 1993).

116

117 The association between med-climate characteristics and vegetation structure
118 and physiology in the ChMZ has been analysed in several studies (e.g., CFP, 1950;
119 Mann, 1964; DiCasteri & Hajek, 1976). The vegetation of the ChMZ consists primarily of

a semidesertic formation of sclerophyll and evergreen trees and shrubs, as well as woodlands with the deciduous *Nothofagus* spp. and the evergreen *Drimyswinteri* (Dallman, 1998; Hajek, 1991). The vegetation of the most arid sector occurs in the northern ChMZ between the Aconcagua and Maipo river basins (Fig. 1). Spiny shrub steppes formed by plants such as *Acacia caven* are highly abundant in the coastal ranges and the Central Valley, whereas sclerophyll forests dominate in the Andes foothills. Southwards, between the Rapel and Maule river basins, the vegetation is dominated by subhumid species in the coastal ranges and the Central Valley, whereas mountain forest species are common in the Andes foothills. From Talca to the south, sclerophyll forests with inclusions of Valdivian hydrophilic forest species are frequent. In this southern region, the rainfall is more regular and allows the occurrence of many endemic species with higher water requirements (Rodríguez et al., 1983). Overall, a total of 57 forest tree and shrubs species occur in the ChMZ, namely, 35 endemics, 12 with South American affinities, and 10 with subantarctic affinities. The typical species are *Peumus boldus* (boldo, which is endemic); *Lithraea caustica* (litre, endemic); *Acacia caven* (espino, endemic); *Cryptocarya alba* (peumo, endemic); *Quillaja saponaria* (quillay, endemic); *Austrocedrus chilensis* (ciprés, subantarctic); *Aextoxicon punctatum* (olivillo, subantarctic); *Nothofagus* spp. (South American beech species group, endemic); *Jubaea chilensis* (Chilean wine palm, endemic, and which is South America's southernmost palm species, and it is almost extinct); *Porlieria chilensis* (palo santo, endemic); *Senecio yegua* (palo yegua, endemic); *Azara integrifolia* (aromo, endemic); and *Lomatia dentata* (palo negro, endemic).

Despite its high number of endemic species, Chilean native vegetation has been strongly modified by agricultural activity, urban expansion, and forestry. In the Biobío

River basin, for example, the coverage of forest plantations can exceed 55%. Land use in the Vergara River basin, an important tributary of the Biobío River, consists of 47% for agriculture use, 31% for native forests, and 18% for scrubland in 1979, whereas forestry plantations occupied 38% of the basin, native forests 21%, and agriculture 32% in 1994 (Stehr et al., 2010). Similarly, deciduous forests around the city of Concepción have been almost totally eradicated by exotic tree species, such as *Pinus radiata* (Monterey pine tree) and *Eucalyptus globulus* (Tasmanian blue gum). The annual report issued by Medio Ambiente in 2010 indicated that only 2.28% of the surface area of the Biobío Region is protected within the National System of Protected Wild Areas of the Chilean State. The amount of protected wild areas in the Biobío Region is the fourth smallest in Chile, after the Metropolitan, Coquimbo, and Maule Regions, all of which are located in the ChMZ (INE, 2012). Recently, the Fundo Nonguén National Reserve was established by decree. This reserve (of 3,055 ha) represents the last fragment of deciduous coastal forest in the Biobío region (Jerez & Bocaz, 2006) and has a high ecological and environmental value (Habit et al., 2003).

Biogeographic studies of Chilean freshwaters have focused primarily on the southern area of the country. This area is highly interesting from a biogeographical perspective because glaciation has been an extremely important determinant of the geomorphology of the area's fluvial ecosystems (Clapperton, 1993; Villagrán & Hinojosa, 1997; Smith-Ramírez, 2004). However, the rivers of the ChMZ have generally been ignored in terms of scientific research. In the ChMZ, fluvial landscapes have been modelled by volcanic and tectonic events before and during the formation of the Andes (Parada et al., 1989; Parada & Peredo 1994; Charrier et al., 2002; Barrientos et al., 2004).

Current status of freshwater biodiversity knowledge

In the ChMZ, freshwater diversity studies have primarily been focused on floristic groups (Bannister et al., 2011) and on the distribution of several major faunal species, including *Lutra provocax* (Chilean otter), *Casmerodius albus* (great egret), *Egretta thula* (snowy egret), *Calyptocephalella gayi* (Chilean helmeted water toad), and *Rhinoderma darwinii* (Darwin's frog) (Quintanilla, 1983). Other groups, e.g., Trichoptera, Plecoptera, and fish, have been considered to be of major ecological importance in the ChMZ, but the current knowledge of these groups is far from complete (Dyer, 2000; Teneb et al., 2004; Palma & Figueroa, 2008). Figueroa et al. (2006) have highlighted the lack of studies in the ChMZ and the unbalanced knowledge of this area relative to other med-regions in the world. These deficiencies can result in incorrect conclusions about its biodiversity status. As a result of the absence of national collections of particular groups (e.g., of aquatic insects) and the lack of available taxonomists, it is extremely challenging to construct inventories of freshwater biodiversity.

Information on Chilean freshwater diversity has recently been collected in a special issue of the journal *Gayana* (Concepción)(2006, volume 70). This information allows detailed analyses of freshwater groups nationwide, such as microalgae (Parra, 2006; Rivera, 2006), macrophytes (Hauenstein, 2006), planktonic protozoans (Woelfl, 2006), zooplankton (Villalobos, 2006), malacostracan crustaceans (Jara et al., 2006), Ephemeroptera (Camousseight, 2006), Plecoptera (Vera & Camousseight, 2006), Trichoptera (Rojas, 2006), Coleoptera(Jerez & Moroni, 2006), Bivalvia (Parada &

Peredo, 2006), Gastropoda (Valdovinos, 2006), Bryozoa (Orellana, 2006), fishes (Habit et al., 2006a), amphibians (Ortiz Z & Díaz-Páez, 2006), birds (Victoriano et al., 2006), and parasites (Olmos & Muñoz, 2006). However, it is difficult to use these reviews to find fauna characteristic of the ChMZ because these publications do not consider the distributional areas of species and are too general for the purpose of this current review. Therefore, to analyse the biodiversity of this med-region we used information provided in the journal Gayana (Concepción) (2006, volume 70) and specific studies conducted in the ChMZ, such as those by Arenas (1995) in the Biobío River basin; Figueroa et al. (2003, 2006, 2007) in the Damas, Nonguén, and Chillán river basins; Valdovinos et al. (2009) in the Itata River basin; and Domínguez & Fernández (2009) for the entire Neotropical region.

Diatoms and Macrophytes

Rivera (2006) noted that most of the diatom species present in Chile are cosmopolitan. Most studies conducted in Chilean rivers have been concentrated in the ChMZ, especially in the Concepción area. Parra (2006) observed the same situation for other benthic algae groups, for which no endemic species have been identified.

Hauenstein (2006) indicated that ~455 macrophyte species are found in Chile, with a high percentage of endemic species (*ca.* 80%). This author also indicated that richness increases from north to south. Ramírez et al. (1979) and Ramírez & San Martín (2006) noted that although macrophyte distributions are poorly known in Chile, the greatest diversity is located between 35 and 40°S, which includes the ChMZ. Despite the low representation of the introduced macrophyte species *Egeria densa*, this species

has caused severe problems in freshwater habitats of this area, hampering sport activity, transportation, and invading irrigation channels and rice fields (Ramírez & San Martín, 2006).

The zooplankton fauna recorded in reservoirs does not include any endemic species in the ChMZ, and the species present are widespread in Chile (Araya & Zuñiga, 1985; Soto & Zuñiga, 1991). Numerous reservoirs are located in the Central Valley. Many of these reservoirs are eutrophic as a result of high nutrient inputs. These ecosystems are characterised by the presence of small cladocerans (*Ceriodaphnia dubia*, *Moina micrura*, *Neobosmina chilensis*, *Daphnia pulex*), calanoids (*Tumeodiaptomus diabolicus*), and cyclopoids (*Mesocyclops longisetus*). De los Ríos-Escalante (2010) found 14 species in 7 reservoirs, with a maximum of 10 or 11 species in the most eutrophic reservoirs and only 4 or 5 in the less eutrophic ones.

Aquatic insects

Information on Ephemeroptera in Chile can be found in Camousseight (2006). Domínguez et al. (1992, 2001, 2006, 2009) have also updated previous knowledge of South American Ephemeroptera, including those of the Chilean region. Seven families of the 14 present in South America occur only in Chile, with 375 genera and ca. 4,000 spp. Of these families, the family Onicogastridae had not been reported in the ChMZ (Table 2) until recently, when it was found in the Maule and Biobío river basins. Similarly, these recent studies indicate that the genus *Camelobaetidius* (Baetidae), which had not previously been recorded for Chile, occurs throughout the ChMZ. Thus, 42 species in all, with 12 endemic species, are recognised for the ChMZ (Table 2). The

biology of the Ephemeroptera in the ChMZ is little known and follows the general patterns described by Domínguez et al. (2006). Recent studies by Sabando et al. (2011) on the population structure of *Andesiops torrens* have shown that this species feeds on fine organic particles as well as on algae.

Of the 16 known families of Plecoptera in the world, Chile has only 6. Recent studies by Vera & Camousseight (2006) and Palma & Figueroa (2008) have confirmed that all six families, with a total of 48 species (5 endemic species), occur in the ChMZ (Table 3). As in other med-regions of the world, Plecoptera have been used in the ChMZ as water-quality bioindicators (Figueroa et al., 2003, 2007) because all families appear to be restricted to rivers with high oxygen concentrations and low levels of human impact (Palma & Figueroa, 2008). One family of particular interest is the Diamphipnoidae, which occurs only in Chile (Fochetti & Tierno de Figueroa, 2007) and comprises 2 genera and 5 species, all of which are present in the ChMZ. *Diamphipnoa virescentipennis* and *Diamphipnopsis samali* are confined to the ChMZ (37 to 38°S and 38° to 42°S, respectively), whereas the distributions of the other 3 species of Diamphipnoidae extend to Patagonia (Vera & Camousseight, 2006).

In Chile, Schmid (1955, 1957, 1958, 1959, 1964, 1989) was the first researcher to conduct significant studies of Trichoptera faunistics. In addition, Flint & Holzenthal have contributed substantially to the knowledge of Chilean species (Flint, 1981; Holzenthal, 1986, 1988; Holzenthal & Flint, 1995; Flint et al., 1999). All of these studies indicate that Chile has 18 families, 62 genera, and 224 species of Trichoptera. In the ChMZ, 18 families, 53 genera, and 150 species are recognised, with 108 endemic species (Table 4). Actually, the current knowledge indicates that central Chile is a

center of diversification for Trichoptera (Pauls et al., 2010). The Biobío River basin is of particular interest because it has the greatest concentration of recorded species (Rojas, 2006). The studies performed also highlight the high degree of endemism (Holzenthal, 2004; Rojas, 2006), although information on juvenile aquatic forms, their behavior, and their ecological requirements is completely lacking (Angrisano & Korob, 2001). According to Angrisano & Korob (2001), the Trichoptera are characterised by a total or partial replacement of species from the headwaters to the lowlands. The pattern of species replacement is influenced by the current velocity, which directly affects the availability of food, the construction of refuges, and the amount of drifting organisms. In addition, Sabando et al. (2011) have demonstrated that the degree of genetic isolation of *Smicridea annulicornis* among the basins of the ChMZ is noteworthy, even in highly deforested basins.

Information on other groups of aquatic insects is scarce. Jerez & Moroni (2006) recognised 12 species of aquatic Coleoptera for Chile and indicated that the knowledge of this group in the country is vague, and is usually derived from extrapolations from other countries. However, Chile lacks endemic families of Coleoptera, and the families present include elements with both tropical and Australian affinities.

In the ChMZ, Puntí (2007) studied the highly diverse dipteran family of Chironomidae and compared species richness, abundance, and composition among the ChMZ, southwestern Australia, and the Mediterranean Basin. Despite the limited knowledge of the group and the problems associated with chironomid taxonomy, Puntí collected 24 genera of Chironomidae at 11 sites belonging to 4 river basins in Chile and identified 16 unknown larval morphological forms of Orthocladiinae, Chironomini,

Tanytarsini, and Heptagyini. The composition of the Chironomidae of the ChMZ is closer to that of southwestern Australia than to that of the Mediterranean Basin, indicating past geological connections between the ChMZ and southwestern Australian med-regions (Brundin, 1966). Thus, the genera *Aproteniella*, *Stictocladius*, and *Botryocladius* are considered Gondwanaland faunal elements and are currently shared by Australia, South America, and New Zealand (Edward, 1989; Cranston & Edward, 1992, 1999). The ChMZ and southwestern Australian med-regions also had similar rarefied richness values, which were lower than that found in the Mediterranean Basin (Puntí, 2007).

Other invertebrates

Knowledge of non-insect aquatic invertebrates is scarce in Chile, and information is only available for molluscs and some crustacean groups. A total of 75 species of freshwater molluscs occur in Chile. Their distribution varies latitudinally from north to south, with a greater concentration between latitudes 26° and 44°S (Fuatealba et al., 2010), which is where the ChMZ is located. Two families of bivalves, the Hyriidae and Sphaeriidae, occur in the freshwater habitats of Chile. The Hyriidae are only represented by a single genus with 2 species (*Diplodon chilensis* and *D. solidulus*), whereas the Sphaeriidae are represented by 3 genera and 11 species. *Pisidium chilense*, *P. huillichum*, and *P. llanquihuensis* are endemic to the ChMZ. However, Parada & Peredo (2006) noted that there is a significant lack of information about freshwater molluscs occurring between 18° and 35°S, a substantial part of the ChMZ.

Freshwater gastropods comprise 73 species in Chile(Valdovinos, 2006), with many endemic species of the families Hydrobiidae (*Littoridina cumingi*), Chilinidae (*Chilina dombeyana*, *C. fluctuosa*, *C. tenuis*, *C. gibbosa*, *C. fasciata*, *C. obovata*, and *C. minuta*), Physidae (*Physa chilensis*), and Planorbidae. The Planorbiidae are distributed between the northern regions of Chile and the ChMZ, with *Biomphalaria chilensis* as the only species in the ChMZ. The family Ancyliidae (*Uncancylus gayanus*), which has a more limited distribution range, reaches its maximum abundance in the rivers of the Biobío region (Valdovinos, 2006).

Six species of Malacostraca are distributed in Chile (5 Parastacidae and 1 Palaemonidae). These species are best represented in the Biobío River basin and in the Valdivia region(Jara et al., 2006).In contrast, the diversity of anomuran crabs, with 18 species and 2 subspecies, is notable. Three species are highly abundant in the ChMZ but are not found exclusively in this area. *Samastacus spinifrons* distributed from the Aconcagua River basin to Chiloé, *Parastacus pugnaxis* distributed within the wetlands of the Central Valleyto the Toltén River, and *Aegla pewenchae* is distributed in the area between the cities of San Fernando and Concepción. In contrast, *A. bahamondei* and *A. occidentalis* are endemic to the Tucapel-Paicaví river and Lleu-lleu lake basins in the coastal ChMZ, respectively (Smith-Ramírez et al., 2005).In addition, *A. expansa*, *A. conceptionensis*, and *A. laevistalcahuano* are also ChMZ endemics. Despite the high number of endemics, the information on the conservation status of this group is incomplete. For the ChMZ, *A. expansa* and *A. conceptionensis* are identified as extinct, whereas *S. spinifrons* and *A. bahamondei* are considered vulnerable (Jara et al., 2006).

Amphipods have rarely been studied in Chile. Gonzalez (2003) provides the most complete information on this group. They are represented by a single genus and 7 species: *Hyalella simplex*, *H. fossamancinii*, *H. kochi*, *H. chiloensis*, *H. costera*, *H. araucana*, and *H. franciscae*. Only *H. chiloensis* and *H. costera* are present in the ChMZ, where they are endemics. Recent discoveries have indicated the presence of 2 new species in Chile, which have not yet been recorded in the ChMZ: *Rudolphia macrodactylus* (Grosso & Peralta, 2009) and *Ruffia patagonica* (Bréhier et al., 2010).

Vertebrates

Amphibians

Fifty-nine amphibian species are recognised for Chile, with 60.7% endemic (Ortiz & Díaz-Paez, 2006; Frost, 2009). Although information is currently available on Chilean amphibians, aspects of their distribution remain unclear. Only the studies by Vidal et al. (2009) and Jofré & Méndez (2011) have presented information about the latitudinal distribution of amphibians in Chile. Based on a parsimony analysis of endemism, these authors recognise three major zones related to different groups of amphibians: a northern zone from 18° to 24°S, a central zone from 24° to 37°S, and a southern zone from 38° to 54°S. The central zone and a portion of the northern zone correspond to the ChMZ. Amphibian endemism reaches 60% in the ChMZ, and the highest species richness (17 species) is attained at the southern limit of the zone (*ca.* 38°S). However, this information could be enhanced by further study because recent studies by Ortiz (*pers. comm.*) have recognised at least 2 new species in primary forests of the coastal ranges of the ChMZ.

Fish

The Chilean freshwater ichthyofauna consists of 11 families, 17 genera, and 66 species (44 native and 22 exotic). Their altitudinal range does not exceed 1,500 m.a.s.l. A total of 20 native and 13 introduced species are recognised for the ChMZ (Table 5). Within the ChMZ, the southern portion is the most diverse, with several endemic species, such as *Trichomycterus chiltoni* and *Percilia irwini* (Vila et al., 2006). However, this is also the area in the ChMZ where populations are most heavily altered because of anthropogenic pressure (Habit et al., 2006b; Vila & Pardo, 2008; Zunino et al., 2009). A total of 26 fish species have been introduced in the ChMZ since the end of the 19th century for such diverse purposes as sport fishing, ornamental use, biological control, and aquaculture (Iriarte et al., 2005) (Table 5). The effects of introducing exotic fishes into native fish communities are very poorly understood, but such introductions are considered to be the drivers of local native fish extinctions (Ruiz, 1993; Soto et al., 2006). In addition, Figueroa et al. (2010) showed that an elevated diet overlap occurred between native and introduced fish species in a river of the ChMZ. This overlap resulted in a significant negative impact on native fish communities.

According to Dyer (2000), the Chilean ichthyofauna is grouped into three provinces: Titicaca, Patagonian, and Chilean. The ChMZ belongs to the Chilean Province and has a very distinct species composition compared to southern areas. Researchers have related this pattern to vicariance for a multiple-taxa divergence event (Dyer, 2000), but this conclusion is not consistent with geological studies that show a gradual uplift of the Andes Mountains during the lower Miocene (Jordan & Gardeweg,

1989; Lundberg et al., 1998) and other geological events that have shaped the current isolation patterns of the basins (Charrier et al., 2002; Munoz et al., 2006). Despite the distinct species composition of the ChMZ, fish diversity is low overall but includes many endemics (Quezada-Romegialli et al., 2010). This pattern, together with the small body size of the species, has been related to the geographic isolation of the country and to the presence of rivers with high levels of discharge (Habit et al., 2006b; Vila et al., 2006). The geographic isolation of Chile has resulted in highly restricted species distributions. For example, *Bullockia maldonai* is only found in the Itata and Cautín River Basins in the ChMZ (Habit et al., 2006b). In contrast, recent genetic studies of *Trichomycterus areolatus* and *Basilichthys microlepidotus* have also demonstrated genetic isolation among ChMZ basins. For this reason, future conservation programs must consider river basins individually (Quezada-Romegialli et al., 2010) to avoid cases such as the extinction of *Diplomystes chilensis* in the Maipo River (Vila & Pardo, 2008).

Conservation and future challenges

Projected climate change

In terms of the modification of the thermal regime, studies conducted by CONAMA (2006) have shown that the ChMZ will be one of the areas in Chile most affected by the global temperature increase. The altitude of the 0°C isotherm has already shifted (~300 to 500 m; CONAMA, 2006); as a result, a greater amount of precipitation falls as rain rather than of snow. The discharge of the rivers flowing from the Andes

foothills in the ChMZ is expected to increase, especially in winter. An increase of 400 m in the altitude of the 0°C isotherm would imply a loss of 23% of the snow area between 30° and 35°S.

The Andean foothills of the ChMZ are one of the areas in the country with the greatest productivity for forest farming. Moreover, a high percentage of Chile's hydroelectric energy (approximately 60%) is generated in the ChMZ. In terms of rainfall, it is expected that precipitation will decrease 40% in winter between 30° and 40°S, with a somewhat smaller decrease in fall and summer (CONAMA, 2006). The loss in rainfall also extends to the summer throughout the region between 38° and 40°S and farther north in the Andean sector. McPhee et al. (2010) have indicated that for the Maule and Laja River basins, a 40% reduction in the availability of water is expected. In the Laja River basin, a greater temperature increase will also occur. In addition, Garreaud (2009) has indicated that climate change models are more uncertain in the Southeast Pacific because of the dependence of the climate on the La Niña phenomenon, assuming an intensification of the South Pacific Anticyclone in recent decades.

The anticipated changes in the climate, added to changes in land use (Aguayo et al. 2009; Schulz et al. 2010) and thermal pollution, are problems not currently addressed in Chile in terms of the protection of Chilean aquatic ecosystems (Parra et al. 2009). In this sense, the only possibility is to address future changes via the sustainable management of rivers and riversides to ensure the maintenance of the most relevant ecosystem services.

444 Pollution and pressures

445

446 The history of environmental protection in Chile has been brief. The first
447 Environmental Law was approved in 1994, and the first “Norm for the Protection of
448 Surface Water Quality” is still under development (CONAMA, 2004). Actually, no
449 legal document exists in Chile with the aim of protecting river basins in the country.
450 More than 2/3 of the Chilean population is located in the ChMZ, and most domestic and
451 industrial wastewater is discharged into the area’s principal rivers and tributaries.
452 Diffuse pollution from the agricultural sector, together with pollution by hazardous and
453 liquid industrial wastes, is also important in particular river basins (e.g., the Maipo and
454 Rapel River basins; CONAMA 2007, 2008, 2009).

455

456 Bioassessment approaches are being investigated in several rivers of the ChMZ.
457 However, most of this work is conducted entirely for research purposes and, although
458 the results of the research are transferred to the local and national administrations, their
459 implementation is still not being done.

460

461 In the Biobío River basin, a number of investigations have focused on the study
462 of the ecological quality of several rivers (Parra et al., 1993a, 1993b; Vighi et al., 1993),
463 proposing management strategies and recognising areas under pressure. The Biobío
464 River basin is the most important hydrologic system in Chile, covering 24,260 km². It is
465 one of the large rivers in Chile showing the greatest disturbance by industrial and urban
466 effluents and by flow regulation for hydropower generation and irrigation (Parra et al.,
467 2009). Nutrients occur at very low concentration in the upper section of the Biobío
468 River, but the concentrations of nitrogenated compounds (ammonium, nitrite, nitrate,

total nitrogen, and total phosphorus) are increased downstream as a result of contributions from cellulose mills, urban settlements, and agricultural/forestry activities (Parra et al., 2009). This situation is particularly critical in the lower section, where the nutrient values approach eutrophication levels. Phenolic compounds also show a clear increasing trend towards the lower part of river. Other relevant variables affecting water quality, however, such as the concentration of heavy metals, hydrocarbons, and pesticides, have shown very low values or are under the detection limits of the methods used. During the past decade, pulp mills have doubled their production in the Biobío River basin (over 1,800,000 tons/year; Parra et al., 2009). Despite this drastic increase in production, the water quality parameters directly associated with cellulose mills have not shown any increases relative to historic levels, perhaps the result of the new cleaner technologies being used in the mills. A number of studies of biomarkers and the ecological status of the aquatic biota have also been conducted in the Biobío River basin, showing the large-scale and long-term effects of human impacts on rivers (Gaete et al., 1999; Orrego et al., 2005, 2006, 2009a, 2009b; Habit et al., 2006; Chamorro et al., 2010; Chiang et al., 2011).

In terms of fragmentation, all large basins of the ChMZ show alterations of natural flow regimes by dams to a certain extent (Table 6). The generation of hydroelectricity represents approximately 70% of the energy used in the country. Approximately 60% of Chile's hydroelectricity is generated in the Biobío River basin, which sustains a significant biodiversity, with many endemics.

From a river conservation perspective, there are no development policies in Chile. River conservation depends on the National System of Protected Wild Areas of

the Chilean State (SNASPE), which represents the principal tool for biodiversity protection through the administration and management of natural areas nationwide. Chile has 36 national parks, 49 reserves, and 15 natural monuments (CONAF, 2010). Of these natural areas, 4, 19, and 1, respectively, are located in the ChMZ. However, only 19% of the area of Chile is protected to some extent, and only 0.3% (Table 6) of Chile's protected area is located in the ChMZ (INE, 2012). In addition, Chile has 12 sites that are recognised under the Ramsar convention (i.e. internationally protected lakes and wetlands). Two of these sites (0.8 %) are located in the ChMZ.

Conclusions

The biological diversity of numerous med-rivers in the ChMZ remains completely unexplored. Taxonomic specialists are rare, and the scarce information available on freshwater biodiversity is found in studies that do not directly address biodiversity issues but focus on other objectives. Research funding has a strong biotechnological and applied character and is not focused on the knowledge of natural systems, their biodiversity, and the ecological services that they provide. Despite all these challenges, existing knowledge already shows that the ChMZ has high levels of endemism in a reduced geographic area, with many primitive faunal elements of Gondwanan origin (de Moor and Ivanov, 2008; Valdovinos, 2008). Many freshwater groups of the ChMZ have a stronger affinity to the fauna of New Zealand and Australia than to the rest of South America (Fittkau, 1969; Zwick, 2000).

Our review indicates that detailed information is available on specific invertebrate groups, such as molluscs (Fuentelba et al., 2010), Plecoptera (Palma & Figueroa, 2008), and Trichoptera (Flint et al., 1999). However, most groups remain poorly known. In this sense, the ChMZ represents an exceptional area for performing taxonomic and ecological studies because of its potential high levels of biodiversity and endemism. For example, our analysis has shown that 28.6% of the species of Ephemeroptera, 10.4% of the Plecoptera, and 70.6% of the Trichoptera in the ChMZ are endemic. These levels of endemism are expected to be modified as more rivers throughout the country are explored.

In the ChMZ, vertebrates, especially anurans (Ortiz & Díaz-Paez, 2006; Vidal et al., 2009) and fish (Habit et al., 2003, 2007), have received more attention than invertebrates. The southern part of the ChMZ (Concepción Province) and its extension farther southwards (Valdivia Province) appears to be one of the most diverse areas for fish in Chile and has been recognised as one of the world's diversity hotspots (Myers et al., 2000). However, it must be recognised that universities with a long tradition of local fish specialists (e.g., †Hugo Campos) are located in both provinces.

From a conservation perspective, only certain fish, amphibian, and crustacean species have some form of protection. Invertebrates other than crustaceans are completely ignored in the Chilean red list. In addition, protected areas are scarce in the ChMZ and only represent 0.3% of the protected areas in Chile (INE, 2012). The ChMZ is being heavily exploited for mining, agriculture, and hydroelectric projects. These activities involve a high level of economic investment but ignore freshwater biodiversity. These projects, together with the rapid degree of contamination of

watercourses in the ChMZ, suggest that many species will move from being unknown to being lost. In this sense, the ChMZ urgently requires policies focused on the protection and conservation of freshwater biodiversity.

Acknowledgements

NB acknowledges support received by the BioFresh EU project-Biodiversity of Freshwater Ecosystems: Status, Trends, Pressures and Conservation Priorities (7th FWP contract No 226874), the RICHABUN project funded by the Spanish Ministry of Education and Science FEDER (CGL2007-60163/ BOS) and Project DIUC 212.310.060-1.0, University of Concepción

References

- Aguayo, M., A. Pauchard, G. Azocar & O. Parra, 2009. Land use change in the south central Chile at the end of the 20(th) century. Understanding the spatio-temporal dynamics of the landscape. *Revista Chilena de Historia Natural* 82:361-374.
- Angrisano, E.B. & P.G. Korob, 2001. Trichoptera. In Fernández H.R. & E. Domínguez (eds), *Guía para la determinación de los artrópodos bentónicos Sudamericanos*. Universidad de Tucumán, Argentina:55-92.
- Araya, J.M. & L.R. Zuñiga, 1985. Manual taxonómico del zooplancton lacustre de Chile. *Boletín Limnológico, Universidad Austral de Chile* 8:1-10.

567 Arenas, J.N., 1995. Composición y distribución del macrozoobentos del curso principal
568 del río Biobío, Chile. *Medio Ambiente* 12(2):39-50.

569 Ball, J.E., L.A. Bêche, P.K. Mendez & V.H. Resh, 2013. Biodiversity in Mediterranean-
570 climate streams of California. *Hydrobiologia* DOI 10.1007/s10750-012-1368-6.

571 Bannister, J.R., O.J. Vidal, E. Teneb & V. Sandoval, 2011. Latitudinal patterns and
572 regionalization of plant diversity along a 4270-km gradient in continental
573 Chile. *Austral Ecology* 37(4):500–509.

574 Barrientos, S., E. Vera, P. Alvarado & T. Monfret, 2004. Crustal seismicity in central
575 Chile. *Journal of South American Earth Sciences* 16:759-768.

576 Bréhier, F., R. Vonk & D. Jaume, 2010. First record of the family Phreatogammaridae
577 in South America, with comments on the arrangement of coxal and sterna gills, and
578 on the biramous condition of the seventh pereopod in amphipod crustaceans.
579 *Journal of Crustacean Biology* 30(3):503–520.

580 Brundin, L., 1966. Transantarctic relationships and their significance, as evidenced by
581 chironomid midges: With a monograph of the subfamilies Podonominae and
582 Aphroteniinae and the austral Heptagyiidae. *Almqvist & Wiksell*, Stockholm.

583 Camousseight, A., 2006. Estado de conocimiento de los Ephemeroptera de Chile.
584 *Gayana (Concepción)* 70:50-56.

585 CFP, 1950. Geografía de Chile. Tomo I. Fundación Pedro Aguirre Cerda de la
586 Corporación de Fomento de la Producción. Editorial Universitaria, Santiago de
587 Chile, Chile.

588 Chamorro, S., V. Hernández, E. Monsalvez, J. Becerra, M. Mondaca, B. Piña & G.
589 Vidal, 2010. Detection of estrogenic activity from kraft mill effluents by the yeast
590 estrogen screen. *Bulletin of Environmental Contamination and Toxicology* 84:165-
591 169.

592 Charrier, R., O. Baeza, S. Elgueta, J.J. Flynn, P. Gans, S. M. Kay, N. Munoz, A.R.
 593 Wyss & E. Zurita, 2002. Evidence for Cenozoic extensional basin development and
 594 tectonic inversion south of the flat-slab segment, southern Central Andes, Chile (33
 595 degrees-36 degrees SL). *Journal of South American Earth Sciences* 15:117-139.

596 Chiang, G., M.E. McMaster, R. Urrutia, M.F. Saavedra, J.F. Gavilan, F. Tucca, R. Barra
 597 & K.R. Munkittrick, 2011. Health status of native fish (*Percilia gillissi* and
 598 *Trichomycterus areolatus*) downstream of the discharge of effluent from a tertiary-
 599 treated elemental chlorine-free pulp mill in Chile. *Environmental Toxicology and*
 600 *Chemistry* 30:1793-1809.

601 Clapperton, C., 1993. Quaternary geology and geomorphology of South America.
 602 Elsevier, Amsterdam.

603 Clapperton, C., 1994. The quaternary glaciation of Chile: a review. *Revista Chilena de*
 604 *Historia Natural* 67:369–383.

605 CONAF, 2010. Sistema Nacional de Áreas Silvestres Protegidas del Estado (SNASPE).
 606 In <http://www.conaf.cl/parques/index.html>. Accessed 24 November 2011.

607 CONAMA RM, 2007. Estandarización de especies bioindicadoras de calidad del agua
 608 en la cuenca del río Maipo. Informe Final. Estudio realizado por EULA, Chile.

609 CONAMA RM, 2008. Aplicación del IB ChSiGNAL desarrollado para comunidades de
 610 macroinvertebrados bentónicos para monitorear la calidad del agua en la cuenca del
 611 río Maipo. Informe final Estudio realizado por EULA, Chile.

612 CONAMA RM, 2009. Validación y Complementación de la aplicación del Índice
 613 Biótico ChSignal en la Cuenca del Río Maipo. Informe Final. Estudio realizado por
 614 EULA, Chile.

615 CONAMA VI R, 2009. Diagnóstico indicadores biológicos en la Cuenca Rapel. Informe
 616 final, estudio realizado por EULA PROYECTO N° 30073967-0 , VI Región, Chile.

617 CONAMA, 2004. Guía relativa al desarrollo de la dictación de Normas Secundarias de
618 Calidad Ambiental para Aguas Continentales Superficiales y Aguas Marinas.
619 Comisión Nacional del medio Ambiente, Gobierno de Chile, Chile.

620 CONAMA, 2006. Informe de la variabilidad climática en Chile para el Siglo XXI. Dpto.
621 de Geofísica Fac. Cs Físicas y Matemáticas, Universidad de Chile, Chile.

622 Cranston, P.S. & D.H.D. Edward, 1992. A systematic reappraisal of the Australian
623 Aphroteniinae (Diptera, Chironomidae) with dating from vicariance biogeography.
624 Systematic Entomology 17:41-54.

625 Cranston, P.S. & D.H.D. Edward, 1999. *Botryocladus* gen.n.: a new transantarctic
626 genus of orthocladinae midge (Diptera: Chironomidae). Systematic Entomology
627 24:305-333.

628 Dallman, P., 1998. Plant Life in the World's Mediterranean Climates: California, Chile,
629 South Africa, Australia & the Mediterranean Basin, Californian Native Plant
630 Society & University of California Press, Los Angeles Garden:
631 www.gardenvisit.com/m/sp.html.

632 De los Rios-Escalante, P., 2010. Crustacean zooplankton communities in Chilean inland
633 waters. Crustaceana Monographs 12:1-109.

634 Dewson, Z., A.B.W. James & R.G. Death, 2007. A Review of the Consequences of
635 Decreased Flow for Instream Habitat and Macroinvertebrates. Journal of the North
636 American Benthological Society 26:401-415.

637 DGA, 2004. Diagnóstico y clasificación de los cursos y cuerpos de agua según objetivos
638 de calidad cuenca del río Biobío. Dirección Nacional de Aguas, Ministerio de Obras
639 Públicas. Informe CADE-IDEPE, Chile.

640 DGA, 2010. Catastro de embalses ubicados entre las regiones de Valparaíso y la
 641 Araucanía. Pag. Informe final Aquaterra ingenieros Ltda. Dirección Nacional de
 642 Aguas, Ministerio de Obras Públicas, Chile.
 643 Di Castri, F., 1981. Mediterranean-type shrublands of the world. In Di Castri, F., D. W.
 644 Goodall & R. L. Specht (eds), Mediterranean-type shrublands. Vol 11. Elsevier
 645 Scientific Publishing Company, Amsterdam:1-52.
 646 Di Castri, F. & E. Hajek, 1976. Bioclimatología de Chile. Editorial Universidad
 647 Católica de Chile, Santiago de Chile, Chile.
 648 Domínguez, E. & H. R. Fernández (eds), 2009. Macroinvertebrados Bentónicos
 649 Sudamericanos. Sistemática y biología. Fundación Miguel Lillo, Tucumán,
 650 Argentina.
 651 Domínguez, E., M.L. Pescador, M.D. Hubbard, C. Molineri & C. Nieto, 2006.
 652 Ephemeroptera of South America. In Adis, J., J.R. Arias, G. Rueda-Delgado &
 653 K.M. Wantzen (eds), Aquatic Biodiversity in Latin America (ABLA). Vol.2.
 654 Pensoft, Sofia-Moscow: 1-646.
 655 Domínguez, E., Hubbard, M. & W. Peters, 1992. Claves para ninfas y adultos de las
 656 familias y géneros de Ephemeroptera (Insecta) Sudamericanos. Instituto de
 657 Limnología "Dr. Raúl A. Ringuelet". Biología acuática 16:5-32.
 658 Domínguez, E., M.D. Hubbard & M.L. Pescador, 2001. Checklist of the Ephemeroptera
 659 of South America. Ephemeroptera Galactica,
 660 <http://www.fmu.org/mayfly/sacat.html>.
 661 Dyer, B., 2000. Systematic review and biogeography of the freshwater fishes of Chile.
 662 Estudios Oceanológicos 19:77-98.

663 Edward, D.H.D., 1989. Gondwanaland elements in the Chironomidae (Diptera) of
 664 south-western Australia. *Acta Biologica Debrecina, Supplementum Oecologica*
 665 *Hungarica* 2:181-187.

666 EULA, 2009. Monitoreo de la calidad del agua del río Mataquito mediante el uso de
 667 indicadores biológicos y biomarcadores. Informe preparado para ARAUCO S.A.
 668 Eula-Chile, Universidad de Concepción, Concepción, Chile.

669 Figueroa, R., A. Palma, V. Ruiz & X. Niell, 2007. Comparative analysis of biotic
 670 indexes used to evaluate water quality in a Mediterranean river of Chile: Chillan
 671 River, VIII Region. *Revista Chilena de Historia Natural* 80:225-242.

672 Figueroa, R., C. Valdovinos, E. Araya & O. Parra, 2003. Benthic macroinvertebrates as
 673 indicators of water quality of southern Chile rivers. *Revista Chilena de Historia*
 674 *Natural* 76:275-285.

675 Figueroa, R., V. H. Ruiz, P. Berrios, A. Palma, P. Villegas & A. Andreu-Soler, 2010.
 676 Trophic ecology of native and introduced fish species from the Chillan River,
 677 South-Central Chile. *Journal of Applied Ichthyology* 26:78-83.

678 Figueroa, R., V.H. Ruiz, X. Niell, E. Araya & A. Palma, 2006. Invertebrate colonization
 679 patterns in a Mediterranean Chilean stream. *Hydrobiologia* 571:409–417.

680 Fittkau, E., 1969. La fauna de Sudamérica. Trad. Alberto Larrain (1973). *Boletín de la*
 681 *Sociedad de Biología de Concepción*:1-31.

682 Flint, O.S., R.W. Holzenthal & S.C. Harris, 1999. Catalog of the Neotropical
 683 Caddisflies (Insecta: Trichoptera). Ohio Biological Survey, Columbus, Ohio.

684 Flint, O.S., 1974. Checklist of the Trichoptera, or Caddisflies, of Chile. *Revista Chilena*
 685 *de Entomología* 8: 83-93.

686 Flint, O. S., 1981. Studies of Neotropical caddis flies, XXVII: *Anomalopsychidae* a new
687 family of Trichoptera. Proceedings of the 3rd International Symposium of
688 Trichoptera:75-85.

689 Flint, O.S., 1983. Studies of Neotropical caddisflies, XXXIII: new species from austral
690 South America (Trichoptera). Smithsonian Contributions to Zoology 377: 1-100.

691 Flint, O.S., 2002. Studies on Neotropical caddisflies, LX: Three new species of the
692 Chilean genus *Microthremma*, with a review of the genus (Trichoptera:
693 Helicophidae). Entomological News 113: 225-232.

694 Fochetti, R. & J.M. Tierno de Figueroa, 2007. Global diversity of stoneflies (Plecoptera;
695 Insecta) in freshwater. Hydrobiologia 595:365-377.

696 Frost, D.R, 2009. Amphibian species on de world: an online reference. American
697 Museum of Natural History Electronic database accessible at
698 <http://research.amnh.org/herpetology/amphibia/>.

699 Fuentealba, C., R. Figueroa & J.J. Morrone, 2010. Endemism analysis of Chilean
700 freshwater mollusks. Revista Chilena de Historia Natural 83:289-298.

701 Fuentes, E., 1988. Sinopsis de Paisajes de Chile. In Fuentes, E. & S. Prenafeta (eds),
702 Ecología del paisaje en Chile Central Estudios sobre sus espacios montañosos.
703 Universidad Católica de Chile, Santiago de Chile, Chile:17-27.

704 Gaete, H., A. Larraín, E. Bay-Schmith, A. Cifuentes, J. Rodriguez & J. Baeza, 1999.
705 Chronic toxicity and physico-chemical characteristics of the receiving water of pulp
706 mill effluents locate in the Biobio river basin (Central Chile). Ecotoxicology and
707 Environmental 2:67-74.

708 Garreaud, R. & M. Falvey, 2009. The coastal winds off western subtropical South
709 America in future climate scenarios. International Journal of Climatology 29:543-
710 554.

711 González, E., 2003. The freshwater amphipods *Hyaletta* Smith, 1874 in Chile
 712 (Crustacea: Amphipoda). *Revista Chilena de Historia Natural* 76(4):623-637.
 713 Grosso, L.E. & M. Peralta, 2009. A new Paraleptamphopidae (Crustacea Amphipoda) in
 714 the burrow of *Virilastacus rucapihuelensis* (Parastacidae) and surrounding peat
 715 bogs. *Rudolphia macrodactylus* n. gen., n. sp. from southern South America.
 716 *Zootaxa* 2243:40–52.
 717 Habit, E. & N. Ortiz, 2009. Composición, distribución y conservación de los peces de
 718 agua dulce de la cuenca del río Itata. In Parra, O, J.C. Castilla, H. Romero, R.
 719 Quiñones & A. Caamaño (eds), *La cuenca hidrográfica del río Itata*. Editorial
 720 Universidad de Concepción, Concepción, Chile: 127-141.
 721 Habit, E., B. Dyer & I. Vila, 2006a. Estado de conocimiento de los peces dulceacuícolas
 722 de Chile. *Gayana (Concepción)* 70:100-113.
 723 Habit, E., M.C. Belk, R.C. Tuckfield & O. Parra, 2006b. Response of the fish
 724 community to human-induced changes in the Biobio River in Chile. *Freshwater*
 725 *Biology* 51:1-11.
 726 Habit, E., P. Victoriano & A. Rodríguez-Ruiz, 2003. Spatial and temporal variations of
 727 the fish assemblage of a low order fluvial system from central-south of Chile.
 728 *Revista Chilena de Historia Natural* 76:3-14.
 729 Habit, E., M. Belk & O. Parra, 2007. Response of the riverine fish community to the
 730 construction and operation of a diversion hydropower plant in central Chile.
 731 *Aquatic Conservation: Marine and Freshwater Ecosystems* 17:37–49.
 732 Hajek, E., 1991. Medio ambiente en Chile. In Hajek, E. (eds), *La situación ambiental en*
 733 *América Latina: algunos estudios de casos*. Centro Interdisciplinario de Estudios
 734 sobre el Desarrollo Latinoamericano, Serie Investigaciones Externas, Buenos Aires,
 735 Argentina:237-294.

736 Hauenstein, E., 2006. Visión sinóptica de los macrófitos dulceacuícolas de Chile.
 737 Gayana (Concepción) 70:16-23.
 738 Holzenthal, R., 2004. Three new species of Chilean caddisflies (Insecta: Trichoptera).
 739 Proceedings of the Entomological Society of Washington 106(1):110-117.
 740 Holzenthal, R.W. & O.S. Flint, 1995. Studies of the Neotropical caddisflies, LI:
 741 Systematics of the Neotropical caddisflies genus *Contulma* (Trichoptera:
 742 Anomalopsychidae). Smithsonian Contribution Zoology 575:1-59.
 743 Holzenthal, R.W., 1986. Studies in Neotropical Leptoceridae (Trichoptera), VI:
 744 Immature stages of *Hudsonema flaminii* Navas and the evolution and historical
 745 biogeography of Hudsonemini (Triplectidinae). Proceedings of the Entomological
 746 Society of Washington 88:268-279.
 747 Holzenthal, R.W., 1988. Systematics of Neotropical Triplectides (Trichoptera:
 748 Leptoceridae). Annals Entomological Society of America 81:187-208.
 749 INE, 2003. Censo 2002. Síntesis de resultados. Instituto Nacional de Estadísticas.
 750 Periodística La Nación S.A. Santiago de Chile, Chile.
 751 INE, 2012. Medio Ambiente, Informe Anual 2010 (Período De Información: 2006–
 752 2010). Instituto Nacional De Estadísticas, Gobierno De Chile, Chile.
 753 Iriarte, J., G. Lobos & F. Jaksic, 2005. Invasive vertebrate species in Chile and their
 754 control and monitoring by governmental agencies. Revista Chilena de Historia
 755 Natural 78:143–151.
 756 Jara, C.G., E.H. Rudolph & E.R. González, 2006. Estado de conocimiento de los
 757 malacostráceos dulceacuícolas de Chile. Gayana (Concepción) 70:40-49.
 758 Jerez, V. & J. Moroni, 2006. Diversidad de Coleópteros acuáticos en Chile. Gayana
 759 (Concepción) 70:72-81.

760 Jerez, V. & P. Bocaz, 2006. *Aulonodera darwini* Champion 1918, a Leaf Litter Flea
761 Beetle from *Nothofagus* Forest, Chile. Redescription and Biological Remarks
762 (Coleoptera: Chrysomelidae). The Coleopterists Bulletin 60(3):217-223.

763 Jofré, C. & M. Méndez, 2011. The preservation of evolutionary value of Chilean
764 amphibians in protected areas. In Figueroa, E. (ed), Biodiversity conservation in the
765 Americas: Lessons and policy recommendations. FEN-Universidad de Chile,
766 Santiago de Chile, Chile:81-112.

767 Jordan, T.E. & M. Gardeweg, 1989. Tectonic Evolution of the Late Cenozoic Central
768 Andes (20°-33°S). In Ben-Avraham, Z. (ed), The Evolution of the Pacific Ocean
769 Margins, Oxford University Press, New York:193-206.

770 Lanfranco, D. 1982. Presencia de *Archiperla willinki* en Chile. Anales del Instituto
771 patagonico 13:207-209.

772 Luebert, F. & Plischoff, P. 2004. Clasificación de pisos de vegetación y análisis de
773 representatividad ecológica de áreas propuestas para la protección en la ecorregión
774 Valdiviana. Documento N° 10, Serie de Publicaciones WWF Chile, Valdivia.

775 Luebert, F. & P. Plischoff, 2006. Sinopsis bioclimática y vegetacional de Chile. Editorial
776 Universitaria, Santiago, Chile.

777 Lundberg, J.G., L.G. Marshall, J. Guerrero, B. Horton, M.C.S.L. Malabarba & F.
778 Wesselingh, 1998. The stage for Neotropical fish diversification: a history of
779 tropical South American rivers. In Malabarba, L.R., R.E. Reis, R.P. Vari, Z.M.S.
780 Lucena & C.A.S. Lucena (eds), Phylogeny and classification of Neotropical fishes.
781 EDIPURCRS, Porto Alegre, Brasil:13-48.

782 Mann, G., 1964. Compendio de Zoología. I Ecología y Biogeografía. Centro de
783 Investigaciones Zoológicas, Universidad de Chile, Chile.

784 Mcphee, J., E. Rubio, R. Meza, A. Ayala, X. Vargas, 2010. Andinas de Chile central:
785 aplicación a las cuencas de Maule alto y Laja. Sociedad Chilena de Ingeniería
786 Hidráulica. XIX Congreso Chileno de Hidráulica.

787 Miller, A., 1976. The climate of Chile. In Schwedtfeger, W. (ed), World survey of
788 climatology. Elsevier, Amsterdam 107-134.

789 Myers, N., R. A. Mittermeier, C. G. Mittermeier, G. A. B. da Fonseca & J. Kent,
790 2000. Biodiversity hotspots for conservation priorities. Nature 403:853-858.

791 Muñoz, M., F. Fuentes, M. Vergara, L. Aguirre, J. O. Nystrom, G. Feraud & A.
792 Demant, 2006. Abanico East Formation: petrology and geochemistry of volcanic
793 rocks behind the Cenozoic arc front in the Andean Cordillera, central Chile (33
794 degrees 50 ' S). Revista Geologica De Chile 33:109-140. Niemeyer, H. & P.
795 Cereceda, 1989. Geografía de Chile. Tomo VIII: HIDROGRAFIA. Instituto
796 geográfico militar, Santiago de Chile, Chile. 320 pp.

797 Oláh, J. & K.A. Johanson, 2010. Description of 33 new species of Calamoceratidae,
798 Molannidae, Odontoceridae and Philorheithridae (Trichoptera), with detailed
799 presentation of their cephalic setal warts and grooves. Zootaxa 2457: 1-128.

800 Olmos, V. & G. Muñoz, 2006. Estado de conocimiento de los parásitos Eumetazoos de
801 organismos Dulceacuícolas de Chile. Gayana (Concepción) 70:122-139.

802 Orellana, M.C., 2006. Estado de conocimiento de los Briozoos dulceacuícolas de Chile.
803 Gayana (Concepción) 70:96-99.

804 Orrego, R., A. Burgos, G. Moraga-Cid, B. Inzunza, M. Gonzalez, A. Valenzuela, R.
805 Barra, & J.E. Gavilan, 2006. Effects of pulp and paper mill discharges on caged
806 rainbow trout (*Oncorhynchus mykiss*): Biomarker responses along a pollution
807 gradient in the Biobio River, Chile. Environmental Toxicology and Chemistry
808 25:2280-2287.

809 Orrego, R., G. Moraga-Cid, M. Gonzalez, R. Barra, A. Valenzuela, A. Burgos, & J. E.
810 Gavilan, 2005. Reproductive, physiological, and biochemical responses in juvenile
811 female rainbow trout (*Oncorhynchus mykiss*) exposed to sediment from pulp and
812 paper mill industrial discharge areas. Environmental Toxicology and Chemistry
813 24:1935-1943.

814 Orrego, R., J. Guchardi, V. Hernandez, R. Krause, L. Roti, J. Armour, M.
815 Ganeshakumar & D. Holdway, 2009a. Pulp and paper mill effluent treatments have
816 differential endocrine-disrupting effects on rainbow trout. Environmental
817 Toxicology and Chemistry 28:181-188.

818 Orrego, R., S. Adams, R. Barra, G. Chiang & J. F. Gavilan, 2009b. Patterns of fish
819 community composition along a river affected by agricultural and urban disturbance
820 in south-central Chile. Hydrobiologia 620:35-46.

821 Ortiz, Z., J. C. & H. Díaz-Páez, 2006. Estado de Conocimiento de los Anfibios de Chile.
822 Gayana (Concepción) 70:114-121.

823 Palma, A. & R. Figueroa, 2008. Latitudinal diversity of Plecoptera (Insecta) on local
824 and global scales. Illiesia 4:81-90.

825 Parada, E. & S. Peredo, 1989. Contribución al Conocimiento de los Hyriidae chilenos.
826 Boletín de la Sociedad Biología Concepción 60:173-182.

827 Parada, E. & S. Peredo, 1994. Un enfoque ecológico evolutivo de las estrategias de
828 historia de vida de los hyriidos chilenos (Molusco: Bivalvia). Boletín de la Sociedad
829 de Biología de Concepción 65:71-80.

830 Parada, E. & S. Peredo, 2006. Estado de conocimiento de los Bivalvos dulceacuícolas
831 de Chile. Gayana (Concepción) 70:82-87.

832 Parra, O., C. Valdovinos, E. Habi & R. Figueroa, 2009. Long term study of the Biobío
833 River: a complex multiuse fluvial system in Chile. Proceedings 7th International
834 Symposium on Ecohydraulics, Chile: 23.

835 Parra, O., L. Chuecas, H. Campos, M. Vighi & R. Vismara, 1993a. Caracterización
836 física y química y evaluación de la calidad para usos múltiple del agua del río
837 Biobío (Chile central). In Faranda, F. & O. Parra (eds), Monografías Científicas N°
838 12: Evaluación de la calidad del agua y ecología del sistema limnético y fluvial del
839 río Biobío. Editorial Universidad de Concepción, Concepción, Chile:15-160.

840 Parra, O., M. Angulo, A. Acuña, M. Vighi, R. Vismara, F. Faranda & S. Munari, 1993b.
841 Propuesta de programa de monitoreo de la calidad del agua del sistema río Biobío.
842 In Faranda, F.& O. Parra (eds), Monografías Científicas N° 12: Evaluación de la
843 calidad del agua y ecología del sistema limnético y fluvial del río Biobío. Editorial
844 Universidad de Concepción, Concepción, Chile:397-409.

845 Parra, O., 2006. Estado de conocimiento de las algas dulceacuícolas de Chile (Excepto
846 Bacillariophyceae). Gayana (Concepción) 70:8-15.

847 Pauls, S.U., R.J. Blahnik, X. Zhou, C.T. Wardwell & R.W. Holzenthal, 2010. DNA
848 barcode data confirm new species and reveal cryptic diversity in Chilean Smicridea
849 (Smicridea) (Trichoptera: Hydropsychidae). Journal of the North American
850 Benthological Society 29: 1058-1074.

851 Puntí, T., 2007. Ecology of Chironomidae communities in mediterranean reference
852 streams. PhD Thesis, University of Barcelona, 151 pp.

853 Quezada-Romegialli, C., M. Fuentes & D. Veliz, 2010. Comparative population
854 genetics of *Basilichthys microlepidotus* (Atheriniformes: Atherinopsidae) and
855 *Trichomycterus areolatus* (Siluriformes: Trichomycteridae) in north central
856 Chile. Environmental Biology of Fishes 89:173-186.

857 Quintanilla, V., 1983. Biogeografía. Instituto Geográfico Militar, Santiago Chile.

858 Ramírez, C. & C. San Martín, 2006 Diversidad de macrófitos chilenos. In Vila, I., A.

859 Veloso, R. Schlatter & C. Ramírez (eds), Biodiversidad: macrófitas y vertebrados

860 de los sistemas límnicos de Chile. Editorial Universitaria, Chile:21-72.

861 Ramírez, C., M. Romero & A. Riveros, 1979, Habit, origin and geographical

862 distribution of chilean vascular hydrophytes. Aquatic Botany 7(3):241-253.

863 Rivera, P., 2006. Estado de conocimiento de las diatoméas dulceacuícolas de Chile.

864 Gayana (Concepción) 70:1-7.

865 Rodríguez, R., O. Matthei & M. Quezada, 1983. Flora arbórea de Chile. Edit

866 Universidad de Concepción. Concepción, Chile.

867 Rojas, F., 2005. Nueva especie de Kokiriidae (Trichoptera) en Chile. Revista Chilena de

868 Entomología 31: 27-36.

869 Rojas, F., 2006. Estado de conocimiento de los Trichoptera de Chile. Gayana

870 (Concepción) 70:65-71.

871 Ruiz, V.H. & M. Marchant, 2004. Ictiofauna de aguas continentales chilenas. Depto. De

872 Zoología Facultad de Ciencias Naturales y Oceanográficas. Universidad de

873 Concepción, Concepción, Chile.

874 Ruiz, V.H., 1993. Ictiofauna del río Andalién. Gayana (Zoología) 57(2): 109-284.

875 Sabando, M.C., I. Vila, R. Penaloza & D. Veliz, 2011. Contrasting population genetic

876 structure of two widespread aquatic insects in the Chilean high-slope rivers. Marine

877 And Freshwater Research 62:1-10.

878 Schmid, F., 1957. Contribution a l'etude des Trichopteres neotropicaux II. Beitrage zur

879 Entomologie 7:379-398.

880 Schmid, F., 1958. Contribution à l'étude des Trichoptères neotropicaux III. Mitteilungen

881 aus dem Zoologischen Museum in Berlin 34(1):183-217.

882 Schmid, F., 1959. Contribution à l'étude des Trichoptères neotropicaux IV. Acta
883 Zoológica Lilloana. 17:477-483.

884 Schmid, F., 1964. Contribution à l'étude des Trichoptères neotropicaux V. Tijdschr
885 Entomologie 107:307-339.

886 Schmid, F., 1989. Les Hydrobiosides (Trichoptera: Annulipalpia). Bulletin Institut
887 Royal Sciences Naturelles Belgique 59:1-154.

888 Schmid, F., 1955. Contribution a la connaissance des Trichopteres neotropicaux.
889 Memories Societé Vaud Sciences Naturelles 11:117-160.

890 Schulz, J. J., L. Cayuela, C. Echeverria, J. Salas & J.M.R. Benayas, 2010. Monitoring
891 land cover change of the dryland forest landscape of Central Chile (1975-2008).
892 Applied Geography 30:436-447.

893 Smith-Ramírez, C., 2004. The Chilean coastal range: a vanishing center of biodiversity
894 and endemism in South American temperate rainforests. Biodiversity and
895 Conservation 13:373-393.

896 Smith-Ramírez, C., J.J. Armesto & C. Valdovinos, 2005. Historia, biodiversidad y
897 ecología de los bosques costeros de Chile. Editorial Universitaria, Santiago de
898 Chile, Chile.

899 Soto, D. & L.R. Zúñiga, 1991. Zooplankton assemblages of Chilean temperate lakes: a
900 comparison with North American Counterparts. Revista Chilena de Historia
901 Natural 64:569-581.

902 Soto, D., I. Arismendi, J. González, J. Santana, F. Jara, C. Jara, E. Guzmán, & A. Lara,
903 2006. Southern Chile, trout and salmon country: invasion patterns and threats for
904 native species. Revista Chilena de Historia Natural 79:97-117.

905 Stehr, A., M. Aguayo, O. Link, O. Parra, F. Romero & H. Alcayaga, 2010. Modelling
906 the hydrologic response of a mesoscale Andean watershed to changes in land use

907 patterns for environmental planning. *Hydrology and Earth System Sciences* 14:
 908 1963–1977.

909 Teneb, E. A., L. A. Cavieres, M. J. Parra & A. Marticorena, 2004. Geographic patterns
 910 of distribution of trees and shrubs in the transitional Mediterranean-temperate
 911 climatic zone of Chile. *Revista Chilena de Historia Natural* 77:51-71.

912 Thrower, N. J. W. & D. E. Bradbury, 1973. The physiography of the Mediterranean
 913 lands with special emphasis on California and Chile. In Di Castri, F. & H. A.
 914 Mooney (eds), *Mediterranean Type Ecosystems: Origin and Structure*. Springer
 915 Verlag, New York-Heidelberg-Berlin:37-52.

916 Valdovinos, C., G. Mancilla & R. Figueroa, 2009. Biodiversidad dulceacuícola de Chile
 917 Central. Macroinvertebrados bentónicos del río Itata. In Parra, O., Castilla, J.C.,
 918 Romero, H., Quiñones, R. & A. Camaño (eds), *La cuenca hidrográfica del río Itata:
 919 Aportes científicos para su gestión sustentable*. Editorial Universidad de
 920 Concepción, Concepción, Chile:111-125.

921 Valdovinos, C., 2006. Estado de conocimiento de los Gastrópodos dulceacuícolas de
 922 Chile. *Gayana (Concepción)* 70:88-95.

923 Valdovinos, C., 2008. Invertebrados dulceacuícolas. In Rovira J., J. Ugalde & M.
 924 Stutzin (eds), *Biodiversidad de Chile. Patrimonios y desafíos*. CONAMA, Chile:
 925 202-223.

926 Vera, A. & A. Camousseight, 2006. Estado de conocimiento de los Plecópteros de
 927 Chile. *Gayana (Concepción)* 70:57-64.

928 Victoriano, P.F., A.L. González & R. Schlatter, 2006. Estado de conocimiento de las
 929 aves de aguas continentales de Chile. *Gayana (Concepción)* 70:140-162.

- 930 Vidal, M.A, E. Soto & A. Veloso, 2009. Biogeography of Chilean herpetofauna:
931 distribucional patterns of species richness and endemism. *Amphibia-Reptilia*
932 30(2):151-171.
- 933 Vighi, M., O. Parra, C. Valdovinos & R. Urrutia, 1993. Mapa de calidad del agua del
934 río Biobío y sus afluentes principales. In Faranda, F. & O. Parra (eds), *Monografías*
935 Científicas N° 12: Evaluación de la calidad del agua y ecología del sistema
936 limnético y fluvial del río Biobío. Editorial Universidad de Concepción,
937 Concepción, Chile:1-14.
- 938 Vila, I. & R. Pardo, 2008. Peces límnicos. In Rovira J., J. Ugalde & M. Stutzin (eds),
939 Biodiversidad de Chile. Patrimonios y desafíos. CONAMA, Chile:223-256.
- 940 Vila, I., R. Pardo, B. Dyer & E. Habit, 2006. Peces límnicos: diversidad, origen y estado
941 de conservación. In Vila, I., A. Veloso, R. Schlatter & C. Ramírez (eds), *Macrófitas*
942 y vertebrados de los sistemas límnicos de Chile. Editorial Universitaria, Santiago,
943 Chile:73-102.
- 944 Villagrán, C. & L. Hinojosa, 1997. Historia de los bosques templados del sur de
945 Sudamérica II: Análisis fitogeográfico. *Revista Chilena de Historia Natural* 70:241-
946 267.
- 947 Villalobos, L., 2006. Estado de conocimiento de los crustáceos zooplanctónicos
948 dulceacuícolas de Chile. *Gayana (Concepción)* 70:31-39.
- 949 Woelfl, S., 2006. Notas sobre protozoos ciliados dulceacuícolas de Chile. *Gayana*
950 (Concepción) 70:24-26.
- 951 Zunino, S., C. Aliaga & P. Da Venezia, 2009. Fish communities in rivers mouths and
952 streams of the Valparaíso Region, central Chile. *Revista De Biología Marina Y*
953 Oceanografía 44:123-130.

954 Zwick, P., 2000. Phylogenetic system and zoogeography of the Plecoptera. Annual
955 Review of Entomology 45:709-46.
956

957
958 **Figure 1.** Location of the Chilean Mediterranean Zone (32-40°S) showing the limits of
959 its major river basins (in grey).

960

961

Online Resource 1

Freshwater biodiversity and conservation in mediterranean climate streams of Chile (published in *Hydrobiologia*)

Ricardo Figueroa^{1*}, Núria Bonada², Meyer Guevara¹, Pablo Pedreros¹, Francisco Correa-Araneda¹, María E. Diaz¹ and Victor H. Ruiz³

¹Corresponding author: rfiguero@udec.cl Center of Environmental Sciences EULA-Chile, University of Concepcion, Casilla 160-C, Concepcion, Chile

²Grup de Recerca Freshwater Ecology and Management (FEM), Departament d'Ecologia, Facultat de Biologia, Universitat de Barcelona (UB), Diagonal 643, 08028 Barcelona, Catalonia/Spain

³Department of Zoology, University of Concepcion, P.O. Box 160-C, Concepción, Chile

*Corresponding author: rfiguero@udec.cl Center of Environmental Sciences EULA-Chile, University of Concepcion, Casilla 160-C, Concepcion, Chile

Sampling and identification details on personal records indicated in Table 2 are listed below. All specimens were collected using handnets or surbers. Codes for taxonomic keys used refer to:

1 Domínguez, E., M.L. Pescador, M.D. Hubbard, C. Molineri & C. Nieto, 2006. Ephemeroptera of South America. In Adis, J., J.R. Arias, G. Rueda-Delgado & K.M. Wantzen (eds), *Aquatic Biodiversity in Latin America (ABLA)*. Vol.2. Pensoft, Sofia-Moscow:1-646.

2 Domínguez, E., M.D. Hubbard & W. Peters, 1992. Claves para ninfas y adultos de las familias y géneros de Ephemeroptera (Insecta) Sudamericanos. Instituto de Limnología "Dr. Raúl A. Ringuelet". *Biología acuática* 16:5-32.

3 Fernández, H.R. & E. Domínguez, 2001. Guía para la determinación de los artrópodos bentónicos sudamericanos. Serie Investigaciones. Edit. Universitaria de Tucumán.

River name	Latitude	Longitude	Species	Individuals	Methods	Date	Taxonomical keys
Estero Piedras	71° 0' 0"	35° 59' 60 "	<i>Siphonella guttata</i>	5	Handnet	10/01/06	1
Itata	70° 59' 60"	35° 59' 60"	<i>Siphonella guttata</i>	4	Handnet	10/02/06	1
Longuén	72° 0' 0"	36° 0' 0"	<i>Siphonella guttata</i>	2	Handnet	10/03/06	1
Chaquivilín	71° 16' 37"	38° 3' 16"	<i>Siphonella guttata</i>	8	Handnet	10/04/06	1
Queuco	71° 40' 36"	37° 49' 45"	<i>Siphonella guttata</i>	6	Handnet	10/05/06	1
Mataquito	71° 57' 38"	35° 0' 36"	<i>Siphonella guttata</i>	Presence	Handnet	01/01/08	1
Mataquito	72° 4' 0.2"	35° 2' 22"	<i>Siphonella guttata</i>	Presence	Handnet	01/02/08	1
Boyen	72° 06' 92"	36° 65' 24"	<i>Siphonella guttata</i>	6	Surber	11/01/00	2-3
Quilmo	72° 16' 49"	36° 66' 87"	<i>Siphonella guttata</i>	11	Surber	01/01/00	2-3
Estero la Vacas	71° 39' 2"	37° 4' 34"	<i>Metamonius anceps</i>	1	Surber	2007	1
Itata	72° 27' 7"	36° 40' 40"	<i>Camelobaetis</i> sp.	14	Surber	01/01/07	1
Itata	72° 27' 51"	36° 38' 55"	<i>Camelobaetis</i> sp.	172	Surber	01/02/07	1
Itata	72° 28' 2"	36° 38' 56"	<i>Camelobaetis</i> sp.	145	Surber	01/03/07	1
Itata	72° 28' 30"	36° 38' 9"	<i>Camelobaetis</i> sp.	6	Surber	01/04/07	1
Itata	72° 29' 52"	36° 37' 21"	<i>Camelobaetis</i> sp.	8	Surber	01/05/07	1
Itata	72° 30' 32"	36° 36' 57"	<i>Camelobaetis</i> sp.	53	Surber	01/06/07	1
Chillán	71° 89' 13"	36° 69' 30"	<i>Camelobaetis</i> sp.	19	Surber	01/01/01	2-3
Chillán	71° 96' 32"	36° 65' 38"	<i>Camelobaetis</i> sp.	42	Surber	01/02/01	2-3
Chillán	72° 08' 11"	36° 63' 31"	<i>Camelobaetis</i> sp.	25	Surber	01/03/01	2-3
Claro	71° 7' 41"	34° 24' 2"	<i>Camelobaetis</i> sp.	2	Surber	07/08/08	1