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EFECTOS DE LA REDUCCIÓN DEL CAUDAL POR ACTIVIDADES AGRÍCOLAS EN RÍOS DE LA ZONA MEDITERRÁNEA DE CHILE

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MEYER EDUARDO GUEVARA MORA
CONCEPCIÓN-CHILE
2015

Dr. Ricardo Figueroa Jara
Tutor
Departamento de Sistemas Acuáticos
Facultad de Ciencias Ambientales
Universidad de Concepción

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Facultad de Ciencias Ambientales
Programa de Doctorado en Ciencias Ambientales

Comisión evaluadora de tesis de grado:

Dr. Ricardo Figueroa Jara (Tutor)
Facultad de Ciencias Ambientales
Universidad de Concepción

Dr. Roberto Urrutia Pérez
Facultad de Ciencias Ambientales
Universidad de Concepción

Dr. José Luis Arumi Ribera
Facultad de Ingeniería Agrícola
Departamento de Recursos Hídricos
Universidad de Concepción

Dra. María Luisa Suárez Alonso
Departamento de Ecología e Hidrología
Universidad de Murcia

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A ti madre, cuya fuerza me ayudó a seguir adelante en los momentos más duros;
rendirse nunca fue una opción.
Tu valentía y ganas de vivir son tu mejor enseñanza,
descansa tranquila viejita linda.

Heidy Mora Rodríguez
QEPD
30 de mayo 1955 – 12 de abril 2013

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RESUMEN

En la zona mediterránea de Chile se localiza la mayor concentración de áreas agrícolas, las cuales requieren los aportes de los ríos para sustentar la producción durante la primavera y verano, aspecto que implica la construcción de diversas obras de infraestructura con efectos directos en el régimen natural del caudal (*e.g.* embalses o bocatomas). A pesar del amplio conocimiento sobre los efectos de los embalses en la diversidad y composición de los *macroinvertebrados bentónicos* (MIB), recientemente se ha planteado la importancia de las bocatomas en la integridad ecológica de los ríos de bajo orden y la posibilidad de establecer relaciones causales mediante los índices bióticos. En la presente investigación se establecen los impactos de la extracción de agua para actividades agrícolas en la comunidad de MIB y morfología del cauce en ríos de bajo orden de la cuenca río Itata. Los sitios seleccionados se caracterizaron por escasa intervención antrópica en las características físico químicas del agua, lo que permite establecer relaciones causales con los cambios en el hábitat físico. En el primer capítulo se establecen los aspectos socio-ambientales que regulan la extracción de agua, así como las posibles respuestas de la comunidad de MIB e índices bióticos ante la extracción del caudal. El segundo capítulo corresponde a la revisión de la biodiversidad de agua dulce, distribución en la zona mediterránea de Chile, y su vulnerabilidad ante algunos estresores ambientales. El tercer capítulo evalúa la respuesta de los parámetros comunitarios, índices de diversidad e índice CHSignal ante la extracción de agua. Se logran establecer leves cambios en la comunidad de MIB, así como la importancia de la velocidad como indicador generalizado de los cambios en el hábitat acuático. En el cuarto capítulo se determinaron los principales rasgos biológicos de MIB, necesarios para su resistencia ante determinadas condiciones propiciadas por la reducción del caudal; además se establece el rango inferior de tolerancia de los MIB en ~ 0.2 m/s. En términos generales se podría indicar que los rasgos son una buena herramienta para la evaluación de múltiples estresores ambientales en los ríos de bajo orden, sin embargo, el escaso conocimiento sobre la autoecología de las especies, principalmente de las endémicas, impide la aplicación generalizada de este método en la zona mediterránea de Chile. Se sugiere la utilización de la utilización en conjunto de diversos métodos para favorecer la determinación de los impactos ambientales relacionados con los cambios del caudal.

INTRODUCCIÓN

Debido al creciente incremento en el consumo de agua, especialmente por parte de las actividades agrícolas, la gestión del recurso hídrico es uno de los mayores desafíos para la sociedad actual (Dudgeon *et al.* 2006; Postel *et al.* 1996; Vörösmarty *et al.* 2010). Al respecto, en Chile el 85% de los recursos hídricos disponibles están destinados al riego en la zona central del país (Matus *et al.* 2004), donde las condiciones climáticas de tipo mediterráneo (Berger *et al.* 2007; Figueroa *et al.* 2013; Oyarzún *et al.* 2008) y los incentivos que apuestan a posicionar al país como potencia alimentaria (Villalobos *et al.* 2006) favorecen el desarrollo de la agricultura.

El modelo actual de uso del agua en la producción agrícola mantiene un enfoque económico de recurso inagotable, en el cual se asignan derechos para su extracción o utilización con escasa consideración de los impactos ambientales de la reducción del caudal de los ríos. Este modelo se diseñó con la intención de promover un mercado del agua, altamente dinámico y competitivo, sin embargo, posteriormente fue necesario incorporar sanciones ante la "no utilización" del recurso para evitar la especulación. Asimismo, la escasa regulación por parte de las instituciones y la falta de inversión para el aprovechamiento del recurso hídrico no han facilitado la resolución de aspectos nocivos como el uso intensivo del agua en áreas donde esta es un factor limitante para la producción agrícola (Boelens & Vos 2012; Solanes & Jouravlev 2006).

A pesar que en la actualidad la agricultura ya se encuentra limitada por el déficit de agua, el modelo tradicional impulsa a la construcción de diversas estructuras para acumulación de agua, tales como los embalses y bocatomas para irrigación (Figueroa *et al.* 2013), siendo estas últimas las más utilizadas para la derivación del caudal en los esteros y ríos de bajo orden (Número de Sthraler < 3; Sthraler 1957). Similar a otras zonas con escasez hídrica (e.g. Australia, Brooks *et al.* 2005; Chessman *et al.* 2010), estas desviaciones de aguas están asociadas a cambios en la geomorfología del cauce (Harden 2006) o alteración del caudal base de los ríos en el período estival (Deitch *et al.* 2009), aspectos relevantes para la conservación de la macrofauna acuática, especialmente en la zona central de Chile que destaca por un alto endemismo (Myers *et al.* 2000).

En este sentido, el régimen natural del caudal constituye la base para la conservación de la geomorfología y biodiversidad acuática de los ríos (Andreoli *et al.* 2012; Arthington *et al.* 2010; Poff *et al.* 1997), no obstante, los estudios sobre la influencia de la extracción del caudal son escasos en Chile. Por ejemplo, Figueroa *et al.* (2003) y Debels *et al.* (2005) indican la posible influencia de las extracciones de agua en la cuenca del río Chillán en el incremento de la concentración de nutrientes asociados a las descargas de aguas servidas de la ciudad de Chillán, mientras que Habit *et al.* (2007) indican que los ríos previamente sometidos a embalses para irrigación son más susceptibles a impactos sinérgicos durante la construcción u operación de embalses para generación hidroeléctrica.

Sin embargo, ninguno de los estudios realizados en Chile ha establecido la influencia de la reducción del caudal en las características del hábitat fluvial y su influencia en las comunidades de *macroinvertebrados bentónicos* (MIB), lo cual si ha sido considerado un estresor significativo para la subsistencia de la fauna acuática en otras áreas con condiciones climáticas similares (Chessman 2003; Chessman *et al.* 2010; Resh *et al.* 2013), situación que podría ser aún más grave si se consideran los estudios de cambio climático para la región Mediterránea chilena, que pronostican en un escenario menos adverso, la disminución del 15% del caudal y aumento en la temperatura ambiental de 2ºC , así como sus consecuencias para la sistemas fluviales (Departamento Geofísica 2006; Stehr *et al.* 2010; Pedreros *et al.* 2013).

Impactos de la reducción de caudal en los sistemas fluviales

En la región mediterránea chilena, la predictibilidad de las condiciones climáticas relativamente cíclicas y anuales permite la adaptación evolutiva de las especies para sobrevivir a los períodos de máximo y mínimos caudales (Gasith & Resh 1999). Estas variaciones temporales de caudal pueden ocasionar cambios en la diversidad y abundancia de las comunidades de MIB (Bonada *et al.* 2006b; Boulton 2003; Lake 2003). Asimismo, estudios recientes destacan la presencia de rasgos en los organismos que les permiten ser resistentes o resilientes a las condiciones ambientales imperantes (Bonada *et al.* 2007; Bradt *et al.* 1999; Miller *et al.* 2007). Estos aspectos son primordiales en ríos de bajo orden (Número de Sthraler < 3; Sthraler 1957) debido a que constantemente están sometidos a periodos de desecación e incremento de la demanda de agua producto de las necesidades agrícolas (Dewson *et al.* 2007; Habit *et al.* 1998).

El caudal es la variable fundamental para explicar la distribución y abundancia de diversos grupos taxonómicos en los sistemas fluviales (Anderson *et al.* 2006; Arthington *et al.* 2006; Benstead *et al.* 1999; Poff *et al.* 1997), dado que propicia la heterogeneidad del hábitat (Stanford *et al.* 2005; Townsend *et al.* 1997). Debido a los cambios temporales en el caudal, el hábitat se contrae y expande constantemente (Karr 1991; Pringle *et al.* 1988; Vannote *et al.* 1980), lo cual funciona como fuente de estrés que propicia el recambio de hábitats (Death 2010; Parsons *et al.* 2005), principalmente durante los períodos de alto caudal. Uno de los primeros efectos relacionados a la reducción del caudal es la reducción en el ancho del río (AR) y disminución de la profundidad de la columna de agua (PC), lo cual está directamente relacionado a la proporción (AR/PC) (Gordon *et al.* 2004). Este cambio es notorio en ríos que son expuestos a importantes reducciones de caudal para actividades hidroeléctricas (García *et al.* 2011; Guevara 2011), aun cuando en ríos de bajo orden, la dependencia de aportes de agua subterránea podrían minimizar los efectos de la extracción (Holmes 2000).

Otro efecto en el hábitat fluvial es el incremento en la tasa de sedimentación, como resultado de la reducción de la velocidad y altura de la columna de agua (James & Suren 2009; McIntosh *et al.* 2008; Miller *et al.* 2007). De acuerdo a Dewson *et al.* (2007), el aumento en la deposición de material en suspensión genera una reducción de los espacios intersticiales, lo cual implica disminución en la disponibilidad de refugio así como homogenización del hábitat para las especies bentónicas (Allan 2004; Wood *et al.* 2005).

A nivel comunitario, la reducción de la riqueza es el principal indicador de cambios ambientales (Dewson *et al.* 2007). En ríos que naturalmente están afectados por la disminución de los caudales, la desecación aísla los parches de hábitat (Boulton 2003), similar a lo que ocurre en ríos afectados por la extracción de agua. Por lo tanto, si consideramos que la resistencia y resilencia de los MIB es parte de los procesos de colonización y adaptación a diversos impactos antropogénicos (Miller *et al.* 2007), es de prever que la ausencia de determinados taxa o grupos funcionales, permitiría establecer relaciones causales con la extracción del agua. Por ejemplo, Wills *et al.* (2006) detectaron la disminución en la densidad de insectos bentónicos (principalmente filtradores y pastoreadores) mientras que Miller *et al.* (2007) asociaron la extracción del 90% del caudal con el cambio de una comunidad de MIB dominada por recolectores (collector-gatherer) y filtradores hacia otro nuevo estado dominado por raspadores o depredadores, lo cual refleja la importancia de las interacciones entre los distintos componente bióticos durante las perturbaciones asociadas a la extracción del caudal (Walters 2011).

En este sentido el impacto de los escenarios futuros para la región está directamente relacionado con el tamaño de los ríos. En particular, los ríos de bajo orden (Número de Sthraler < 3; Sthraler 1957) poseen valor ecológico para la VIII Región debido a que en ellos se dan los procesos de captura y flujos de energía (Bernhardt *et al.* 2005; Gomi *et al.* 2002; Lowe & Likens 2005; Vargas *et al.* 2011; Wipfli *et al.* 2007), mediado por la acción de los MIB, que se agrupan en los diversos hábitats que existen en éstos ríos (Meyer *et al.* 2007), por lo cual pueden servir como herramienta para evaluar los cambios del caudal (Bonada *et al.* 2006; Reynoldson *et al.* 1997; Rosenberg & Resh 1993a; Sánchez-Montoya *et al.* 2009; Statzner & Beche 2010), a través de aproximaciones comunitarias, índices biológicos o rasgos biológicos, a distintos niveles de sensibilidad según se muestra en la Figura 1:

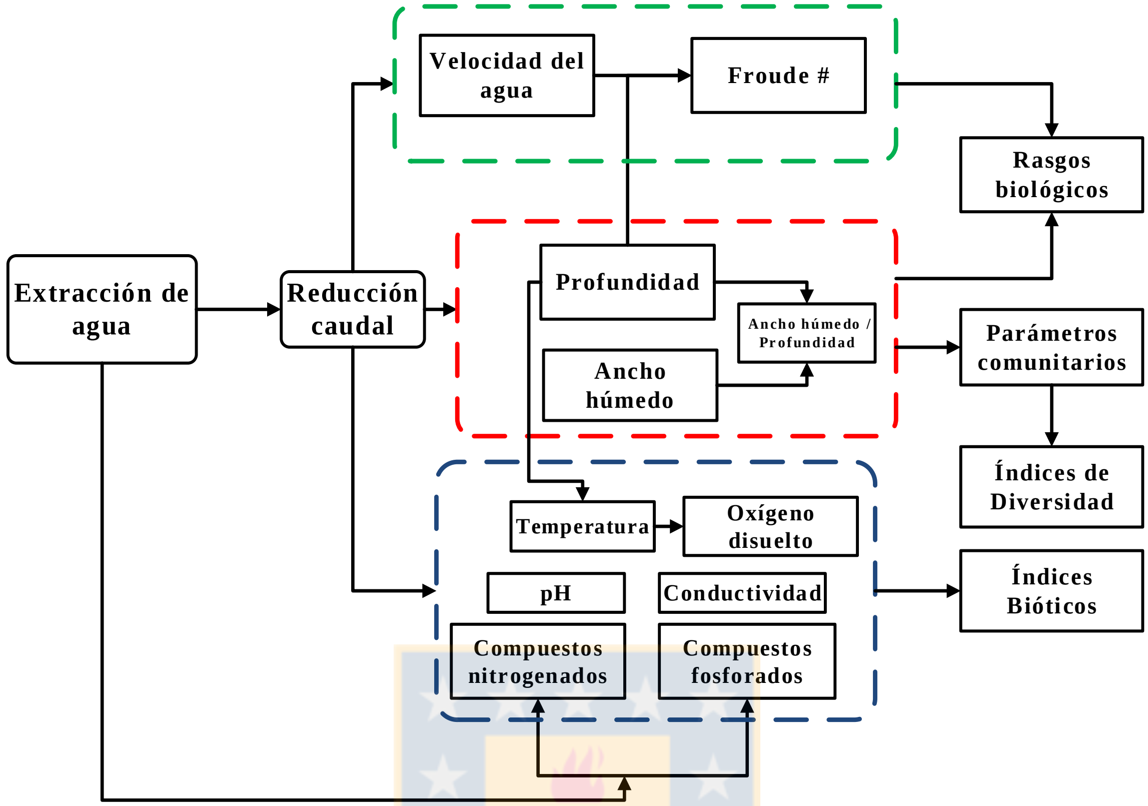

Figura 1. Esquema de los efectos de la reducción del caudal en los ríos de bajo orden.

Utilización de bioindicadores para la estimación de los impactos de la reducción de caudal

La sensibilidad de los MIB ha permitido su utilización como herramienta para la gestión de los recursos fluviales en Norteamérica (Barbour 1997; Barbour *et al.* 1995; Resh *et al.* 1995a; Resh *et al.* 1995b), Australia (Chessman 1995; Chessman 2003; Metzeling & Miller 2001), Inglaterra (Wright *et al.* 1998) y Latinoamérica (Figueroa *et al.* 2007; Guevara 2011; Roldán 2003), dada su reconocida respuesta a las perturbaciones humanas. Algunos índices bióticos han mostrado alta correlación con las condiciones físico-químicas del agua en ambientes expuestos a la contaminación antrópica (Haase & Nolte 2008), permitiendo valorar la recuperación de los sistemas fluviales luego de la aplicación de medidas correctivas en los efluentes industriales (Besley & Chessman 2008). Sin embargo, las investigaciones realizadas hasta el momento carecen de un patrón claro de respuesta ante la extracción de agua (ver Dewson *et al.* 2007) debido las diferencias en la magnitud, duración y época en que se dan los procesos de extracción de agua (Miller *et al.* 2007), degradación de la cobertura boscosa de ribera (Boothroyd *et al.* 2004; Naiman & Decamps 1997), uso del suelo, geología y la selección de los sitios de comparación (Allan & Johnson 1997; Biggs 1995; Biggs & Gerbeaux 1993; Chessman *et al.* 2008; Chessman *et al.* 2011; Ometo *et al.* 2000; Sánchez-Montoya *et al.* 2009; Townsend *et al.* 2003), variables que tienden a confundir el origen de los impactos. Tradicionalmente los estresores ambientales son evaluados mediante variables químicas del agua y cambios de las comunidades de MIB (Rosenberg & Resh 1993) y recientemente, se han ido incorporando los cambios del hábitat en la métrica de la calidad del agua (Schwendel *et al.* 2011; Townsend *et al.* 1997).

Los sistemas fluviales se caracterizan por presentar variados hábitat (Pringle *et al.* 1988; Stanford *et al.* 2005) que se distribuyen a lo largo de un continuo fluvial (Vannote *et al.* 1980) conectados por el caudal (Poff *et al.* 1997). Desde esta visión multiparamétrica, los sistemas hídricos son unidades dinámicas y complejas que interactúan con el medio que los rodea (Ward 1989) y es a escala de cuenca donde se han detectado cambios en el ciclo hidrológico y escorrentía asociados al uso del suelo (Vörösmarty *et al.* 2005). Sin embargo, los efectos sobre los MIB se evidencian principalmente a escala de tramo (reach), asociado a la estabilidad de los sustratos de fondo (Death & Collier 2010; Death & Zimmermann 2005), los cuales son fundamentales para la permanencia de los macroinvertebrados (Townsend *et al.* 1997). En la presente investigación se pretende estimar la influencia de la extracción de agua para actividades agrícolas en la comunidad de MIB y su hábitat fluvial, así como su factibilidad como herramienta de biomonitoreo, principalmente en los ríos de bajo orden, los cuales son un componente esencial para los procesos ecológicos y conservación de la biota acuática del país.

HIPÓTESIS

La irrigación constituye la actividad económica de mayor demanda de agua en los ríos de bajo orden la Zona Mediterránea Chilena, situación que implica amenaza constante a la sobrevivencia de la biota acuática con alto endemismo. El principal método para extraer el caudal en estos ríos son las bocatomas, las cuales generan cambios en la geomorfología del cauce y características físico químicas del agua. Los métodos tradicionales para evaluar los impactos en este tipo de ecosistemas son los biondicadores, sin embargo estos no consideran los cambios en el hábitat fluvial dentro de su métrica y construcción, por lo cual es necesario utilizar otras estrategias complementarias como los rasgos biológicos, cuya funcionalidad radica en su sensibilidad ante múltiples estresores ambientales.

Por lo tanto:

Los cambios en la morfología del cauce asociados a la reducción del caudal en ríos de bajo orden modifican la composición de macroinvertebrados bentónicos, producto de la reducción de la disponibilidad de hábitat, lo cual se refleja en los índices bióticos, parámetros comunitarios o rasgos biológicos.

OBJETIVOS

Objetivo general

Estimar los efectos de la extracción de agua para actividades agrícolas en el hábitat fluvial de ríos de bajo orden y la respuesta de la comunidad de MIB como herramienta de biomonitoreo durante el periodo estival (primavera-verano).

Objetivos específicos

1. Identificar los factores socio-ambientales que definen el modelo actual de extracción de agua para actividades agrícolas en ríos de bajo orden de la zona mediterránea de Chile.

2. Estimar los cambios en la comunidad de MIB, índices bióticos y geomorfología del cauce asociados a la extracción de agua para actividades agrícolas en tres ríos de bajo orden de la zona mediterránea de Chile.

3. Definir la tolerancia de los MIB a los cambios en el hábitat acuático producto de la extracción de agua para actividades agrícolas en ríos de bajo orden de la zona mediterránea de Chile.

4. Evaluar respuesta de los MIB a través de los rasgos biológicos a la extracción de agua para actividades agrícolas en ríos de bajo orden de la zona mediterránea de Chile.

METODOLOGÍA

Área de estudio

La presente investigación se efectuó en tres localidades de muestreo (Dehesa, Recinto y Marchant) localizados en la parte alta del río Itata (35° a 37° Latitud Sur) (Fig. 2). El clima dominante es de tipo mediterráneo (Gasith & Resh 1999), con veranos secos y calurosos, inviernos fríos y húmedos, con precipitación promedio anual de 1550 mm. El caudal del río principal varía entre 120 m^3/s en la parte media y 240 m^3/s en la desembocadura (Urrutia *et al.* 2009). En ninguno de los sitios estudiados existen registros previos del caudal que permitieran establecer el régimen hídrico. El sustrato del fondo del río está compuesto por una combinación de cantos rodados y bolones propios de zonas de ritrón para los tres sitios de estudio (Araneda *et al.* 2009).

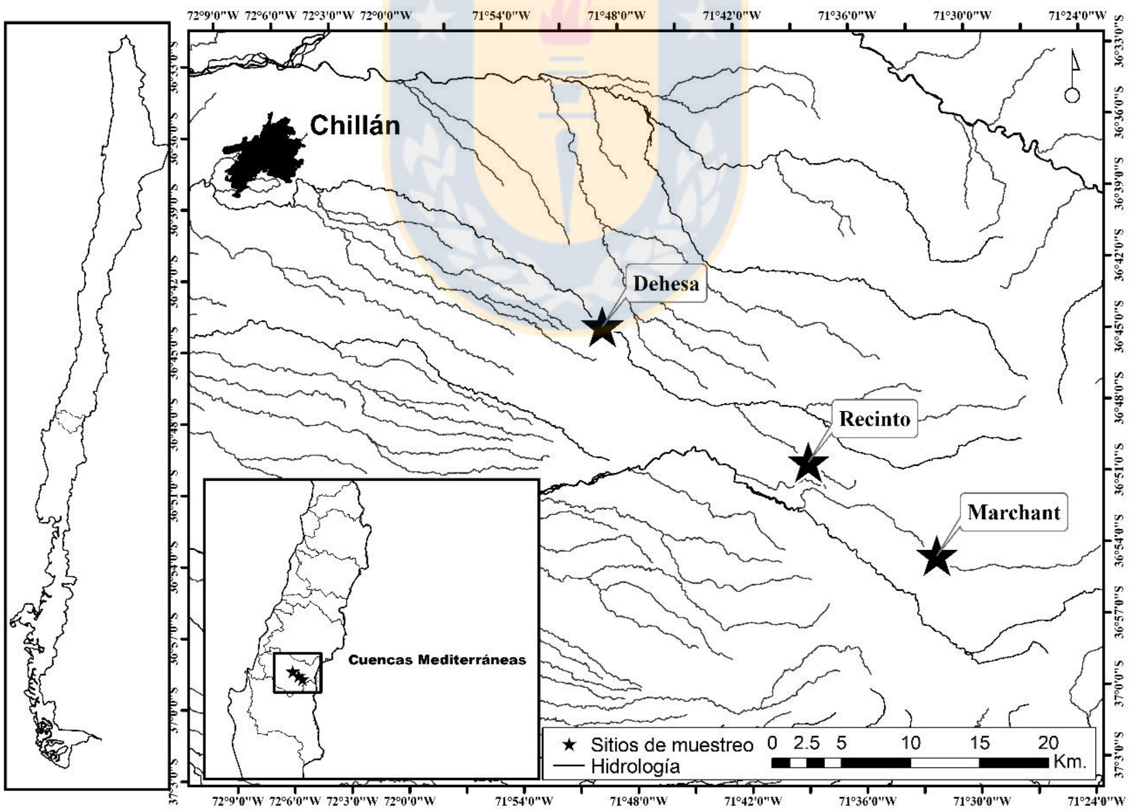

Figura 2. Ubicación de las localidades de muestreo en la parte alta de la cuenca del río Itata.

Estudios previos realizados por Figueroa *et al.* (2007) indican la escasa influencia de las actividades agrícolas en la condición físico química del agua durante el periodo de menor caudal (verano o primavera), siendo la principal fuente de contaminación la descarga de aguas servidas de la ciudad de Chillán. La cobertura boscosa nativa se concentra principalmente en la zona alta de la cuenca, con predominancia de especies perennes (e.g. *Drymis winteri*) y caducifolias (*Nothophagus spp.*), mientras que la parte media se caracteriza por uso del suelo agrícola, para lo cual es recurrente la creación de bocatomas de riego. Los métodos más utilizados para la construcción de estas bocatomas son la aglomeración de sacos con arena, bolones y madera para lograr el embalsamiento del cauce. La protección de la bocatoma durante el periodo de crecidas se logra mediante estructuras metálicas, apilamiento de sacos con arena o rocas en la entrada de la bocatoma (Fig. 3).

Figura 3. Métodos utilizados para la derivación del caudal en ríos de bajo orden.

Recolección de información bibliográfica y diseño de muestreo

Para la elaboración de esta investigación se utilizaron diversos enfoques analíticos. En los capítulos 1 y 2 se efectuó una recopilación de información utilizando bases bibliográficas disponibles tales como ISI Web of Knowledge, Science Direct, JStor o Scielo, así como revisión de tesis de posgrado relacionadas con la agricultura y su demanda de agua en Chile. También se realizaron consultas en las bases de datos disponibles en la Dirección General de Aguas o reuniones con diversos usuarios del agua tales como las Asociaciones de Canalistas o Juntas de Vigilancia. Debido a la importancia de la zona mediterránea de Chile como zona de alto endemismo y la concentración de actividades agrícolas, también se recopiló la literatura relacionada con la fauna acuática, principalmente de la zona mediterránea de Chile, en donde ocurre la mayor concentración de actividades antropogénicas con impacto en la conservación de la fauna acuática.

Para establecer el impacto de la reducción del caudal se seleccionaron tres localidades de muestreo en ríos de bajo orden localizados en la parte alta de la cuenca del río Itata. En cada una de las localidades se estableció un sitio de control y otro de impacto, definidos a partir la posición de la bocatoma para la extracción del caudal. En todos los casos no se utilizó una distancia superior a 100 m en cada localidad de muestreo, con el fin de evitar la posible influencia de la recarga de aguas subterráneas.

Para establecer los efectos en la geomorfología del cauce, índices bióticos, parámetros comunitarios o rasgos biológicos de MIB, se efectuaron 6 muestras aleatorias durante los 4 muestreos realizados: Octubre y Diciembre 2012 (primavera y transición verano), Marzo 2013 (verano) y Agosto 2013, esta última fecha corresponde al periodo en el cual las bocatomas se encuentran cerradas y el caudal se restaura a una condición normal con el aporte de las precipitaciones propias del invierno. Las diferencias significativas entre las zonas de control e impacto se establecieron mediante diversos enfoques estadísticos: ANOVA BACI; Prueba de T Student, Regresiones lineales, PERMANOVA o Fourth Corner Analysis implementados en R, los cuales serán abordados en cada uno de los capítulos de la presente tesis.

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CHAPTER 1. EFFECTS OF IRRIGATION WATER WITHDRAWALS IN MEDITERRANEAN LOW ORDER RIVERS OF CHILE: A REVIEW

Meyer Guevara-Mora; Pablo Pedreros, Ricardo Figueroa

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RESUMEN

Las condiciones geográficas y climáticas de la zona central de Chile favorecen la concentración de actividades agrícolas. Al igual que otras regiones mediterráneas, durante primavera y verano incrementa la demanda de agua de los ríos, con efectos directos en el caudal y la biota acuática. El objetivo de este estudio fue describir el estado de conocimiento de los cambios en el hábitat fluvial asociados a la demanda de agua en zonas agrícolas. De acuerdo a la legislación vigente en Chile, la distribución del agua se realiza mediante un enfoque económico-productivo, donde el estado es responsable de vigilar y regular el funcionamiento del mercado de derechos de agua asignados en función de la disponibilidad de agua en cada uno de los cauces naturales. Sin embargo, los efectos de la reducción del caudal en los ríos de Chile ha sido un tema de escaso desarrollo por parte de la comunidad científica, enfocándose principalmente en los embalses de generación hidroeléctrica, y no en las extracciones que se realizan de manera preferencial en ríos de bajo orden, donde la calidad del agua depende directamente de las condiciones ambientales aledañas y las características del hábitat fluvial son fundamentales para las comunidades de MIB. Basados en la importancia de los MIB para los procesos ecológicos y su amplio uso como bioindicadores, planteamos la utilización de los rasgos biológicos de los MIB como herramienta novedosa para la gestión de los ríos en la región mediterránea de Chile.

Palabras clave: Chile, extracciones de agua, Gobernabilidad del agua, rasgos de macroinvertebrados, hábitat fluvial.

ABSTRACT

The geographical and climatic conditions of Mediterranean Central Zone of Chile impulse the concentration of agriculture in this area. Thus, like any other Mediterranean region, in the spring and summer increases the water demand from the rivers by irrigation agriculture, with direct effects on the fluvial habitat of most of the endemic aquatic biota. The aim of this study was to describe the state of knowledge of the influence of irrigation water withdrawals in the fluvial habitat of low order rivers in the Mediterranean Chile. According to the legislation in Chile, water distribution is done through an economic-productive approach, where the governmental institutions are responsible for the surveillance and monitoring of the available water resources, in order to keep a dynamic water market. However, the effects of reduced flow in the rivers of Chile has been poorly considered in the assignation of water rights. Most of the scientific production of the country are focused on hydropower dams, but scarce information considered small water intakes and their effects in the fluvial habitat and composition of benthic macroinvertebrates (MIB). Based on the importance of MIB for ecological processes and their widespread use as bioindicators, we propose the use of biological traits of the MIB as a novel tool for river management in the Mediterranean region of Chile.

Keywords: Chile, water withdrawals, water governance, macroinvertebrate traits, fluvial habitat

INTRODUCTION

In the south-central Chile (~ 30° - 38° Lat. South) the agriculture is an important economy activity, promoted by the orographic and Mediterranean climate conditions (Di Castri & Hajek 1976; Niemeyer & Cereceda 1984). According to the OECD (2012) evaluations, the agriculture contributes with 13% exportation and 11% employment, for a total of 4.9 billion USD/year to the economy of the country. However, the agricultural techniques has influenced the conservation of aquatic ecosystems in aspects such as chemical composition (Debels *et al.* 2005; Figueroa *et al.* 2013; Parris 2011; Ribbe *et al.* 2008; Scanlon *et al.* 2007) and modification of the riparian forest (Miserendino *et al.* 2011; Naiman *et al.* 2005; Riseng *et al.* 2011).

The Chilean agriculture require the input from rainfall to sustain the traditional production model (Torrejón & Cisternas 2002), but in lower rainfall periods the increasing demand of annual crops require contributions of streams. According to the Ministerio del Medio Ambiente (2012), in the Mediterranean Chile area exists 62 water storage reservoirs for agriculture or human consumption, and some projects for interbasin water transferring (*eg.* Laja-Diguillín 50 000 ha and 30 000 ha Maipo) designated to increase the agricultural lands (Palerm-Viqueira 2010). Despite the increase in state investments for irrigation, it is necessary to solve engineering issues in the irrigation system, for example the loss of 70% by evapotranspiration and infiltration (Figueroa *et al.* 2013), the modification of the hydromorphological characteristics and community parameters on low order rivers (Ahearn *et al.* 2005; Andreoli *et al.* 2012; Nilsson *et al.* 2005; Poff *et al.* 1997) and the increase in the number of small hydraulic structures to divert the flow (Harden 2006; Palerm-Viqueira 2010; Wohl 2006).

The concentration of agricultural activities in the Central Chilean area contrasts with the Hot Spot designation for the conservation of aquatic and terrestrial biodiversity (Bonada *et al.* 2008; Figueroa *et al.* 2013; Myers *et al.* 2000; Smith-Ramírez 2004) due to the lack of a conceptual framework about the negative effects of water withdrawals in the rivers of Chile. Also, the future scenarios of climatic variation and water availability in the streams (Arnell & Gosling 2013; Döll & Zhang 2010) is an important aspect in the discussion of agricultural productivity of Chile (Meza *et al.* 2008; Oyarzún *et al.* 2008).

Our aim was to review the existent literature about the water abstraction from agricultural activities, and a description of the characteristics of Central Chile water market. We propose the use of benthic macroinvertebrates (MIB) as a bioindication tool to identify the disturbance impact of the diverted flows in low orders of Chile.

Characteristics of the Chilean water market and the relation with the fluvial ecosystem

The Chilean water market began with the modification of the Water Code in 1981, which allowed the government institutions to provide free and perpetual rights for water use without requiring to justify the economic activity (Valenzuela *et al.* 2013). The principal effects of the new economic model was the de-territorialization or de-localization of the water rights from the land rights in order to increase the economical trades and the most productive activities by water volume (Boelens & Vos 2012; Solanes & Jouravlev 2006). These modifications produced the substitution of the traditional and effective water distribution system in the most arid areas in the North of Chile (*e.g.* Aymaras, see Boelens & Vos 2012).

The new water market was created to increase the active participation of different economic groups, but the poor supervision and lack of infrastructure to divert water (low governmental inversion on hydraulic structures) affects the feasibility of the water market in the country (Berger *et al.* 2007). According to the Water Code of Chile (República de Chile 2006), the Dirección General de Aguas (DGA, a governmental water agency) must take active participation in the surveillance and monitoring of the water resources, but private organizations must regulate the distribution into their organization participants (Jara *et al.* 2009) (listed below):

1. River Administration Boards: include natural water resources in the basin, also groundwater resources.
2. Irrigation Channel Association: artificial watercourses include the multi farm water distribution and channel complexity.
3. Water Communities: distribute the natural water resources according to the individual water rights. All the organizations distribute the water rights or shares which are different in the level of internal organization or management of the water resources.

Other effects associated to the neoliberal water legislation were speculation and dynamism in the transaction of the rights without any water conservation purpose (Boelens & Vos 2012; Solanes & Jouravlev 2006; Valenzuela *et al.* 2013). In 2005, the modification of the Water

Code includes some issues like reducing the effects of the new water market as: a) taxes by not used water rights, b) limitation of the rights according to the technical requirements of the new project proposals and c) inclusion of the public interests in the definition of water depletion or restrictions to the water abstractions in a specific geographical area.

Despite of the multiple changes in the legislation, the non-used approach supposes an abundance in water resources with a strong relation between water diverted and used (Boelens & Vos 2012; Cai *et al.* 2008; Valenzuela *et al.* 2013), but these positions refuse the importance of the river ecosystem integrity and the protection of the flow. The flow is an important factor in the spatial and temporal conformation of the morphology of the streams because promotes a shifting habitat mosaic (Andreoli *et al.* 2012; Poff *et al.* 1997; Stanford *et al.* 2005; Townsend *et al.* 1997). During the high peaks of flow, the movement of the water supports the change of the river bed and also the increase of the biota diversity (Bonada *et al.* 2006b; Boulton 2003; Death 2010; Lake 2003; Parsons *et al.* 2005).

Like any other rivers in Mediterranean zones, Chilean rivers base flow occurs on spring and summer (Di Castri & Hajek 1976; Gasith & Resh 1999; Munné & Prat 2011), but the ice melting and snow peaks in the spring enhance a permanent river flow on spring and summer (Figueroa *et al.* 2013). This flow promotes the water abstraction on low order rivers which also alters the habitat for the benthic macroinvertebrates, fish and algae (Feminella 1996; Garcia-Roger *et al.* 2011; Magoulick & Kobza 2003; Matthews & Marsh-Matthews 2003; Robson & Matthews 2004).

The magnitude of the effect of the water withdrawal in the aquatic ecosystem is related to (1) the hydraulic infrastructure for the water deviation and (2) the operation technique to regulate the flow. In general, agricultural reservoirs are characterized by limited daily flow variations and high water volume storage to satisfy the demand on spring and summer which are different features from the hydropower dams.

According to Habit *et al.* (2007), in the Laja and Rucúe rivers of Chile, the beginning of the operations in the hydropower dams changed the fish community assemblage. However, the greatest impacts were observed in the Laja River, associated with its historical flow reduction by the water diversion project (Laja-Diguillín irrigation channel) which is necessary to enable irrigation on 40 000 ha (Arumí-Ribera *et al.* 2012; Salgado 1993). Meanwhile, García *et al.* (2011) also found changes in the habitat of native fishes by the alteration of the summer flows in the Biobío River by the combination of hydropower and water withdrawals of 3 irrigation weirs. In contrast to the proposals for hydropower generation projects (Goodwin *et al.* 2006), no examples are known about water reservoirs for agricultural activities.

Another characteristic of the water withdrawals in Chile was the low hydraulic technologies. The most common materials to deviate the water were sand bags, wood or rocks which do not allow the flow regulation or the effective monitoring of the government institutions in low order rivers. For example, in Itata river basin (Fig. 4), with an area of 11500 km^2 and mean annual flow of 396 m^3/s, 1943 water intakes has 348 m^3/s of water rights, despite low base flow of 122.7 m^3/s during summer (Parra & Habit 1998). Recently, we detected significant base flow variation in 3 streams with irrigation water abstraction (Dehesa: 36 ° 44 '25.74 "-71 ° 49' 11.36"; Recinto: 36 ° 50 '21.99 "-71 ° 38' 38.07"; Marchant: 36 ° 54 '26.33 "-71 ° 32' 3.23") in the Itata basin related to the water demand for agricultural production (Table 1). Similar to Australian water withdrawals (Chessman *et al.* 2011), other common methods were intermittent pumping, with low inclusion in legal records of the DGA. Some authors considered that this kind of water intakes manifest less intervention in dispersion and feeding for fish and macroinvertebrates (Benejam *et al.* 2010; Nilsson *et al.* 2005; Poff *et al.* 1997), however, the high concentration of weirs in the same sector could mean greater impacts in this region with extended drought periods (Núñez *et al.* 2013).

The first study about the aquatic fauna and irrigation infrastructure in Itata watershed was conducted in Quillón, and Cruz Cypress Zañartu canals (Habit *et al.* 1998). The main results indicated that artificial water channels allowed the colonization of macroinvertebrates but with less diversity, richness and abundance in comparison to the river. Other studies determined the importance of the irrigation canals for the predation protection and food availability of *Trichomycterus areolatus*, a vulnerable conservation fish in Chile (Habit *et al.* 2005).

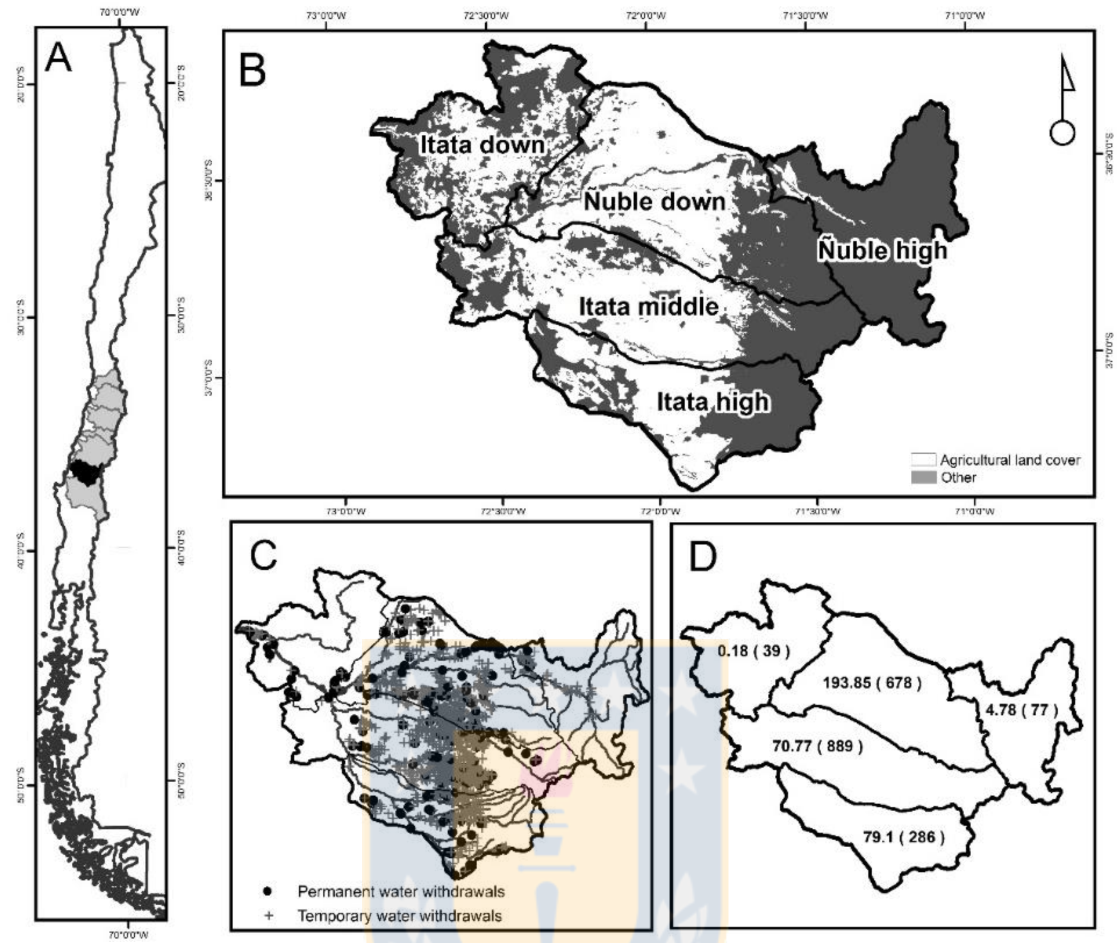

Figure 4. Agricultural water demand in the Itata river, Chile. a) Mediterranean basins (grey) and Itata basin (black), *sensu* Figueroa *et al.* (2013); b) Agriculture land use; c) Legal water rights; d) Legal flow (m^3/s) and amount of withdrawals.

Table 1. Water withdrawals (L/s) in different sites of the Itata basin (October, December 2012, March 2013).

Sampling site	Stream reach	October 2012	December 2012	March 2013
Recinto	Up	217.2	92.8	54.4
	Down	135.5	68.6	22.9
	% of change	*37.6*	*26.1*	*57.9*
Dehesa	Up	110.8	1505.9	368.6
	Down	23.6	34.0	33.2
	% of change	*78.7*	*97.7*	*91.0*
Marchant	Up	1806.7	*1245.7*	*1018.5*
	Down	*1108.5*	*661.8*	*728.4*
	% of change	*38.6*	*46.9*	*28.5*

Normally, the irrigation canal network has an influence in the groundwater recharge in relation to seepage infiltration (Arumí-Ribera *et al.* 2012; Arumí *et al.* 2009; Arumí *et al.* 2013; Rivera *et al.* 2007). The most common solution was the protection of the canals to prevent water losses (Morgado *et al.* 2012). However, these actions can cause changes in the ability to recharge groundwater aquifers during the period of greatest water scarcity (Arumí-Ribera *et al.* 2012; Arumí *et al.* 2009; Rivera *et al.* 2007). Thus, the complex relationship between the water demand from agricultural activities and the changes in the river habitat yet remains an undeveloped scientific area in the Mediterranean Chile are where exist a lot of endemic aquatic species and concentration of economic activities (Bonada & Resh 2013; Bonada *et al.* 2004; Bonada *et al.* 2005).

Changes in the fluvial ecosystems by water withdrawals

The modifications in the stream flow by water withdrawals affect morphological and physicochemical characteristics of the aquatic ecosystem. The wetted width/depth ratio is directly related to changes in river flow with hydropower generation (García *et al.* 2011; Gordon *et al.* 2004), however, in streams the dependence from groundwater inflow can reduce the extraction effects (Holmes 2000). Recently Pedreros *et al.* (2013) reported that the width-depth ratio is essential to control the thermal dynamics in Andean rivers.

The modification in the water level has influenced in water thermal regimen due to changes in the energy budget (Caissie 2006; Olden & Naiman 2010). In the case of water reservoirs, the water release with low temperature is common when it comes below the thermocline (Olden & Naiman 2010) or higher, when it corresponds to surface water release (Caissie 2006). According to Link *et al.* (2008), in the Biobío River basin, discharges of Pangue and Ralco dams do not show changes in water temperature caused by the daily generation of electricity, but this has not yet been addressed in irrigation reservoirs.

However, dissolved oxygen (DO) do not display specific changes related to the reduction in the water level. In natural conditions, the temporary rivers show a gradual variation of the DO due to the degradation of organic matter and mineralization of the detritus in the remaining pools (Schiller *et al.* 2011), but in streams with water abstraction there are no modifications in DO (Benejam *et al.* 2010; James & Suren 2009), such differences are associated to the scarce evaluation of DO concentration at night (Dewson *et al.* 2007a).

Moreover some studies determined the increase in the sedimentation rate when the water abstraction reduce speed, depth and dilution effect of the rivers (Harden 2006; James *et al.* 2009; James & Suren 2009; McIntosh *et al.* 2008; Miller *et al.* 2007). Also suspended material can generate a reduction in interstitial spaces, which implies the homogenization of habitat for benthic species (Allan 2004; Dewson *et al.* 2007a; Wood *et al.* 2005).

Since the physicochemical parameters are influenced by the flow, the most notorious effects are determined in temporary streams (Acuña *et al.* 2005; Lake 2003; Larned *et al.* 2010). Although the temporary streams are not common in the Mediterranean basins of Chile (Figueroa *et al.* 2013) we could expect their existence due to the increase in the water demand and future scenarios of water scarcity (Barceló & Sabater 2010; Bonada & Resh 2013).

Macroinvertebrates community assemblage

The flow is the fundamental variable to explain the distribution and abundance of aquatic biota (Poff *et al.* 1997). The seasonal changes in the flow determines the river morphology and fluvial habitat (Death 2010; Parsons *et al.* 2005), and thus it promotes high diversity (Pringle *et al.* 1988; Stanford *et al.* 2005; Townsend *et al.* 1997) for some groups like macroinvertebrates in low order streams. Streams are dynamic and complex units that change the environment (Ward 1989) in which effects are noticeable on a reach scale due the stability bottom substrates (Death 1995; Death 2010).

The geographical, geological and seasonal conditions of the low order streams generate high endemism of aquatic macroinvertebrates in the Mediterranean Chile area (Bonada *et al.* 2008; Myers *et al.* 2000). Some groups like Plecoptera or Trichoptera (Palma & Figueroa 2008; Rojas 2006) have the highest number of species in these streams as well as the highest water demand for agricultural purposes (Figueroa *et al.* 2013).

The streams affected by reduced flows show separation between different habitats, similar to drying process of temporary rivers (Boulton 2003). The new habitat conditions determine the permanence of tolerant species to water stress and significative richness reduction (Datry 2012; Miller *et al.* 2007). Some groups like Odonata, Coleoptera and Hemiptera (OCH) have desiccation and flying strategies to survive in low water condition (Bêche *et al.* 2006), however Ephemeroptera, Plecoptera and Trichoptera requires connectivity between riffles to reach favorable habitat conditions (Bonada *et al.* 2006b; Munné & Prat 2011). According to Bonada *et al.* (2006b), the EPT / (EPT + OCH) index could be used to estimate the alteration under natural conditions reduced flow, where EPT taxa is expected to increase in streams with riffle predominance (Watson & Dallas 2013).

The density of aquatic invertebrates is a widely used indicator to express the effects of the water withdrawals in streams (Dewson *et al.* 2007a). Recently, Wills *et al.* (2006) found low density of filter feeders and grazers in 50% reduction of the flow, while Miller *et al.* (2007) determined predator prevalence when 90% of the flow was removed. Another functional group that could be affected is shredders, mainly because the flow is relevant to preconditioning and leaves degradation, essential in the diet of various taxa (especially Plecoptera) (Dieter *et al.* 2011). The variation in the density reflects the importance of interactions between biotic components and community assemblage feeding characteristics to low flow situations (Dewson *et al.* 2007a; Walters 2011; Walters & Post 2011).

Biomonitoring low flow impacts with macroinvertebrates

Biomonitoring is the use of organisms to assess anthropogenic impacts on the environment, based on changes in the presence, abundance and behavior of aquatic biota in order to establish the link between ecosystem quality and policies of environmental conservation (Bonada *et al.* 2006a; Turnhout *et al.* 2007). The main challenge is the assessment of variable environmental conditions with simple biological parameters that reflects the ecosystem integrity for some specific human use (Karr 1991; Turnhout *et al.* 2007).

In Chile, the common group for bioindication purposes was the macroinvertebrates because they are able to change in relation to water quality variations (Córdova *et al.* 2009; Figueroa *et al.* 2007; Figueroa *et al.* 2005). Moreover, the diversity of species involved gives a wide range of environmental changes to assess the aquatic ecosystem (Bonada *et al.* 2006a; Rosenberg & Resh 1993). In some Chilean scientific literature, the main indices are Ch-IBF and Ch-SIGNAL which are designed to define water quality variations, but none of them are used in a water withdrawal context. In the Table 2 we summarize some metrics for the assessment of low flow conditions in natural or anthropogenic intervention.

Despite the extensive development of biotic indices, research so far denote the lack of a response pattern of water extraction (Dewson *et al.* 2007a). For example, Miller *et al.* (2007) found that resistance of macroinvertebrates to flow reductions are attributable to the hydrologic characteristics of the study area, however, it does not excluded the possibility of synergistic interaction the increase of some parameters like water temperature or conductivity. In other study, Chessman *et al.* (2011) could not establish differences in the assembly of the macroinvertebrate community due to similarities in his reference sites and the ones with human intervention.

Recently, Menezes *et al.* (2010) propose the use of biological traits for bioindication of aquatic systems. A biological trait defines how the set of taxa reflects adaptation to certain environment characteristics (Menezes *et al.* 2010; Townsend & Hildrew 1994); because of its multiparametric nature, it would be a useful tool to establish the impact associated with the reduction of water (Horrigan & Baird 2008; Statzner & Beche 2010; Walters & Post 2011).

Table 2. Principal biological indicators (macroinvertebrates) related to natural and anthropogenic low flow condition

Location of rivers	Biological indicators	Fuente
Mediterranean, California, USA	Total richness; relative richness; Ephemeroptera, Plecoptera, Trichoptera/Odonata, Coleoptera, Heteroptera ratio	(Bonada *et al.* 2006b)
New South Wales, Australia	Rapid biological assessment (RBA)	(Chessman *et al.* 2011)
North Island, New Zealand	Drift; size.	(James *et al.* 2009)
Kaiapoi River, New Zealand	Total abundance; richness; %EPT; Macroinvertebrate Community Index (MCI), Quantitative MCI.	(James & Suren 2009)
Waihee River, Maui, Hawaii, USA	Density; biomass; community assemblage.	(McIntosh *et al.* 2008)
Umantilla River, Oregon, USA	Total abundance; richness; EPT; Shannon diversity.	(Miller *et al.* 2007)
Connecticut	Biological traits.	(Walters 2011)
Connecticut	Feeding groups; density; diversity; richness; EPT.	(Walters & Post 2011)
Hunt Creek, Michigan, USA	PHABSIM modelling	(Wills *et al.* 2006)
Evros River, Greece	Spanish BMWP, EPT, family number	(Argyroudi *et al.* 2009)

Due to the high endemism and reduced number of species, we propose the use of macroinvertebrates in Mediterranean streams of Chile in order to define conservation strategies related to flow variation (Figueroa *et al.* 2013). The new proposals for bioindication should lead to the use of new techniques such biological traits (Resh *et al.* 2013), with the approach of allowing the management of water resources through its diffusion to public and private authorities in Chile (Ormerod *et al.* 1999).

CONCLUSIONS

The current distribution system of water rights in Chile, as well as pressure to satisfy high demands during lower rainfall periods encourage the spread of multiple intakes in low-order streams. Although the state has invested to improve resource utilization, these extraction points have little regulation and poor water infrastructure while modifying the river habitat. Regarding this, the rivers of the Mediterranean zone of Chile may show variations in physical and chemical parameters (*e.g.* temperature and DO) and channel morphology (*e.g.* width and depth), relevant to the conservation of macroinvertebrates, an abundant taxonomic group in endemic hotspot area of aquatic biodiversity. Regional variations in the abundance and richness of this group allow their use as biomarkers for reducing flow, which should be complemented with new approaches as multiparametric biological traits. Therefore, we believe that the use of this taxon could be of great value for Chile since we consider the need to generate knowledge about reducing flow rates in order to establish management measures and protection of water resources of this area.

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CHAPTER 2. FRESHWATER BIODIVERSITY CONSERVATION IN MEDITERRANEAN CLIMATE STREAMS OF CHILE

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Ricardo Figueroa; Núria Bonada; Meyer Guevara; Pablo Pedreros; Francisco Correa-Araneda; María E. Díaz; Víctor H. Ruiz.

Keywords: Central Chile, diversity, endemism, fauna, flora, stream and rivers

ABSTRACT

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

INTRODUCTION

Chile is located in southwestern South America in a region with a predominantly temperate climate. Mountains dominate 80% of the country. Mediterranean climate conditions (med-climate) occur only in the Central Zone, between the IV and the VIII administrative regions. The mediterranean climate region (med-region), also called the Chilean mediterranean zone (ChMZ), is located primarily between the Aconcagua and Biobío River basins (32–40°S, Fig.5) (Di Castri 1981) and includes the west side of the Andes Cordillera, the coastal ranges, and the Central Valley (Mann 1964). However, the limits of the ChMZ are not clearly established, and the El Niño and La Niña phenomena can expand or contract the area influenced by the med-climate (e.g., Di Castri & Hajek 1976; Luebert & Pliscoff 2004, 2006). Mesoclimate variability within the ChMZ was already recognized by Mann (1964), who distinguished between a "preclimax" area with low water availability and a "postclimax" area with greater water availability.

The area of the ChMZ with the highest temperatures is the Central Valley. The coastal mountains (up to 2,000 m.a.s.l.) prevent the maritime influence inland, resulting in an increase of 5 to 6ºC in the Central Valley. However, winter frost can be also present in areas of the Central Valley close to the foothills of the Andes. Winter precipitations in the whole ChMZ are concentrated between May to July, with a variation from 300 to 1,500 mm/year from north to south (Niemeyer & Cereceda 1989). Such precipitations increase river flows and accumulate great amounts of both ice and snow in the mountains from 1,500 m.a.s.l. upward (Clapperton 1994; Fuentes 1998). Melting peaks of ice and snow are produced at the end of spring, maintaining permanent riverbeds during the whole summer. Temporary rivers are thus less frequent in rivers flowing from the Andes but are common in rivers in the coastal ranges.

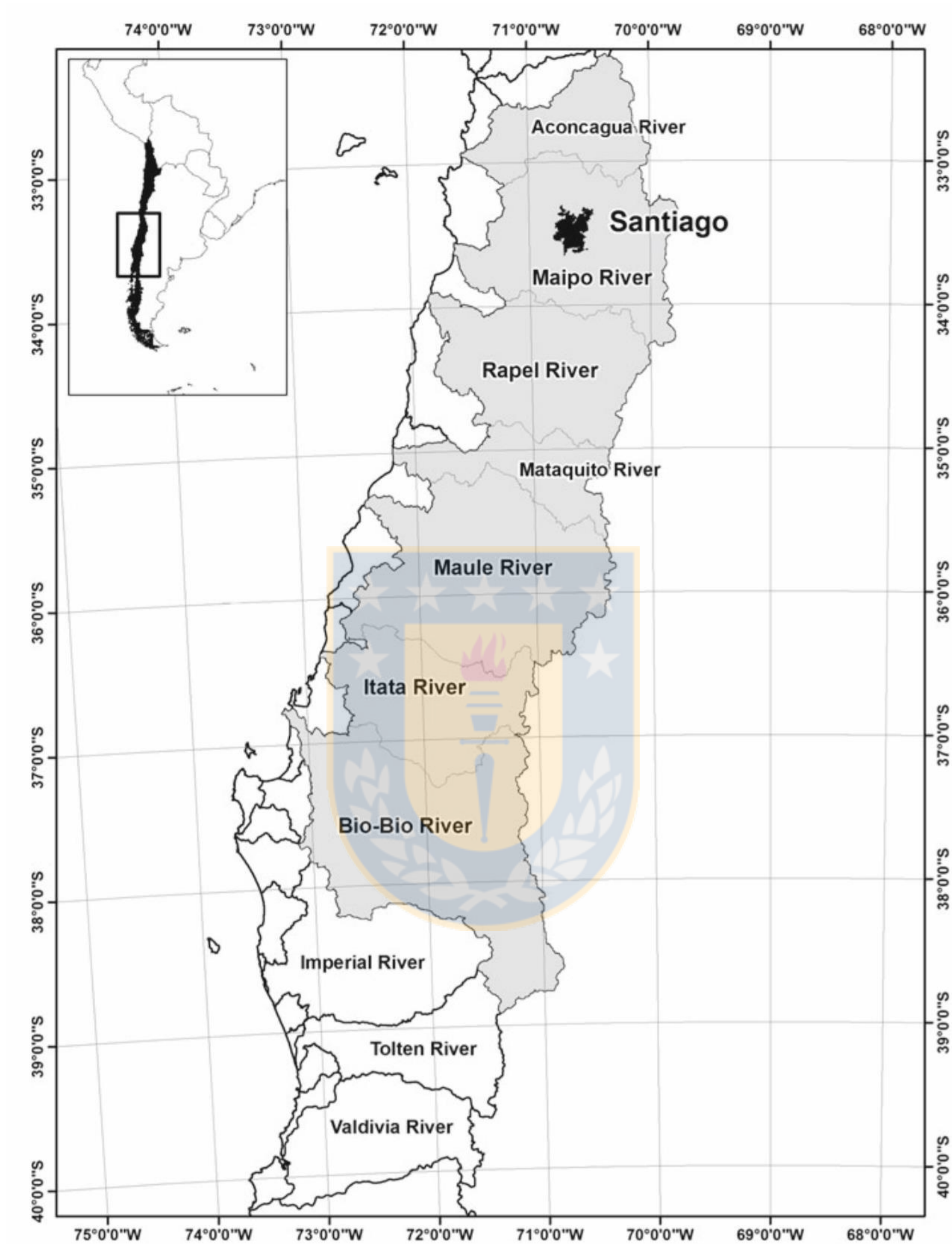

Figure 5. Location of the Chilean Mediterranean zone (32–40 °S) showing the limits of its major river basins (in grey)

Variation in med-climate conditions not only occurs in longitude (i.e., from the coastal ranges to the Andes foothills) but also in latitude. Di Castri &Hajek (1976) indicated that by means of climatogram analyses, it is possible to distinguish all the med-climate varieties in latitude, with a progressive decrease in the dry period southward. However, from the Biobío River basin to the south, two fundamental aspects determine the change to another climatic regime, the temperate climate of the Valdivian rainforest (Miller 1976). On one hand, the influence of the westerly winds results in winter precipitations and extreme summer drought (Villagrán & Hinojosa 1997). Second, the fragmentation of the coastal ranges allow maritime influence extends inland, increasing precipitation (Miller 1976). The city of Valdivia in southern Chile, for example, does not have the typical dry period in summer and wet period in winter of med-climate.

The ChMZ is the Chilean region with the higher human density and the most fertile soils, with ~ 14.5% of land used for wheat, sugar beet, oats, potatoes, oilseed rape, barley, and maize crops (Fuentes 1988). This extensive agriculture, together with the also important livestock and industrial activities, has resulted in a strong pressure on both land use and water resources (Figueroa *et al.* 2007). Thus, for example, whereas 85% of the water is used for agriculture in the ChMZ, already 70% is lost by evaporation or infiltration of the open channels used for irrigation (Table 3).

The orography of Chile results in a longitudinal orientation of most river basins. Seven large river basins are located from north to south in the ChMZ (Aconcagua, Maipo, Rapel, Mataquito, Maule, Biobío, and Itata rivers), with the headwaters in the Andes foothills and draining the Central Valley and the coastal ranges (Fig. 5). In addition, several smaller and steep river basins are located in the coastal ranges. This particular distribution of river basins in the ChMZ resembles that found in the med-region of California (Ball *et al.* 2013). Contrary to other med-regions, however, rivers in the ChMZ have rarely been studied, and the knowledge of their freshwater biodiversity is extremely scarce and fragmented. The aim of the present study is to gather the available information on freshwater biodiversity of the ChMZ and to identify the gaps that can guide further fundamental and applied research in the region.

Table 3. Characteristics of the administrative regions of the Chilean Mediterranean Zone and pressures faced by their aquatic resources.

	Valparaíso	Metropolitan of Santiago	O'Higgins	Maule		Biobío	
Total population	1 539 852	6 061 185	780 627	908 097		1 528 306	
Urban population	1 409 902	5 875 013	548 544	603 020		1 528 306	
% urban population	91.6	96.9	70.3	66.4		21.8	
Rural population	129 950	186 172	232 043	305 077		333 256	
% rural population	8.4	3.1	29.7	33.6		78.2	
Agriculture water demands (m^3/s)	461.9	1292.8	1599.0	1654.9		855.6	
Drinking water demands (m^3/s)	39.5	178.6	16.8	17.0		28.8	
Industry water demands (m^3/s)	40.4	86.7	8.2	22.8		392.5	
Mining water demands (m^3/s)	9.6	3.9	86.5	0.0		13.2	
Energy water demands (m^3/s)	211.4	1362.1	3270.7	8860.0		2462.1	
Main river basin	Aconcagua	Maipo	Rapel	Mataquito	Maule	Itata	Biobío
River length (km)	190	220	240	250	230	195	380
Watershed area (km^2)	7 640	15 400	13 520	6 050	21 690	11 480	24 000
Average discharge (m^3/s)	40	102	161	53	380	140	900
Hydrological regimen	Snow-pluvial	Snow-pluvial	Snow-pluvial	Snow-pluvial	Snow-pluvial	Snow-pluvial	Snow-pluvial
Principal tributaries	Putaendo, Blanco and Colorado	Colorado, Volcán, Yeso and Mapocho	Cachapoal, Tinguiririca and Alhue	Teno and Lontué	Melado, Claro and Loncomilla	Ñuble, Cato, Chillán, Palpal, Diguillín and Larqui	Vergara, Laja, Malleco, Rahue, Ranquil, Queuco, Duqueco and Bureo

Source: Niemeyer & Cereceda (1989), INE (2003), DGA (2004)

Biogeography

The geology of the ChMZ is mainly composed by metamorphosed sediments and igneous batholithic rocks in the Andes, sediments in the Central Valley and metamorphosed and granites deposits in coastal ranges (Thrower & Bradbury 1973). The landscape was strongly modeled by an ancient and intense tectonic activity and recent glacial events (Clapperton 1993).

The association between med-climate characteristics and vegetation structure and physiology in the ChMZ has been analyzed in several studies (e.g. CFP 1950; Mann 1964; Di Castri & 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 *Drimys winteri* (Hajek 1991; Dallman 1998). The vegetation of the most arid sector occurs in the northern ChMZ between the Aconcagua and Maipo river basins (Fig.5). 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 punctantum* (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 integrifollia* (aromo, endemic); and *Lomatia dentate* (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 be higher than 55%. Land use of the Vergara River basin, an important tributary of the Biobío River, included 47% of agriculture, 31% of native forests, and 18% by scrubland in 1979, whereas in 1994 forestry plantations occupied 38% of the basin, native forests 21%, and agriculture 32% (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 of the Biobío Region is protected within the National Estate System of Protected Wild Areas, becoming the fourth region with less protected wild areas in Chile, after the Metropolitan, Coquimbo, and Maule Regions, all of them in the ChMZ (INE 2012). Only recently, the Fundo Nonguén National Reserve has been decreed. This reserve, with 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 & Peredo 1989; Charrier *et al.* 2002; Barrientos *et al.* 2004, 1994).

CURRENT STATUS OF FRESHWATER BIODIVERSITY KNOWLEDGE

In the ChMZ, freshwater diversity studies have been mainly focused on floristic groups (Bannister *et al.* 2011) and on the distribution of several major faunal species, such as *Lutra provocax* (Chilean Otter), *Casmerodius albusegretta* (Big Egret), *Egretta thula* (Small Egret), *Calyptocephalella gayi* (Chilean Big Frog), and *Rhinoderma darwinii* (Darwin's Frog), among others (Quintanilla 1983). Other groups, *e.g.* Trichoptera, Plecoptera, and fish have been considered 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) highlights 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 gathered in a special issue of the journal Gayana (Concepción) (2006, volume 70). This information allows a detailed analyses of freshwater groups nationwide, such as microalgae (Parra 2006; Rivera Ramírez 2006), macrophytes (Hauenstein 2006), planktonic protozoans (Woelfl 2006), zooplankton (Villalobos 2006), malacostraca 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 Liebbe 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 distribution areas of species and are too general for the purpose of this review. Therefore, to analyze the biodiversity of this med-region we used information provided in the Gayana (Concepción) journal (2006, volume 70) and specific works 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 whole Neotropical region; among others.

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 Martin (2006) pointed out that although macrophyte distribution is poorly known in Chile, the greatest diversity is located between 35 and 40ºS, 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 present endemic species in the ChMZ and they are widespread along Chile (Araya & Zuñiga 1985; Soto & Zuñiga 1991). Numerous reservoirs are located in the Central Valley, many of these reservoirs are eutrophic because as a result of high nutrient inputs. These ecosystems are characterized by the presence of small cladocerans (*Ceriodaphnia dubia*, *Moinamicrura*, and *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 and 11 species in the most eutrophic reservoirs, and only 4 and 5 in the less eutrophic ones.

Aquatic insects

Information of Ephemeroptera in Chile can be found in Camousseight (2001). Domínguez *et al.* (1992, 2001, 2006, 2009) have also updated the knowledge on South American Ephemeroptera, including the Chilean region. Seven families of the 14 occur only in South America, are located only in Chile, with 375 genera and *ca.* 4,000 spp. From these families, Onicigastridae was not reported in the ChMZ (Table 4) until recently, where it was found from the Maule to Biobío River basins. Similarly, these recent studies indicate that the genus *Camelobaetidius* (Baetidae), which had not previously recorded for Chile, occurs throughout the ChMZ. Thus, 42 species in all, with 12 endemic species, are recognized for the ChMZ (Table 4). 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 *Adesiops torrens* have reported that this species feeds on fine organic particles as well as on algae.

Table 4. Distribution of families and species of Ephemeroptera present in the Chilean Mediterranean Zone.

Family	Genera/Species	Distribution (ºS)
Ameletopsidae	*Chaquihua bullock**	37° - 38°
	Chiloporter penai	36° - 41°
Baetidae	*Baetis (Americobaetis) albinervis*	32° - 33°
	*Andesiops (Deceptiviosa) angolina**	37° - 38°
	*Andesiops ardua**	40° - 41°
	Andesiops peruvianus	30° - 32°, 38°- 40°
	Andesiops torrens	30°, 32° - 33°, 40°
	Callibaetis fasciatus	32° - 33°
	Callibaetis jocosus	32° - 33°
	Callibaetis lineatus	32° - 33°
	Camelobaetidius sp.	32° - 38°
Caenidae	*Caenis axillata* sp.*	32° - 33°
	*Caenis nigella**	32° - 33°
Coloburiscidae	*Murphyella needhami*	32° - 45°
Leptophlebiidae	*Archethraulodes spatulas*	35°
	Dactylophlebia carnulenta	38° - 39º - 43°
	*Demoulinellus coloratus**	30°, 33°,35°, 37°- 40°
	*Gonserellus atopus**	40°
	Massartellopsis irarrazavali	29° - 35°, 42°
	*Meridialaris biobionica**	36°
	Meridialaris chiloeensis	32° - 42°
	*Meridialaris diguillina**	33° - 40°
	*Meridialaris inflate**	38°
	Meridialaris laminate	33° - 43°
	Meridialaris spina	33° - 43°
	Hapsiphlebia anastomosis	34° - 38°,40°- 43°
	Nousia bella	33° - 42°
	Nousia crena	34° - 42°
	Nousia grandis	33° - 43°
	Nousia maculate	34° - 43°
	Nousia delicate	32° - 43°
	Nousia minor	34° - 43°
	*Penaphlebia (Penaphlebia) barriai**	32° - 33°
	Penaphlebia (Penaphlebia) chilensis	31°, 33º - 40°
	Penaphlebia (Penaphlebia) fulvipes	39° - 42°
	Penaphlebia (Penaphlebia) flavidula	37° - 38°
	Penaphlebia (Megalophlebia) vinosa	33°, 36°, 38°- 42°
	Rhigotopus andinensis	39° - 43°
	Secochela illiesi	35° - 43°
Nesameletidae	*Metamonius anceps*	33°- 39°
Oniscigastridae	*Siphlonella guttata**	40° - 43°

Family	Genera/Species	Distribution (ºS)
	Siphlonella ventilaus	40° - 41°

Source: Figueroa *et al.* 2003, 2007; Domínguez *et al.* 2006; Domínguez & Fernández 2009 and personal records. *= endemic species of the ChMZ.

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 (five endemic species), occur in the ChMZ (Table 5). As in other med-regions of the world, Plecoptera have been used in ChMZ as bioindicators (Figueroa *et al.* 2003, 2007) because all families seem to be restricted to rivers with high oxygen concentration and low levels of human impact (Palma & Figueroa 2008). One family of particular interest is Diamphipnoidae, which is only distributed in Chile (Fochetti & Tierno de Figueroa 2008) and comprises 2 genera and 5 species, all present in the ChMZ. *Diamphipnoa virescentipennis* and *Diamphipnopsis samali* are confined to the ChMZ (37 to 38ºS and 38º to 42ºS, respectively), whereas the other 3 species of Diamphipnoidae reach down to Patagonia (Vera & Camousseight 2006).

Table 5. Distribution of families and species of Plecoptera registered in the Chile Mediterranean Zone.

Family	Species	Distribution (ºS)
Eustheniidae	*Neuroperlopsis patri**	36°- 37°, 39°-40°
	Neuroperla schendingi	37°, 39°-40°
Diamphipnoidae	*Diamphipnoa annulata*	35°-36°, 39°
	Diamphipnoa helgae	38°-40°
	Diamphipnoa virescentepennis	36°-37°
	Diamphipnopsis beschi	39°
	Diamphipnopsis samali	37°, 39°- 40°
Austroperlidae	*Klapopteryx armillata*	36°-40°
	Penturoperla barbata	35º
	Klapopteryx costalis	37°
Gripopterygidae	*Notoperlopsis femina*	36°-38°, 39°
	Notoperla archiplatae	33°, 34°, 35°
	Senzilloides panguipulli	36 - 39°
	Aubetoperla kuscheli	37°
	Aubetoperla illiesi	34°-38°, 40°

	Claudioperla tigrina	39°-40°
	Limnoperla jaffueli	32°-33°, 35°- 40°
	Potamoperla myrmidon	32°,34° - 40°
	Rhithroperla rossi	36°, 39° - 40°
	Teutoperla auberti	36°
	Teutoperla brundini	40°
	Teutoperla rothi	37° - 40°
	Antarctoperla michaelseni	33° - 40°
	Araucanioper labrincki	40°
	Araucanioperla bullock	37°
	Ceratoperla fazi	38° -40°
	Ceratoperla schwabei	40°
	Chilenoperla beschi	34° - 39°
	Chilenoperla puerilis	40°
	Chilenoperla semitincta	39°
	Perlugoperla personata	38° - 45°
	*Plegoperla borggreenae**	37° - 38°
	*Plegoperla punctata**	37° - 38°
Notonemouridae	*Austronemoura araucana*	37°
	Austronemoura caramavidensis	37°
	Austronemoura chilena	38° - 40°
	Austronemoura encoensis	39°
	Austronemoura eudoxiae	36° - 39°
	*Neofulla spinosa**	38°
	Neonemoura barrosi	33°, 35° - 40°
	Udamocercia antarctica	39° - 40°
	Udamocercia arumifera	39° - 40°
	Udamocercia frantzi	39° - 40°
Perlidae	*Inconeuria porter*	35° - 40°
	Kempnyella genualis	36° - 40°
	Kempnyella walperi	36°, 39°
	*Nigroperla costalis**	35° - 38°
	Picteroperla repanda	37°

Source: Lafranco 1982; Vera & Camousseight 2006; Palma & Figueroa 2008; *= endemic species of the ChMZ).

In Chile, Denning (1947, 1962, 1964) and Schmid (1955, 1957, 1958, 1959, 1964, 1982, 1989) was the first researcher to conduct significant studies of Trichoptera faunistics. In addition, Flint & Holzenthal have notoriously contributed 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 recognized, with 108 endemic species (Table 6). 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 (Rojas 2006) although the information on the juvenile aquatic forms, their behavior, and their ecological requirements are completely lacking (Angrisano & Korob 2001). According to Angrisano & Korob (2001), the Trichoptera are characterized by a total or partial replacement of the species from headwaters to lowlands. The pattern of species replacement is influenced by the current velocity, which directly affects the availability of food, 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.

Table 6. Distribution of families and species of Trichoptera present in the Chilean Mediterranean Zone.

Family	Species	Distribution(ºS)
Anomalopsychidae	*Anomalopsyche minuta**	36°
	*Contulma cranifer**	38° - 39°
Calamoceratidae	*Phylloicus distans**	33°
Ecnomidae	*Austrotinodes armiger*	38°
	*Austrotinodes brevis**	38°
	*Austrotinodes cekalovici**	39°
	*Austrotinodes irwini**	38°
	*Austrotinodes quadrispina**	37° - 38°
	*Austrotinodes recta**	38°
	*Austrotinodes recurvatus**	35°
	*Austrotinodes talcana**	35°
	*Austrotinodes triangularis**	37°
Glossosomatidae	*Mastigoptila bicornuta**	36°
	*Mastigoptila curvicornuta**	36°
	*Mastigoptila ecornuta**	37°
	*Mastigoptila longicornuta**	36°
	Mastigoptila ruizi	37°
	*Tolhuaca cupulifera**	37°
Hydropsychidae	*Smicridea figueroai**	37°

Family	Species	Distribution(ºS)
	Smicridea anticura	40°
	*Smicridea decora**	37°
	*Smicridea albescens**	37°
	Smicridea frequens	35°
	*Smicridea matancilla**	34°
	*Smicridea redunca**	36°
	Smicridea tregala	37°
	*Smicridea turgida**	37°
Hydroptilidae	*Celaenotrichia edwardsi*	35°
	Ochrotrichia (Metrichia) bidentata	37° - 38°
	Ochrotrichia (Metrichia) patagonica	36°, 40°
	Neotrichia chilensis	35°
	*Nothotrichia cautinensis**	39°
	*Nothotrichia illiesi**	39°
Kokiriidae	*Pangullia faziana**	39°
Helicophidae	*Alloecentrellodes elongatus*	36°
	Alloecentrellodes obliquus	38°
	Austrocentrus griseus	37°
	Austrocentrus valgiformis	36° - 38°
	Austrocentrus bifidus	39°
	Eosericostoma inaequispina	33°, 37° - 39°
	Eosericostoma aequispina	37° - 38°
	Microthremma caudatum	36°
	Microthremma crassifimbriatum	36°
	Microthremma griseum	37°
	Microthremma villosum	37°
	Pseudosericostoma simplississimum	37°
Helicopsychidae	*Helicopsyche caligata**	36°
Hydrobiosidae	*Amphichorema costiferum*	39°
	*Amphichorema monicae**	35°
	*Amphichorema zotheculum**	36°
	*Apatanodes sociata**	32°, 37°
	*Australobiosis bidens**	36°
	Cailloma rotunda	33°
	Cailloma angustipennis	33°
	Cailloma erinaceus	34°
	*Clavichorema capillata**	33°, 36°
	*Clavichorema complicatissima**	36°
	*Clavichorema pillimpilli**	37° - 38°
	*Clavichorema purgatorium (purgatoria)**	36°
	*Clavichorema trancasicum (trancasica)**	36°
	*Iguazu flavofuscum**	37° - 38°
	*Isochorema curvispinum**	36°
	Microchorema larica	39°
	Microchorema extensum	35°

Family	Species	Distribution(ºS)
	*Microchorema recintoi**	36°
	Neoatopsyche brevispina	37° - 38°
	Neoatopsyche chilensis	36°, 38°
	Neoatopsyche obliqua	32°, 33°
	Neoatopsyche spinosella	33°, 38° - 39°
	*Neochorema jaula**	35°
	*Neochorema lobiferum**	39°
	*Neochorema sinuatum**	37°
	*Neopsilochorema chilense**	37°
	*Nolganema chilense**	37°
	Parachorema bifidum	36°
	*Pomphochorema chilensis**	37°,
	*Pseudoradema spinosissimum**	38° - 39°
	*Rheochorema robustum**	38°,
	*Rheochorema tenuispinum**	36°
Leptoceridae	*Brachysetodes bifidus**	33°
	*Brachysetodes bifurcatus**	38°
	*Brachysetodes extensus**	37°,
	Brachysetodes forcipatus	37°
	Brachysetodes major	35°
	*Brachysetodes nublensis**	36°
	*Brachysetodes spinosus**	37°
	*Brachysetodes trifidus**	33°
	*Brachysetodes tripartitus**	34°
	*Neptopsyche fulva (Leptocela fulva)**	36°
	*Neptopsyche navasi (Leptocela candida)**	33°
	Triplectides jaffuelli (robustus)	33°
	Hudsonema flaminii	32°, 35° - 38°
Limnephilidae	*Austrocosmoecus hirsutus*	32°, 38°
	Monocosmoecus minor	32°, 38°
	Monocosmoecus obtusus	36°
	Monocosmoecus pulcherrimus	37°
	*Verger bispinus (Magellomyia)**	37°
	*Verger curtior**	35°
	*Verger fuscovittatus**	33°
	Verger pirioni	38°
	Verger porteri	33°
	*Verger cuadrispinus**	33°
	*Verger vespersus**	38°
Philopotamidae	*Dolophilodes angulata (Chimarra angulata)**	34°
	*Dolophilodes bifida (Chimarra bifida)**	36°
	*Dolophilodes chilensis (Chimarra chilensis)**	33°
	*Dolophilodes duplex (Chimarra duplex)**	33°
	*Dolophilodes dupliplex (Chimarra dupliplex)**	35°
	*Dolophilodes edwardi (Chimarra edwardi)**	36°

Family	Species	Distribution(ºS)
	*Dolophilodes elongata (Chimarra elongata)**	37°
	*Dolophilodes paxillifera (Chimarra paxilifera)**	39°
	*Dolophilodes pectinifera (Chimarra pectinifera)**	35°
	*Dolophilodes prolixa (Chimarra prolixa)**	36°
	*Dolophilodes scopula (Chimarra scopula)**	36°
	*Dolophilodes spectabilis (Chimarra spectabilis)**	38°
	*Dolophilodes spinifera (Chimarra spinifera)**	37°
	*Dolophilodes spinosella (Chimarra spinosella)**	35°
	*Dolophilodes ventricosta (Chimarra ventricosta)**	36°
Philorheithridae	*Mystacopsyche longipilosa*	37° - 39°
	*Mystacopsyche ochracea**	38°
	*Psilopsyche chillana**	36°
	Psilopsyche kolbiana (blanchardi)	36°
Polycentropodidae	*Polycentropus aspinosus**	37°
	*Polycentropus obtusus**	35°
	*Polycentropus tuberculatus**	36°
Sericostomatidae	*Chiloecia lacustris**	39°
	*Myotrichia murina**	33°
	*Notidobiella chacayana**	35°
	*Notidobiella parallelipipeda**	36°
	*Parasericostoma abruptum**	38°
	*Parasericostoma acutum**	36
	*Parasericostoma corniculatum**	38
	Parasericostoma cristatum	36°
	*Parasericostoma dinocephalum**	35°
	*Parasericostoma drepanigerum**	38°
	*Parasericostoma laterale**	38°
	Parasericostoma ovale	33°
	*Parasericostoma peniai**	36°
	*Parasericostoma rufum**	36°
Stenopsychidae	*Pseudostenopsyche davirosum**	35°, 36°
	*Pseudostenopsyche gracilis**	37°
Tasimiidae	*Tasimiidae penicillata**	35°, 36°
	*Trichovespula macrocera**	33°, 36°

Source: Flint *et al.* 1999; Rojas 2006; Holzenthal 2004; *= endemic species of the ChMZ).

Information on other groups of aquatic insects is scarce. Jerez & Moroni (2006) recognized 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 between ChMZ, southwestern Australia, and the Mediterranean Basin. Despite the limited knowledge and of the group, and the problems associated with chironomid taxonomy, Puntí collected 24 Chironomidae genera in 11 sites belonging to four 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 these two med-regions (Brundin 1966). Thus, the genera *Aproteniella*, *Stictocladius*, and *Botryocladius* are considered Gondwanaland elements and are currently shared by Australia, South American, and New Zealand (Edward 1989; Cranston & Edward 1992, 1999). The ChMZ and southwestern Australia med-regions also had similar rarified richness values that were lower than that found in the Mediterranean Basin (Puntí 2007).

Other invertebrates

The knowledge of non-insect aquatic invertebrates is scarce in Chile and information is only available for mollusks and some crustacean groups. A total of 75 species of freshwater mollusks occur in Chile. Their distribution varies latitudinally from north to south, with a greater concentration between latitudes 26º and 44ºS (Fuentealba *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. Hyriidae only represented by a single genus with two species (*Diplodon chilensis* and *D. solidulus*), whereas Sphaeriidae is composed of 3 genera and 11 species. *Pisidium chilense*, *P. huillichum*, and *P. llanquihuensis* are endemic to the ChMZ. However, Parada & Peredo (2006) pointed out that there is a significant lack of information from freshwater molluscs between 18º and 35ºS, which covers an important 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. Planorbiidae is distributed between the northern regions of Chile and the ChMZ, with *Biomphalaria chilensis* being the only species in the ChMZ. The family Ancylidae (*Uncancylus gayanus*), which has a more reduced distribution range, has 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 are better 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 very abundant in the ChMZ but not exclusively found in this area. *Samastacus spinifrons* is distributed from the Aconcagua River basin to Chiloé; *Parastacus pugnax* is distributed within the wetlands in Central Valley to the Toltén River; and *Aegla pewenchae* is located between the cities of San Fernando and Concepción. In contrast, *A. bahamondei* and *A. occidentalis* are endemic of particular coastal river basins in the ChMZ (Tucapel-Paicaví river and Lleu-lleu lake basins) (Smith-Ramírez *et al.* 2005). In addition, *A. expansa*, *A. concepcionensis*, and *A. laevis Talcahuano* 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. concepcionensis* are identified as extinct, whereas *S. spinifrons* and *A. bahamondei* are considered as vulnerable (Jara *et al.* 2006).

Amphipods have been scarcely studied in Chile. Gonzalez (2003) provides the most complete information of 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 recorded in the ChMZ: *Rudolphia macrodactylus* (Grosso & Peralta 2009) and *Ruffia patagonica* (Bréhier *et al.* 2010).

VERTEBRATES

Amphibians

Fifty-nine amphibian species are recognized for Chile, with 60.7% endemic (Ortiz & Díaz-Páez 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 endemicity, 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 recognized at least two new species in primary forests of the coastal ranges of the ChMZ.

Fish

The Chilean freshwater icthyofauna consists of 11 families, 17 genera, and 66 species (44 native and 22 exotic). Their altitudinal range does not exceed the 1500 m.a.s.l. A total of 20 native and 13 introduced species are recognized for the ChMZ (Table 7). Within the ChMZ, the southern part 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 anthropic pressures (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 19^{th} century for such diverse reasons as sport fishing, ornamental use, biological control, and aquaculture (Iriarte *et al.* 2005) (Table 7). The effects of introducing exotic fishes into native fish communities are very poorly understood but are supposed to be the drivers of local native fish extinctions (Ruiz 1993; Soto *et al.* 2006). In addition, Figueroa *et al.* (2010) showed an elevated diet overlap between native and introduced fish species in a river of ChMZ, which resulted in a significant negative impact on native communities.

According to Dyer (2000), Chilean icthyofauna 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 does not match geological studies that evidence a gradual raising of the Andes Mountains during lower Miocene (Jordan & Gardeweg 1989; Lundberg *et al.* 1998), and other geological events that have conditioned the current isolation pattern 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 has many endemics (Quezada-Romegialli *et al.* 2010). This pattern, together with the small body size of species, has been related to the geographic isolation of the country and to the presence of rivers with high discharge values (Habit *et al.* 2006b; Vila *et al.* 2006). The geographic isolation of Chile has resulted in species distributions very restrict. For instance, *Bullockia maldonai* is only found in the Itata and Cautín River Basins in the ChMZ (Habit *et al.* 2006b). On the other hand, recent genetic studies on *Trichomycterus areolatus* and *Basilichthys microlepidotus* have also shown genetic isolation among ChMZ basins. For this reason, further 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) showed that the ChMZ will be one of the most affected are in Chile by the global temperature increase. The 0ºC isotherm has been already moved in altitude (*ca.* 300 to 500 m; CONAMA 2006) and therefore a higher amount of precipitation falls as rain instead of snow. The discharge of the rivers flowing from the Andes foothills in the ChMZ is expected, 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.

Table 7. Native and introduced fish species identified in several river basin of the Chilean Mediterranean Zone.

Native species	**Aconcagua**	**Maipo**	**Rapel**	**Mataquito**	**Maule**	**Biobío**	**Itata**
Basilichthys australis	x	x	x	x	x	x	x
Brachygalaxias bullocki					x	x	x
Bullockia maldonadoi						x	x
Cheirodon australis					x	x	x
Cheirodon galusdae					x	x	x
Cheirodon pisiculus		x	x	x			
Diplomystes chilensis		x	x	x	x	x	x
Diplomystes nahuelbutaensis						x	x
*Eleginops maclovinus**				x			x
*Galaxias maculatus**	x	x	x	x	x	x	x
*Geotria australis**	x	x	x	x	x	x	x
*Mugil cephalus**	x	x	x	x	x	x	x
Nematogenys inermis	x	x	x	x	x	x	x
Odontesthes debueni	x	x	x	x	x	x	x
Odontesthes maleanum	x	x	x	x	x	x	x
Percichthys melanops				x			x
Percichthys trucha	x	x	x	x	x	x	x
Percilia gillissi		x	x	x			x
Percilia irwini					x	x	
Trichomycterus aerolatus	x	x	x	x	x	x	x
Introduced species	**Aconcagua**	**Maipo**	**Rapel**	**Mataquito**	**Maule**	**Biobío**	**Itata**
Ameiurus nebulosus		x					
Carassius carassius	x	x	x	x	x	x	x
Cauque mauleanum							
Cnesteredon decenmaculatus	x		x				
Cyprinus carpio	x	x	x	x	x	x	x
Gambussia affinis	x	x	x	x	x	x	x
Ictalarus nebulosus					x		
Odonthestes bonariensis	x	x	x			x	
Oncorhynchus mykiss	x	x	x	x	x	x	x
Percichthys melanops		x					
Salmo trutta	x	x	x	x	x	x	x
Trichomycterus chiltoni					x	x	

*: Associated to the estuary zone; Source: DGA (2004), Ruiz & Marchant (2004), CONAMA (2009), EULA (2009), and Habit & Ortíz (2009).

The Andean foothills of the ChMZ correspond to one of the area in the country with the greatest productivity from the forest-farming point of view. Moreover, a great percentage of hydroelectric generation of Chile (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 is also extended to the summer period throughout the territory between 38º and 40ºS and further north in the Andean sector. McPhee *et al.* (2010) indicated that for the Maule and Laja River basins, a 40% reduction in the availability of the water resource is expected. In the Laja River basin, a greater increase of the temperatures will be added. In addition, Garreaud & Falvey (2009) has indicated that climate change models are more unpredictable in the Pacific Southeast, because there is a dependency from La Niña phenomenon, supposing the intensification of the South Pacific anticyclone in the last 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.

Pollution and pressures

The history of the environmental protection in Chile has been brief. The first Environmental Law was approved in 1994, and the first "Norm for the Protection of the Surface water Quality" is still under development (CONAMA 2004). Actually, there is not any legal document in Chile that aim to protect river basins in the country. More than 2/3 of the Chilean population inhabits in the ChMZ and most of both domestic and industrial wastewaters are discharged into the main rivers and tributaries. Diffuse pollution from the agricultural sector together with pollution by hazardous and liquid industrial wastes is also important in particular river basins (e.g., the Maipo and Rapel River basins; CONAMA 2007, 2008, 2009).

Bioassessment approaches are being investigated in several rivers of the ChMZ. However, most of this work is entirely done for research purposes and, although outputs are transferred to local and national administrations, their implementation is still not feasible. Regarding the Biobío River basin, several works have been focused on the study of the ecological quality of several rivers (Parra *et al.* 1993a, 1993b; Vighi *et al.* 1993), proposing management strategies and recognizing areas under pressure. The Biobío River basin is the most important hydrologic system in Chile, covering 24,260 km^2. It is one of the most disturbed large rivers in Chile by industrial and urban effluents, and by flow regulation for hydropower generation and irrigation (Parra *et al.* 2009). Nutrients are present at very low concentration in the upper section of the Biobío River but the concentration of nitrogenated compounds (ammonium, nitrite, nitrate, total nitrogen and total phosphorous) 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 nutrient values are close to eutrophication levels. Phenolic compounds also show a clear trend to increase towards the lower part of river. Other relevant water quality variables, however, like heavy metals, hydrocarbons, and pesticides presented very low values or are under the detection limits of methods. During the last decade, pull mill doubled its production in the Biobío River basin (over 1.800.000 ton/year; Parra *et al.* 2009). Despite such drastic increase in production, water quality parameters directly associated to cellulose mills have not shown any variation respect to historical levels, showing the effect of new cleaner technologies used in such processes. A number of researches dealing with biomarkers and ecological status of aquatic biota have also been conducted in the Biobío River basin, showing large-scale and long-term effect 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 have in some degree of alteration of natural flow regimes by dams (Table 8). Hydroelectricity generation represents about 70% of the energy used in the country, about 60% generated only in the Biobío River basin. In this sense, a great part of that the headwaters sustaining significant biodiversity with many endemics converge in large dams.

From a river conservation point of view, there are no development policies in Chile. River conservation depends on the National System of Protected Areas of the State (SNASPE), which represents the main tool for biodiversity protection by means of administration and management of natural areas nationwide. Chile has 36 national parks, 49 reserves, and 15 natural monuments (CONAF 2010). From these natural areas, 4, 19, and 1 are found in the ChMZ, respectively. However, only 19% of the surface of the Chilean surface is found under some degree of protection and only 0.3% (Table 8) is located in the ChMZ (INE 2012). In addition, by means of the RAMSAR convention, Chile has subscribed 12 sites. From these, 2 are located in the ChMZ, representing the 0.8% of the total protected surface in the country.

Table 8. Number of cadastral reservoirs in the Chilean Mediterranean Zone.

Administrative region	Number of dams	% of dams within the ChMZ	% SNASPE respect to regional surface	% SNASPE respect to national surface
V of Valparaíso (Aconcagua Basin)	218	24.8	2.7	0.1
Metropolitana de Santiago (Maipo Basin)	138	15.7	0.9	0.0
VI of O'Higgins (Rapel Basin)	70	8.0	2.8	0.1
VII del Maule (Maule Basin)	212	24.1	0.6	0.0
VIII del Biobío (Itata and Biobío basins)	242	27.5	2.9	0.1
Total Mediterranean region	880	100.0		0.3

Source: DGA (2010) based on several studies and satellite data, and INE (2012) in this annual report on the environment. (SNASPE: National System of Protected Areas of the Chilean State).

CONCLUSIONS

There are numerous med-rivers in the ChMZ that remain completely unexplored. Taxonomic specialists are scarce and the little information available on freshwater biodiversity comes from studies no directly addressing biodiversity issues but other objectives. Research funding has a strong biotechnological and applied character and is not focused on the knowledge of natural systems, their biodiversity, and services. Despite all these challenges, the existing knowledge already evidence that the ChMZ has high levels of endemism in a reduced geographic area, with many primitive fauna of Gondwanic origin (Valdovinos 2008). Many freshwater groups have more affinity with fauna from New Zealand and Australia than with the rest of South America (Fittkau 1969; Zwick 2000).

Our revision indicates that there is detailed information on specific invertebrate groups, such as mollusks (Fuentealba *et al.* 2010), Plecoptera (Palma & Figueroa 2008), and Trichoptera (Flint 1999), but most groups remain unknown. In this sense, the ChMZ is presented as an exceptionally place for performing taxonomic and ecological studies because its potential high levels of biodiversity and endemism. Thus, in our analysis we have identified a 28.6% of Ephemeroptera, 10.4% of Plecoptera, and 68.53% of Trichoptera endemic species in the ChMZ. The level of endemism is expected to increase or decrease as more rivers of the whole country are explored.

Vertebrates have been more studied in the ChMZ, especially anurans (Ortiz & Díaz-Paez 2006; Vidal *et al.* 2009) and fish (Habit *et al.* 2003, 2007). The southern part of the ChMZ (Concepción Province) and its prolongation southwards (Valdivia Province) appears as one of the most diverse area for fish in Chile and it has been recognized as one of the diversity hotspots in the world (Myers *et al.* 2000). However, it must be taken into account that in both provinces there are universities with long tradition of local fish specialists (e.g., †Hugo Campos).

From the conservation point of view, only some fish, amphibians, and crustacean species have some type of protection. The rest of the invertebrates are completely ignored in the Chilean red list. In addition, protected areas are also scarce in Chile and only represent the 0.3% of the national territory surface (INE 2012). The ChMZ is being heavily exploited for mining, agriculture, and hydroelectric projects with a high economic investment and ignoring freshwater biodiversity. These projects, together with the fast contamination rate 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 freshwater biodiversity protection and conservation.

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CHAPTER 3. EFFECTS OF WATER WITHDRAWALS BY AGRICULTURAL ACTIVITIES IN THE FLUVIAL HABITAT OF BENTHIC MACROINVERTEBRATES OF CENTRAL CHILE

Meyer Guevara-Mora; Pablo Pedreros, Roberto Urrutia, Ricardo Figueroa

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ABSTRACT

The climatic and geographic characteristics of the Central Chile allows the concentration of agriculture activities and high flow demand from low order rivers. This combination of factors are closely related to profound changes in the fluvial habitat characteristics of the MIB. We expect that changes in the MIB diversity parameters or biotic indices (CHSIGNAL and EPT) could reflect the modification of river channels by water withdrawals for agricultural purposes. We sampled 3 sites with different % of water abstraction during austral spring, summer and winter in the Itata basin. We determined statistical differences ($p<0.05$) in some habitat parameters like depth, current velocity, Froude number, wetted width/depth ratio and dissolved oxygen parameters. Only Shannon and Simpson diversity parameters shows statistical differences in control and impact reach sections of the sampling sites. We suggest the use biological traits in order to determine specific relationships between water withdrawals and environmental changes in low order rivers of Chile affected by water withdrawals.

Keywords

Water withdrawals, benthic macroinvertebrates, Mediterranean climate, stream disturbance, Chile.

INTRODUCTION

The benthic macroinvertebrates in Chile are characterized by a limited geographic distribution in the Mediterranean area (Valdovinos 2008; Figueroa *et al.* 2013). Some groups like Plecoptera (Palma & Figueroa 2008), Trichoptera and Ephemeroptera (Figueroa *et al.* 2013) show the maximum diversity and species richness in the central area of the country, a Hot Spot for biodiversity conservation (Myers *et al.* 2000). However, the climatic and geographic conditions also promotes the concentration of agriculture activities with direct effects in the rivers biodiversity conservation (García *et al.* 2011; Habit *et al.* 2006).

The rivers contamination by nitrate and phosphate compounds is the principal threat associated to agriculture activities (Dudgeon *et al.* 2006; Vörösmarty *et al.* 2010). In several basins of the central zone of Chile, the levels of these compounds do not represent a hazard condition (Pizarro *et al.* 2010; Ribbe *et al.* 2008), but the variation of the river flow could increase the probability of future effects in the morphological and hydraulic characteristics of low order rivers in the zone (Andreoli *et al.* 2012).

The natural flow regime is fundamental in rivers conservation because generate shifting habitat conditions (Parsons *et al.* 2005; Poff *et al.* 1997; Stanford *et al.* 2005; Townsend *et al.* 1997) which increases the aquatic biodiversity (Death 2010; Townsend *et al.* 1997). Most of the scientific literature about the flow modification of rivers in Chile show the relation between aquatic fauna and hydroelectric dams (Andreoli *et al.* 2012; García *et al.* 2011; Habit *et al.* 2007). In Laja and Rucúe rivers, the construction and operation of diversion dam modifies fish species composition (Habit *et al.* 2007), and in Biobío river, daily peaks of electric generation produces changes in the hydraulic and physical habitat characteristics (García *et al.* 2011). However, agriculture water abstraction is a long neglected environmental issue, despite the high demand and low water return in low order rives in Mediterranean Chile.

Similar to other world regions (Chessman *et al.* 2011; Dewson *et al.* 2007a), in the central zone of Chile there are a lot of irrigation users which collect water from low order rivers in base flows of spring and summer (Figueroa *et al.* 2007). This geographic dispersed environmental impact could change the physical characteristics of low order rivers and also could change the habitat characteristics of benthic macroinvertebrates. Thus, the aim of our study is to determine the effects of water abstraction in the habitat of benthic macroinvertebrates in low order rivers of central zone of Chile. We also want to determine the relationship between macroinvertebrate biotic indices (CHSIGNAL and EPT) and flow reduction to improve the conservation of Mediterranean rivers in Chile.

METHODS

Characteristics of the sampling sites

The sampling sites were located in the Itata basin, a Mediterranean climate area with annual average temperature of 14.1 °C and 1550 mm of precipitation (Di Castri & Hajek 1976; Urrutia *et al.* 2009). Native forests of evergreen *Drimys winteri* and *Nothophagus* spp. are present in the foothills of the basin, while agriculture landscapes are common in the central valley (Figueroa *et al.* 2013). According to Figueroa *et al.* (2007) and Debels *et al.* (2005), changes in the water quality are related to the sewage discharges from Chillán city and non-natural variations of the low flow period (spring/summer).

We selected 3 sites with different % of water abstraction with small weirs (Deh: 36° 44' 25.74''S - 71° 49' 11.36''O, Rec: 36° 50' 21.99''S - 71° 38' 38.07''O and Mar: 36° 54' 26.33''S - 71° 32' 3.23''O). The small weirs were constructed with boulders, sand bags or wood. Only Rec site is partially sealed in the winter to protect the irrigation channel; meanwhile, Deh and Mar channels are protected by steel doors and sand bags in the channel which sealed the irrigation channels. The river bed is composed by a combination of cobbles with riffle and pool alternation.

Habitat sampling strategy

In all the sampling sites, we selected a 100 m reach section before (control) and after (effect) the weirs. According to Dewson *et al.* (2007c), 100 m reach section is enough area to observe the effects of water abstraction and gives no chance to recover the flow by groundwater influence. We collect nutrient and suspended sediment water samples in March (low flow) and August 2013 (high flow) to characterize the sampling sites. Water samples were kept cold until their analyses with colorimetric techniques in the Environmental Chemistry Laboratory, EULA Center for Environmental Sciences, University of Concepción (Greenberg *et al.* 2005).

We recorded the habitat characteristics in spring/summer: October, December 2012, March 2013 (low flow) and also we compare with no water abstraction period in winter, August 2013 (high flow). The stream discharge (L/s) was determined in the control and impact reach sections by 10 equidistant measurements of the depth and current velocity (0.6 depth) with a Flow Velocity Indicator Gurley 1100.1 (Gore 2007). Morphological habitat characteristics in control and impact reach sections corresponds to river wetted width, water depth, current velocity; the chemical and physical parameters were temperature, conductivity (Hanna Instruments HI 9835), pH (Hanna Instruments HI 9126) and dissolved oxygen (Hanna Instruments HI 9146). All the parameters were registered in the sampling dates in 6 random points in each reach section of the sampling sites. Additional chemical characteristics of the sampling sites was determined in low and high flow period with analytical methods in the Laboratory of Environmental Chemistry, EULA Center.

Macroinvertebrate sampling

We sampled benthic macroinvertebrate community for each stream reach section in all the sampling dates. All the macroinvertebrate sampling points were near to habitat sampling points. A Surber sampler (mesh size=250 µm) was placed in 6 random points to remove organisms in 0.09 m^2 area. The organisms collected were fixed in 95% alcohol, transported to Bioindicators Laboratory in the EULA Center for Environmental Sciences. We identify the macroinvertebrates up to family level with the available taxonomic literature (Domínguez *et al.* 2006; Stark *et al.* 2009) due to the scarce taxonomic knowledge of the Mediterranean area and high endemic condition (Figueroa *et al.* 2013).

The biodiversity indices of Shannon (H') and Simpson (D') were calculated in the samples, also we registered the abundance and family richness to describe the changes between control and impact reach sections. According to McKay & King (2006), the orders Ephemeroptera, Plecoptera and Trichoptera are sensitive to disturbances in the flow condition, so we calculated the number of families of the 3 orders in the samples. To assess the sensitivity of biotic indices we selected the CHSignal, an adaptation of the SIGNAL index (Chessman 2003) with Chilean benthonic macrofauna, used in the evaluation of the water quality in Chile (Figueroa *et al.* 2007).

Data analysis

To assess the relation between the habitat variables and flow (L/s), a Pearson correlation was used ($R>0.8$; $p<0.05$). In the rest of the analyses, two data matrices were used, 1) aggregated data of all the sites in order to detect a general response of the streams of the area, and 2) separated data of every site to define specific responses to low flow conditions.

The statistical difference between the control and impact reach sections in low flow were calculated with the Student t-test ($p<0.05$), but the differences between low flow (spring/summer) and high flow (winter) conditions were calculated with ANOVA BACI design (Downes 2002). In the BACI model for statistical differences, B corresponds to each of the sampling dates in spring or summer, A is the sampling date in high flow period (winter), C refers to control reach sections and I is the impact reach sections. Therefore, a significant difference in the BA x CI indicated that the change in the environmental parameter is associated to water withdrawals (Downes 2002).

The relationship between habitat parameters, biotic and diversity indices was established with a Multiple Linear Regression analysis, Akaike Information Criterion and the Forward/Backward selection in the statistical package MASS (Venables & Ripley 2002). The most important environmental predictor was determined from the previous selected variables with all-subsets regression model in LEAPS R statistical package ($p<0.05$).

The differences in the macroinvertebrate community assemblage was determined with ADONIS statistical analysis (Anderson 2001); the comparisons were made in the Bray Curtis similarity matrix, abundance data was previously transformed with Log_{10} (x+1) for the values > 0 to reduce the contribution of the families with greater numerical representation in the samples (Anderson *et al.* 2006; Gauch 1982). The most important families in terms of the differences between control and impact reach sections were established by IndVal (Dufrene & Legendre 1997). IndVal method considers the abundance and relative frequency of the different families in each sample in order to assign an indicator value and a probability *p* derived from the Monte Carlo permutation.

RESULTS

The sampling reach sections showed flow variations in all sampling dates. The highest summer flow reduction was registered in Deh (97.7%), while the lowest value was in Rec (26.1%), both in December, 2012. In August, 2013 (winter period), we observed closed weirs in Mar and Deh; however, it was possible to record low water withdrawals (Table 1). Only water depth (R: 0.85; $p < 0.05$), current velocity (R: 0.84; $P < 0.05$) and conductivity (R: 0.65; $p < 0.05$) showed correlation with the flow. According to the chemical characteristics, Deh and Rec showed oligotrophic conditions in low and high flow periods (< 0.03 mg/L NH_4^+, < 0.2 mg/L NO_3^- , <0.04 mg/L PO_4^{3-}); meanwhile, in Mar the concentration of NO_3^- (0.384 mg/L) and PO_4^{3-} (0.13 mg/L) tends to decrease in the high flow period (0.293 mg/L NO_3^- and 0.06 mg/L PO_4^{3-}) (Table 9).

Table 9. Environmental characteristics of the sampling sites in low (March 2013) and high flow (August 2013) hydrological condition

Date/ Site / Reach			NO_2 (mg/L)	NO_3^- (mg/L)	NH_4^+ (mg/L)	Organic N (mg/L)	Total N (mg/L)	Organic P (mg/L)	Total P (mg/L)	PO_4^{3-} (mg/L)	Suspended solids (mg/L)
March	Mar	Control	**0.015**	0.384	**0.03**	0.04	0.15	0.04	0.12	0.13	**1.0**
		Impact	**0.015**	0.384	0.03	0.06	0.17	0.03	0.11	0.13	**1.0**
	Rec	Control	0.077	0.039	**0.03**	0.03	0.09	0.02	0.03	**0.04**	1.0
		Impact	0.076	0.038	**0.03**	0.03	0.09	0.01	0.02	**0.04**	**1.0**
	Deh	Control	**0.015**	0.025	**0.03**	0.04	0.07	**0.01**	0.04	**0.04**	4.3
		Impact	**0.015**	0.037	**0.03**	0.04	0.08	0.01	0.05	**0.04**	5.0
August	Mar	Control	**0.015**	0.293	**0.03**	0.01	0.10	0.04	0.06	0.06	1.2
		Impact	**0.015**	0.202	**0.03**	0.03	0.10	0.03	0.05	0.05	1.0
	Rec	Control	**0.015**	0.139	**0.03**	**0.01**	0.06	0.01	0.02	**0.04**	2.0
		Impact	**0.015**	0.410	**0.03**	**0.01**	0.12	**0.01**	0.01	**0.04**	2.3
	Deh	Control	**0.015**	0.101	**0.03**	0.04	0.09	**0.01**	0.01	**0.04**	1.0
		Impact	**0.015**	0.121	**0.03**	0.03	0.09	**0.01**	0.01	**0.04**	**1.0**

Note: In bold values under detection limit

Most of the habitat variables showed variation between control and impact reach sections (Table 10). We registered differences of more than 10% in variation coefficient (control <impact) for depth, current velocity, wetted width/depth ratio, Froude number, richness, abundance and EPT. The t-test indicated that water abstraction affects habitat parameters like DO, depth, hydraulic Froude number, current velocity and wetted width/depth ratio. It was not possible to detect differences in the EPT and CHSignal biotic index (Fig. 6). In the comparison between low and high flow sampling dates with ANOVA BACI design, only current velocity showed significant differences in 2 different sampling dates (October 2012 and March 2013). No statistical differences were detected for water temperature, wetted width and hydraulic Froude number in December 2012 (Table 11).

According to linear regression models, the habitat parameters were good predictors of community assemblages; however, it was not possible to establish a model for community assemblage descriptors. The best significative model (R^2: 0.37) was determined for CHSignal index (pH and DO), while the lower explanatory power of the models was recorded for Shannon diversity (R^2: 0.19) (Table 12).

Table 12. Mean ($\bar{x}$), standard deviation (SD) and variation coefficient (CV) of the habitat characteristics and community assemblage descriptors in control and impact reach sections in low flow sampling dates.

Parameters		Recinto		Marchant		Dehesa		All sites	
		Control	Impact	Control	Impact	Control	Impact	Control	Impact
Dissolved oxygen (mg/L)	$\bar{x}$	11.42	10.72	10.02	10.15	10.54	10.08	10.66	10.31
	SD	0.49	0.32	0.41	0.35	0.31	0.60	0.71	0.52
	CV (%)	4	3	4	3	3	6	7	5
Temperature (ºC)	$\bar{x}$	10.11	10.88	13.83	13.69	16.29	15.85	13.41	13.47
	SD	0.99	2.41	0.71	0.63	2.94	3.09	3.13	3.04
	CV (%)	10	22	5	5	18	19	23	23
pH	$\bar{x}$	7.23	7.52	7.81	7.80	7.74	7.70	7.59	7.67
	SD	0.22	0.16	0.27	0.31	0.22	0.13	0.35	0.24
	CV (%)	3	2	3	4	3	2	4	3
Conductivity (µScm^{-1})	$\bar{x}$	36.56	38.41	228.7	229.2	118.4	118.9	127.9	128.8
	SD	1.69	4.31	23.22	22.18	17.13	16.62	81.16	80.53
	CV (%)	5	11	10	10	14	14	63	62
Wetted width (cm)	$\bar{x}$	358.2	295.3	753.6	717.9	459.2	716.0	523.6	576.4
	SD	145.65	68.04	93.7	58.54	272.4	231.3	249.2	245.0
	CV (%)	41	23	12	8	59	32	47	42
Depth (cm)	$\bar{x}$	19.53	21.17	32.53	26.14	29.06	13.94	27.04	20.42
	SD	6.09	9.46	7.51	9.29	10.01	4.71	9.64	9.43
	CV (%)	31	45	23	35	34	34	36	46
Current velocity(m^3s^{-1})	$\bar{x}$	0.39	0.24	0.73	0.51	0.46	0.21	0.53	0.32
	SD	0.16	0.09	0.25	0.43	0.27	0.13	0.27	0.30
	CV (%)	41	40	34	85	60	61	51	92
Width/depth ratio	$\bar{x}$	20.33	15.77	24.73	31.64	17.71	61.68	20.92	36.36
	SD	10.50	5.59	8.20	13.72	13.94	36.82	11.31	29.57
	CV (%)	52	35	33	43	78	60	54	81
Froude #	$\bar{x}$	0.30	0.17	0.41	0.23	0.30	0.18	0.34	0.23
	SD	0.14	0.07	0.14	0.75	0.20	0.11	0.17	0.17
	CV (%)	50	43	34	75	69	61	51	74
Richness	$\bar{x}$	16.44	16.11	13.3	11.33	12.56	10.94	14.09	12.80
	SD	2.68	4.24	3.40	4.10	2.38	2.66	3.28	4.36
	CV (%)	16	26	26	36	18	24	23	34
Abundance	$\bar{x}$	265.4	145.1	289.5	387	195.7	108.8	250.2	213.7
	SD	197.05	90.12	239.5	352.4	212	88.19	216.7	246
	CV (%)	74	62	83	91	100	81	87	100
Shannon (H')	$\bar{x}$	2.19	2.06	1.76	1.59	1.98	1.88	1.98	1.84
	SD	0.29	0.41	0.30	0.33	0.31	0.20	0.35	0.38
	CV (%)	14	20	17	21	16	10	17	20
Simpson (D)	$\bar{x}$	6.84	5.72	4.53	3.98	6.02	5.11	5.80	4.93
	SD	2.28	2.56	1.43	1.26	2.13	0.99	2.17	1.85
	CV (%)	33	45	31	32	35	19	37	38
EPT	$\bar{x}$	8.28	8.11	6.27	5.66	4.00	3.89	6.18	5.89
	SD	1.60	2.37	1.96	2.40	1.08	1.32	2.35	2.69
	CV (%)	19	29	31	42	27	34	38	46
CH SIGNAL	$\bar{x}$	6.68	6.45	5.63	5.37	6.10	6.14	6.14	5.99
	SD	0.48	0.71	0.60	0.49	0.48	0.53	0.67	0.74
	CV (%)	7	11	11	9	8	9	11	12

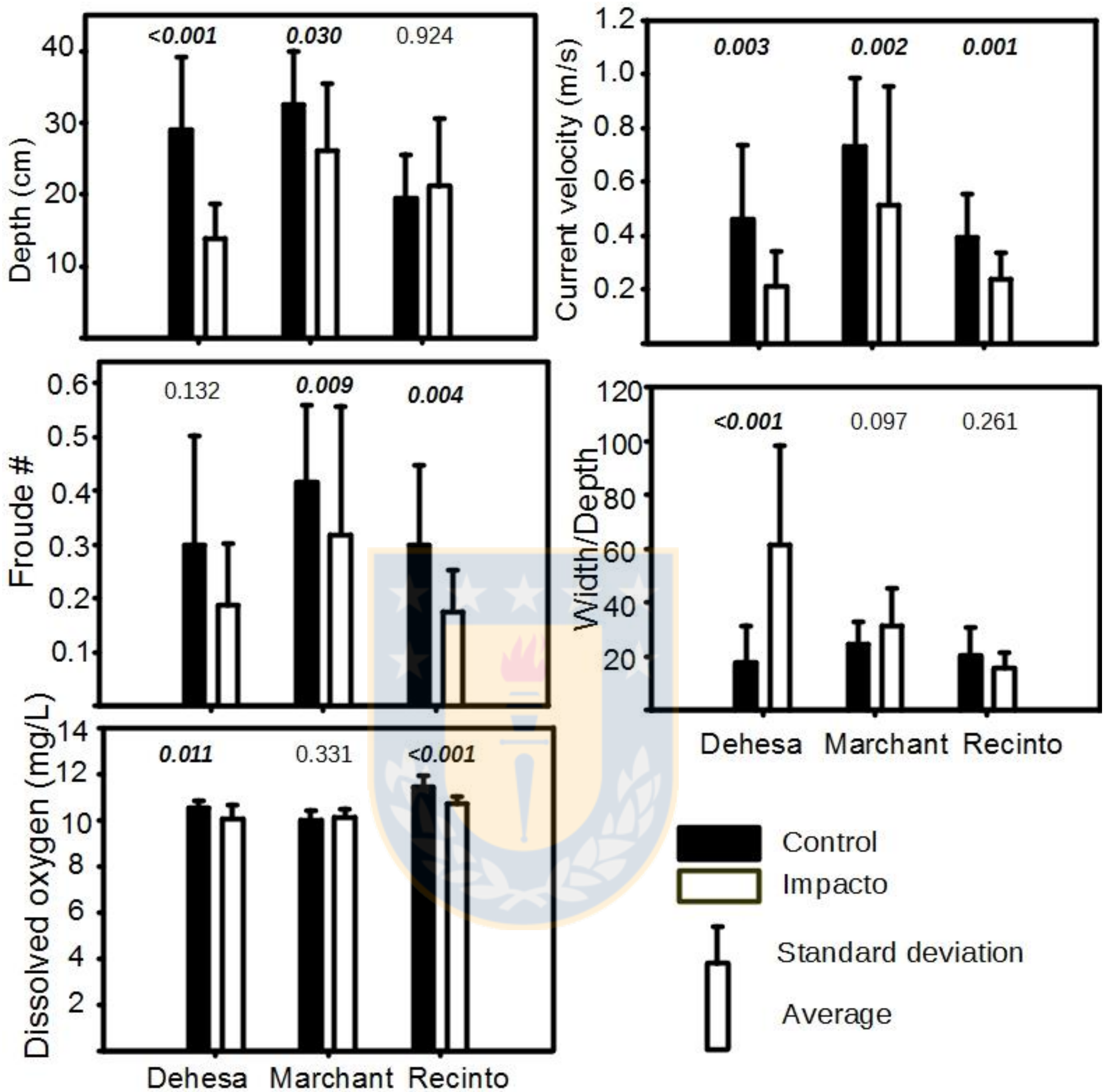

Figure 6. Habitat parameters and diversity indices with *T test* statistical significant differences ($p<0.05$) between control and impact reach sections in low flow period.

Table 11. Summary of ANOVA test for BA x CI comparison (*: < 0.05; **:< 0.01) in control and reach sections of all the sampling sites.

	October 2012		December 2012		March 2013	
	F	p	F	p	F	p
Dissolved oxygen (mg/L)	***4.83***	***0.032 ****	2.57	0.110	0.87	0.350
Temperature (°C)	2.65	0.110	0.03	0.870	0.32	0.570
pH	***12.21***	***<0.001 *****	0.57	0.450	0.03	0.860
Conductivity (µS/cm)	***4.31***	***0.042 ****	0.45	0.510	0.05	0.830
Wetted width (cm)	0.94	0.340	0.44	0.500	0.75	0.390
Depth (cm)	1.57	0.220	3.83	0.055	***8.4***	***0.005****
Current velocity (m/s)	***4.51***	***0.038 ****	3.27	0.075	***7.83***	***0.007****
Width/depth ratio	2.28	0.140	3.17	0.080	***6.06***	***0.016****
Froude number	3.25	0.076	1.63	0.206	2.92	0.092

Table 12. Multiple linear regression and single best parameter for all the sampling sites in the low flow time

	Chemical parameters				Physical parameters					Statistical analysis		
	OD	Temp	Cond	pH	Vel	Wid	Dep	Fr	Wid/Dep ratio	R^2	p	Slope
Richness	X		✓				X	X		**0.22**	**<0.001**	-
Abundance					X		X	✓		**0.20**	**<0.001**	+
Shannon	X	X		X	X	✓	X	X	X	**0.19**	**<0.001**	-
Simpson	X	X		✓	X			X		0.06	0.070	-
EPT	X			✓		X	X	X	X	**0.25**	**<0.001**	-
CHSignal	✓			X						**0.37**	**<0.001**	+

Note: Dissolved oxygen (OD), temperature (T), conductivity (Cond) and pH. Water velocity (Vel), wetted width (Wid), depth (Dep), Froude number (Fr), Wetted width/depth ratio (WW/Dep). The value of R^2 correspond to the Adjusted R^2. Statistical significance of the multiple regression model are denoted (p). The significant parameters of multiple regression are marked (X), also the best singular parameter (✓).

The benthic macroinvertebrate community was composed of 41133 individuals, distributed in 10 orders and 49 families. The order with the highest abundance was Diptera (n= 16465) followed by Ephemeroptera (n= 7371), Trichoptera (n= 7122) and Plecoptera (n= 6486). Approximately 35% of the collected families has endemic species distributed in the sampling area, also Calamoceratidae (*Phylloicus aculeatus*) could be a new report of the distributional range of this family in the Mediterranean area of Chile. It was possible to determine that impact reach sections showed the highest abundance of Baetidae, Leptophlebiidae (Ephemeroptera), Gripopterygidae and Notonemouridae (Plecoptera) in samples of low flow period. The comparison of macroinvertebrate assemblage between low and high flow periods allowed us to establish significant differences in October and December 2012, while in March the differences were determined for the control and impact reach sections (Table 13).

IndVal test determined that Notonemouridae (Plecoptera; IndVal: 0.385, p: 0.004) was a good indicator of impact reach sections and Diamphipnoidea (Plecoptera; IndVal: 0.630, p: 0.002) or Glossosomatidae (Trichoptera; IndVal: 0.394, p: 0.036) in the control reaches of all the sites.

Table 13. Summary of ADONIS test for statistical differences ($p<0.05$) in the macroinvertebrates assemblage between reach sections in low and high flow sampling dates

	October 2012		December 2012		March 2013	
	R^2	p	R^2	p	R^2	p
Before –After (BA)	0.107	**0.001**	0.085	**0.013**	0.104	**0.001**
Control – Impact (CI)	0.029	**0.003**	0.027	**0.001**	0.009	0.474
BA x CI	0.028	**0.003**	0.026	**0.022**	0.009	0.436

DISCUSSION

The variation of natural flow regime affects the chemical characteristics of the rivers (Bunn & Arthington 2002; Dewson *et al.* 2007a; Larned *et al.* 2010). Scarce water availability produce temporal and spatial changes in some parameters like nitrogen compounds (Caruso 2002; Dahm *et al.* 2003; Schiller *et al.* 2011), similar trends are expected in rivers influenced by anthropogenic water withdrawals in agricultural landscapes. Despite our sampling sites showed high water abstractions, it was not possible to detect variations in most of the nutrients.

In the Itata river basin, it was not possible to detect diffuse contaminations, but there are some punctual sewage discharges of Chillan city, which are related to incipient contamination (Debels *et al.* 2005; Figueroa *et al.* 2007; Urrutia *et al.* 2009). However, in other basins, the intense irrigation farming and multiple economical activities produced changes in nitrogen or aquatic fauna (Ribbe *et al.* 2008). Another factor that explains the condition of the sampling sites is the traditional construction system of water intakes. The absences of a reservoir to store water do not allow anoxic condition, which promotes changes in the ionic concentration of surface waters in large reservoirs (Ahearn *et al.* 2005; Friedl & Wüest 2002).

The DO concentration in the sampling sites could be an indicator of environmental stress by water withdrawals. Several authors indicate that DO concentration decrease in the impact reach sections (Dewson *et al.* 2007b; McKay & King 2006) in relation to reduced turbulence condition or increasing heating exposure in the impact reach sections (Brown *et al.* 2012; Chessman *et al.* 2010; Dewson *et al.* 2007b). Recently Pedreros *et al.* (2013) indicate that the absence of forest cover in high mountain rivers of the Mediterranean zone of Chile conditioned the thermal regimen in Andean streams.

The combination of current velocity, water depth and substrate roughness regulates the microhabitat conditions of benthic macroinvertebrates (Brooks *et al.* 2005) and DO concentration in streams (Allan & Castillo 2007). Froude number is positive related to the total abundance, it indicates the importance of the microhabitat characteristics in the patchy distribution of benthic fauna (Schwendel *et al.* 2010).

In the present research, we could not detect statistical differences in the total abundance or richness for the sampling sites in low flow period; however Ephemeroptera, Plecoptera and Trichoptera (EPT), most of them are filter feeding macroinvertebrates and they are more abundant in control reach sections. According to Growns & Davis (1994), high shear velocities and turbulent conditions are necessary to supply suspended food for passive filterers, while 90% of flow reduction generates filter feeding decrease and presence of predatory (Walters & Post 2011; Wills *et al.* 2006).

Increases in water velocity during the floods generates movement of the river bed with direct influence in the macroinvertebrate community (Death & Zimmermann 2005; Parsons *et al.* 2005; Schwendel *et al.* 2010). In our sampling sites, temporal variation of water abstraction and high flow period promotes a reset opportunity for the macroinvertebrate community to recolonize the sampling sites.

The principal mechanism for site recolonization is the active drifting. In other regions, the drift is an ecological process necessary to environmental assessment of river health (Death *et al.* 2009; Dewson *et al.* 2007b) and related to the water velocity (James *et al.* 2009). In Chile, the active drifting behavior is related to circadian cycle (Figueroa *et al.* 2000), but it is necessary more information about this dispersal mechanisms like functional bioindication technique.

The use of biotic indices are a common practice to determine the environmental impacts on surface waters (Bonada *et al.* 2006; Rosenberg & Resh 1993a). In Chile the CHSignal demonstrate sensibility to water pollution in semiarid rivers of the North of Chile (Alvial *et al.* 2013) or in the Chillán river, a tributary of Itata river (Figueroa *et al.* 2007). In our sampling sites, no significant differences in the reach sections would be related to the good chemical water condition and low sensitivity of biotic indices to morphology changes. Similar trends are determined for other biotic indices like RIVPACS (Armitage & Petts 1992) or AUSRIVAS (Chessman *et al.* 2010).

We also believe that the communities in the study area have suffered many years this kind of impact, so they have developed strategies to survive in adverse environmental conditions (Miller *et al.* 2007). In Mediterranean climate areas, seasonal predictable flow variations are closely related to macroinvertebrate biological or behavioral characteristics (Bonada *et al.* 2007), which give the opportunity to detect the magnitude of water abstraction (Doledec & Statzner 2010; Menezes *et al.* 2010). In contrast, Walters & Post (2011) indicated that trait and classical taxonomic approach give the same power to detect habitat changes in low flow condition, but they do not discard to evaluate specific traits like high crawling or armoring and resistance characteristics of MIB. In Chile, the low biological and taxonomic available information about several macroinvertebrates families affects the improvement of bioindication techniques (Stark *et al.* 2009). For example, Gripopterygidae family has a 55% of undetermined species (Vera & Camousseight 2006), but Growns & Davis (1994) determined positive correlation of this family with Froude number in Australian rivers. In addition, expected low rainfall and increased temperature (Figueroa *et al.* 2013; Pedreros *et al.* 2013) require improvement of bioindication techniques for the conservation of endemic macroinvertebrates in low order rivers of Mediterranean Chile.

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CHAPTER 4. INFLUENCE OF THE WATER ABSTRACTION IN THE MACROINVERTEBRATE TRAITS OF MEDITERRANEAN LOW ORDERS OF CHILE.

Meyer Guevara-Mora; Pablo Pedreros, Figueroa, R.

In preparation

INTRODUCTION

The flow regulation is a significant threat to the ecological integrity of the rivers (Biemans *et al.* 2011; Vörösmarty *et al.* 2010), specifically in the Mediterranean area because it plays a fundamental role in the structure of river characteristics (Barceló & Sabater 2010; Benejam *et al.* 2010; Brown *et al.* 2012) and composition of MIB (Bêche *et al.* 2006; Bonada *et al.* 2007; Resh *et al.* 2013). In this climate zone is recurrent the presence of periods of low flow associated to relative cyclic and stable climatic conditions (Bonada & Resh 2013), but the increase of water demand for agricultural activities tend to produce deleterious effects in the community parameters of MIB during the base flow period.

According to Figueroa *et al.* (2013), in the Mediterranean region of Chile are accounted ~ 62 dams on the principal rivers of the area, most of them to sustain the high concentration of agricultural activities. Perhaps, the biggest threat is found in the low order rivers, where is common the presence of water withdrawals with low technological development for flow regulation and extensive synergistic effects on the morphology of natural streams (Harden 2006), rarely evaluated by the traditional bioindication methods based on the composition of the MIB (Resh *et al.* 1995).

Bioindication methods assume that the presence/absence, abundance or behavior of a specific group of organisms gives the opportunity to detect the human intervention in the aquatic ecosystem, but the combination of annual climatic variation or presence of multiple stressors alter the ability to detect causal relationships. A novel bioindication method is the use of biological traits, based on the River Habitat Templet, which considers the environment as a filter, that select the biological or behavioral characteristics of the organisms to survive in different environmental stressors (Townsend & Hildrew 1994). The use of multiple traits to assess diverse environmental stressors is an important statement to consider the use of biological traits as a biondication suitable method for the river integrity (Menezes *et al.* 2010).

According to Walters (2011), an increase in the abundance of traits such a dessication resistance, high crawling rate and armoring is common areas with reduced river flows under controlled river conditions, similar to Miller *et al.* (2010) in a basin with intensive use of water for irrigation purposes. In this study we examine the importance of biological traits and community MIB parameters to detect the effects of reduced flow in 3 low-order rivers affected by reduced flow irrigation.

METHODOLOGY

Sampling sites

We selected low order rivers disturbed by agricultural water abstraction in the Itata basin, Chile (Dehesa: 36°44' 25.74"S- 71º49'11.36"O; Recinto: 36º 50’ 21.99’’S-71º38’38.07’’O; Marchant: 36º 54’26.33’’S-71º32’3.23’’O). In all the sites the diversion structures are constructed with wood and sand bags which partially dam the rivers and diver water to determined point.

The principal agriculture land cover is a combination of wheat, oats, potatoes and maize. Native forests patches of evergreen *Nothophagus* spp. and *Drymis winteri* are common in the foothills (Figueroa *et al.* 2013). The annual average precipitation was 1550 mm and snow melting in spring and summer reduces the presence of temporary rivers in the area. According to Figueroa *et al.* (2013) and Debels *et al.* (2005), low discharge values was common in spring and summer months when precipitation decreases and agriculture water demand increases.

Sampling design

In the sampling sites we selected two adjacent 100 m reach transect before (Control) and after (Impact) of the weirs (Dewson *et al.* 2007; Walters 2011). We sampled in 3 occasions every site during the austral spring and summer period (October and December 2012, March 2013), when the water diversions are open to supply agriculture demand. In order to define the effects of water withdrawals in the aquatic habitat, we measured the wetted width (cm), depth (cm), current velocity (m/s), temperature (°C), dissolved oxygen (mg/L, Hanna Instruments HI 9146), pH (Hanna Instruments HI 9126) and conductivity (µS/cm, Hanna Instruments HI 9835) in all the sampling dates. Additionally, we recorded water temperature with a data logger (HOBO Mod. UA-001-08; -20 to 70°C; precision ±0.5 ◦C) every 30 minutes in all the reach sections (period December 2012-December 2013).

Thermal heterogeneity in the control and impact reach section of each section was described by the accumulated degree-days due to its influence in the metabolism of macroinvertebrates (Caissie 2006). The flow reduction in control and impact reach sections was defined by the velocity-area method in 10 equidistant measures, 0.6 depth and current velocity with a Gurley 1100.1 Flow Velocity Indicator (Gordon *et al.* 2004; Gore 2007).

Invertebrate sampling

We collected benthic macroinvertebrates with a Surber net (area=0.09 m^2; mesh size= 500 µm) in six random points of the reach sections. In the laboratory, benthic macroinvertebrate samples was rinsed and determined to family level with available keys for South America fauna (Domínguez *et al.* 2006; Stark *et al.* 2009), as reliable taxonomic level in areas with scarce knowledge of macroinvertebrate natural history (Camousseight 2006; Domínguez *et al.* 2006; Tomanova *et al.* 2008) and simplified method for the study of macroinvertebrate studies in biomonitoring surveys (Brooks *et al.* 2011; Gayraud *et al.* 2003; Melo 2005; Walters 2011).

We registered the richness (S), abundance (n), biodiversity indices of Shannon (H'), Pielou (P) and Simpson (D') in the sampling reach sections. Also we counted the number of families from Ephemeroptera, Plecoptera and Trichoptera (EPT) due to their sensibility to low flow conditions (McKay & King 2006). The CHSignal biotic index, modification of the SIGNAL biotic index, was selected to define the importance of low flow conditions in the biotic integrity of sampling sites (Chessman 2003; Figueroa *et al.* 2007).

We assigned macroinvertebrates traits with available databases from North America (Bêche *et al.* 2006), Europe (Tachet *et al.* 2002), New Zealand (Doledec *et al.* 2006) and South America (Tomanova *et al.* 2008). The affinity of each category was defined with a fuzzy coding technique which gives the opportunity to reduce the error from different levels of available macroinvertebrates information (Chevenet *et al.* 1994). In the fuzzy coding 0 indicates no affinity and 3 high affinity for the organisms in the same family (Table 14).

Data analysis

We transformed the environmental parameters to reach the normality and reduce the effect of extreme values (Log_{10} transformation). Analysis of variance was used to compare control and impact reach sections in the sampling sites for biotic indices, community and environmental parameters; we accounted for statistical differences between control and reach sections in the different sampling dates (ANOVA, $p<0.05$).

The relationship between the environmental variables and benthic macroinvertebrates was established with the Redundancy analysis (RDA) (Ter Braak 1995) on Hellinger transformed abundance (Legendre & Gallagher 2001). We used the mean abundance in the sampling dates and avoid environmental variables collinearity selecting variables with Variance Inflation Factor < 10 (Borcard *et al.* 2011). The best explanatory variables was defined by Forward Selection (Packford package in R) and then related with the biotic macroinvertebrate families through the Weighted Average models (WARMs). WARMs was calculated to determine the optimum and tolerance of the macroinvertebrate to best explanatory variable (Ter Braak & Looman 1986). The WARMs method is an important biomonitoring tool which gives the chance to determine the Gaussian response of macroinvertebrates (Hamalainen & Huttunen 1996).

Table 14. Traits, categories (code) for benthic macroinvertebrates in the sampling sites based on Tomanova *et al.* (2008), Bêche *et al.* (2006) and Tachet *et al.* (2002).

Trait	Categories (Code)	Trait	Categories (Code)
1. Food	Sediment (S)	5.Body Flexibility (degrees)	None (<10)
	Fine detritus < 1 mm (FPOM)		Low (>10-45)
	Coarse detritus > 1mm (CPOM)		High (>45)
	Microphytes (MiPH)	6.Body Form	Streamlined
	Macrophytes (MaPH)		Flattened
	Dead animals (DA)		Cylindrical
	Microinvertebrates (MIIn)		Spherical
	Macroinvertebrates (MAIn)	7. Mobility and attachment to substrate	Fliers
2. Feeding habits	Collector-Gatherer (CG)		Surface swimmer (SwS)
	Shredder (SH)		Full water swimmer (SwW)
	Scraper (SC)		Crawler (Cl)
	Collector- Filterer (CF)		Epibenthic burrower (EpB)
	Piercer (PI)		Endobenthic burrower (EnB)
	Predator (PR)		Temporarily attached (TA)
3.Respiration	Tegument	8. Type of sclerotization	Totally sclerotized (Tescle)
	Gill		Eslerotized (Escl)
	Stigmata		Soft body (Su)
	2.5 – 5		Desiccation resistance absent (RDA)
	5 – 10	9. Current velocity preferences	Null
4. Body size (mm)	10 – 20		<25 cm/s (Len)
	20 – 40		25 - 50 cm/s (Med)
	40 – 80		> 50 cm/s (Rap)
	> 80		

The relationship between the environmental variables and macroinvertebrate traits was determined with "4th Corner method" (Dray & Legendre 2008; Legendre *et al.* 1997). This statistical method evaluated the null hypothesis Ho: species traits not related to environmental parameters, and assumes a relationship between the taxon distribution (taxa vs sites), trait characteristics (taxa vs traits) and environmental parameters (sites vs environment) matrices with a global F-statistic ($p<0.05$) and a Pearson product moment correlation coefficient (r) the correlation between the matrices. We choose the Model-6 permutation model and 999 random permutations to avoid errors Type 1 (Dray *et al.* 2014). Prior to Fourth Corner and RDA analyses, a Hellinger transformation was applied to family abundance to reduce the effects of the most abundant families (Legendre & Gallagher 2001). We do not adjust probability values to avoid logical problems related to sequential probability correction methods (Moran 2003). According to Fourth Corner method, when determined environmental parameter increase is predictable more abundance of individuals of determined traits in positive relationships; opposite condition is expected in negative relationships (Gallardo *et al.* 2009).

RESULTS

The sites presented different % of flow change in the sampling period. The site most affected by water withdrawals was Dehesa, in all the sampling dates the water abstraction was > to 75%. Marchant was the only site where the flow increase in the last sampling date, the other sites tends to decrease in the same sampling date (March 2013) (Fig. 7).

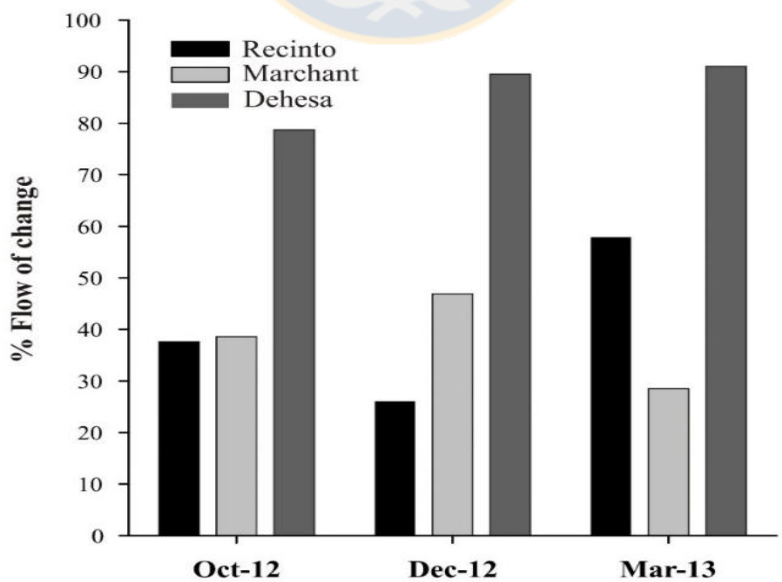

Figure 7. Percentage of flow abstraction in the sampling period for the sites.

The ANOVA analysis detected differences in reach section and sampling date comparisons for most of the environmental, community or biotic parameters (Table 15). The mean of the variables tended to be higher in the control reach sections, however, it was possible to determine higher impact reach section means for abundance and Berger-Parker index (Marchant), Wetted width, Width/depth ratio (Dehesa), pH and Conductivity on Recinto and Dehesa. Accumulated degree days do not showed differences in the temperature data logger register in any of the sampling sites. Dehesa and Marchant showed similar tendency in the accumulated degree days (Fig. 8).

Table 15. Mean and ANOVA of biotic indices, environmental and community parameters in sampling sites (ANOVA statistical differences, $p<0.05$; A: reach sections; B: sampling dates; C: A * B interaction)

		Recinto			**Dehesa**			**Marchant**		
	Variable	**Control**	**Impact**	**ANOVA**	**Control**	**Impact**	**ANOVA**	**Control**	**Impact**	**ANOVA**
Hydraulic	Froude number	0.30	0.17	A	0.30	0.18	A	0.41	0.31	A
	Current velocity	0.39	0.24	A	0.46	0.21	A	0.73	0.51	-
Morphology	Wetted width	358.20	295.3	-	459.2	716.00	A	753.6	717.90	-
	Depth	19.53	21.17	-	29.06	13.94	A, B	32.53	26.14	A
	Width/depth ratio	20.33	15.77	-	17.71	61.68	A	24.73	31.64	-
Chemical	Dissolved oxygen	11.42	10.72	A, C	10.54	10.08	A	10.02	10.15	B
	Temperature	10.11	10.88	-	16.29	15.85	-	13.83	13.69	-
	pH	7.23	7.52	A, C	7.74	7.70	B, C	7.81	7.80	B
	Conductivity	36.56	38.41	-	118.40	118.90	B	228.70	229.20	B
Community parameters	Abundance	265.44	145.05	A	195.70	108.80	-	289.50	387.00	B
	Richness	16.44	16.11	C	12.56	10.94	A	13.30	11.33	B
Diversity indices	Berger Parker index	0.29	0.37	-	0.31	0.32	-	0.35	0.39	B
	Pielou index	0.78	0.75	-	0.79	0.79	-	0.69	0.67	-
	Shannon index	2.19	2.06	-	1.98	1.88	-	1.76	1.59	A, B
	Simpson index	6.84	5.72	-	6.02	5.11	-	4.53	3.98	B
Biotic indices	CHSignal	6.68	6.45	-	6.10	6.14	-	5.63	5.37	-
	EPT	8.28	8.11	C	4.00	3.89	B	6.27	5.66	B

The macroinvertebrate community was composed by 9 orders and 42 families (total abundance, n=40388). The site with highest abundance was Dehesa (n=16311), followed by

Marchant (n=13543) and Recinto (n=10534). During all the sampling dates, Chironomidae, Simuliidae (Diptera), Gripopterygidae (Plecoptera), Hydropsychidae (Trichoptera) and Baetidae (Ephemeroptera) were the most abundant families, 65% of total abundance. Among them, Chironomidae and Hydropsychidae showed the highest abundance in the control reach sections. It not was clear a common pattern of abundance in control or impact reach sections, however, only Recinto control always was higher than impact reach section.

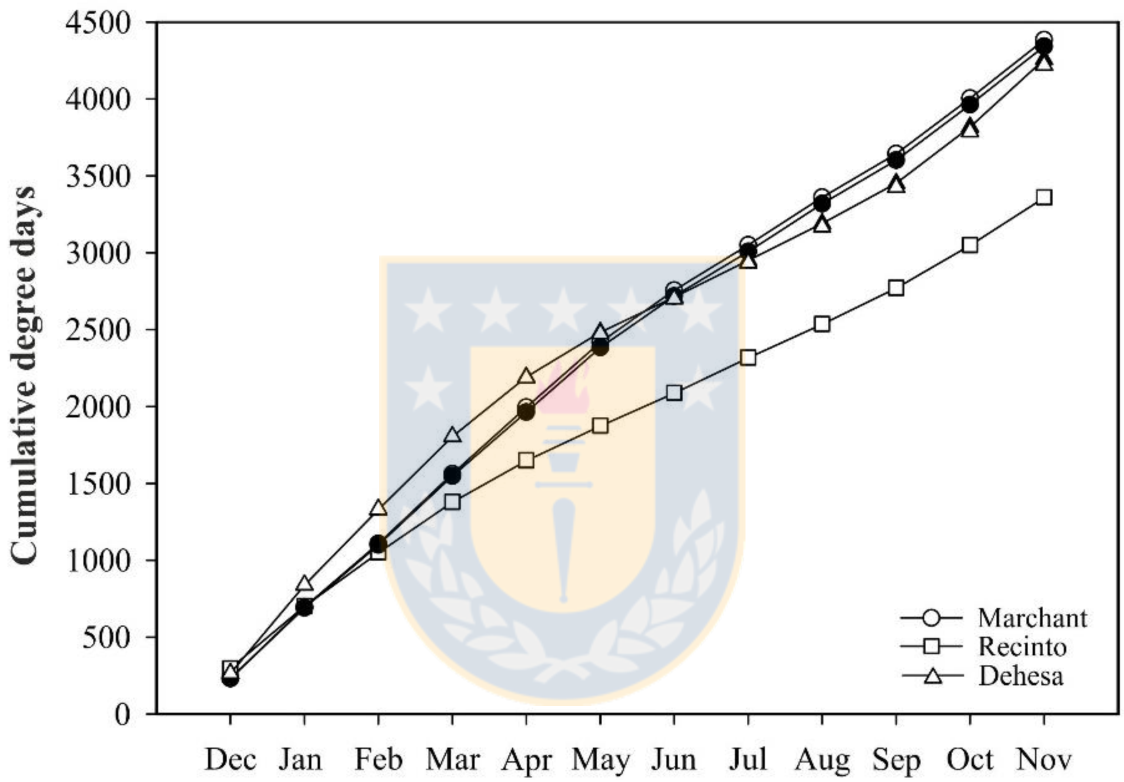

Figure 8. Accumulated degree days in the sampling period (December 2012-November 2013) (Black dots correspond to control reach sections).

According to RDA analysis, conductivity, dissolved oxygen, pH, temperature and velocity explained 51% of the variance of macroinvertebrate community assemblage (F: 1.94, $p<0.05$) with variance inflate factor <10. The forward selection method determined current velocity as the most significant variable to explain the macroinvertebrate distribution in the sampling sites (F: 5.02; $p<0.05$). The RDA analysis do not showed clear differences between control and impact reach sections but it was possible to clearly separate the sampling sites (Fig. 9). The Recinto sampling site was positive related with dissolved oxygen and abundance of some families like Coloburiscidae (Ephemeroptera), Austroperlidae, Diamphipnoidea (Plecoptera), Leptoceridae and Hydroptilidae (Trichoptera); in Marchant the most important families were Gripopterygidae (Plecoptera), Hydrobiosidae (Trichoptera) and velocity or conductivity variables. Dehesa site was positive related with the Elmidae (Coleoptera) and some dipteran families (Athericidae and Simuliidae) or Width/depth ratio.

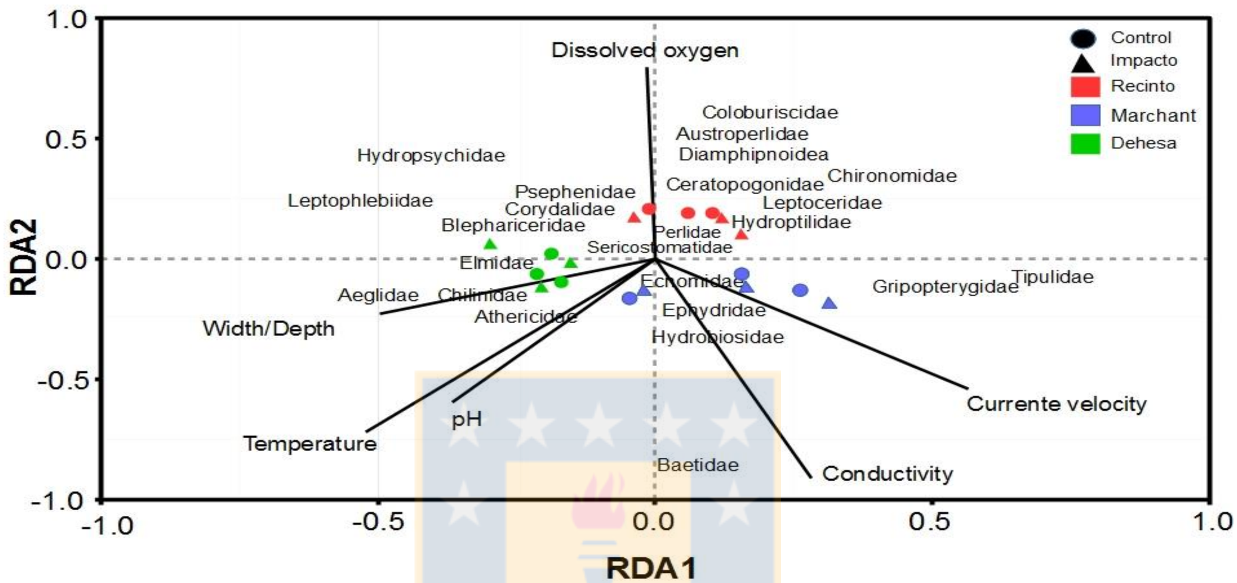

Figure 9. RDA triplot results for the control and impact reach sections in the sampling dates. Ellipses equivalents to different sampling sites. Only shows most important families in RDA analysis

The optimum velocity for the macroinvertebrate families changed between 0.99 and 0.31 m/s while tolerance between 0.31 and 0 m/s. Sialidae, Dixidae, Hydrophilidae and Polycentropodidae showed null tolerance to current velocity. Ecnomidae (Trichoptera) was related to high current condition and narrow tolerance values (± 0.09 m/s). Most of the families collected was able to tolerate current velocity near to 0.23 m/s. In Dehesa was found most of the harmful velocity records for the collected families (Fig. 10).

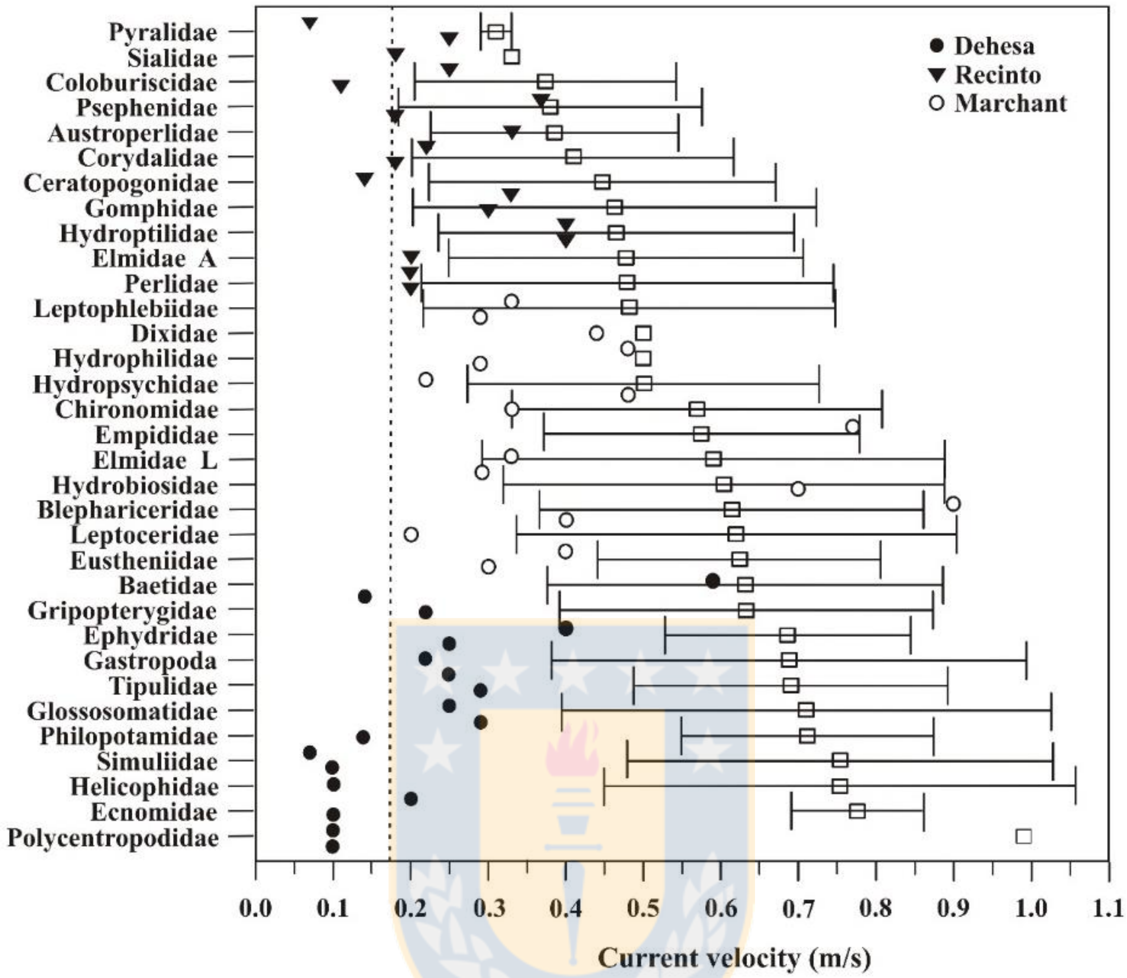

Figure 10. Current velocity optimum (square) and tolerance (error bars) for the macroinvertebrate families in control reach sections. Current velocities registered in impact reach sections (Black dot: Dehesa; White dot: Marchant; Triangle: Recinto). Vertical reference line correspond to minimum velocity tolerance for the collected macroinvertebrates.

The Fourth Corner analysis was able to detect 27 possible relationships between trait categories and environmental parameters (n=15 positive; n=12 negative significant relationships). In morphology environmental parameters, we detected positive relationships with Michophytes (Food), Tegument (Respiration) and totally sclerotized (Armoring). Among chemical environmental parameters and traits, Microphytes, Streamlined and Middle (Current velocity preference) showed positive relationships. In the hydraulic and traits comparisons, only Gill (Respiration) and Flattened (Body form) showed negative relationships. In general, the hydraulic parameters described a positive significant relationship with Respiration and Armoring trait groups (Table 16).

Table 16. Fourth-corner analysis for family abundance, traits and environmental matrices in all the sampling sites with a Pearson significant correlation (The sign indicates the direction)

	Morphology			Chemical				Hydraulic	
	Width	Depth	Width/Depth Ratio	OD	Temp	Cond.	pH	Current velocity	Froude #
Food									
Sediment particles (S)				-					
Microphytes (MiPh)	+						+		
Dead animals (DA)		-	+						
Microinvertebrates (MIIn)		-	+						
Respiration									
Tegument		+						+	+
Gill								-	
Stigmata								+	+
Maximal body size (mm)									
10–20 mm	-	-		+		-	-		
Body form									
Streamlined					+		+		
Flattened								-	-
Armoring									
Totally sclerotized (Tescle)	+								
Soft body (Su)									+
Resistance desiccation									
Absent (RDA)					-		-		
Current velocity									
Middle (25-50 cm/s)					+				

DISCUSSION

The good water quality and limited influence of agricultural activity in the sampling sites, demonstrate the importance of natural variability of pH, conductivity and water velocity in sampling sites. According to Matthaei *et al.* (2010), in experimental stream channels the combination of sediment addition and concentration of agricultural nutrients tends to hide the relevance of the water abstraction (*e.g.* water velocity change) to the composition of MIB and other important components in the ecosystem functionality (algal biomass and leaf decay).

The acidity and dissolved oxygen concentration was the chemical parameters affected by the flow reduction. The main source of H^+ ions in rivers with little human intervention is the leaching of leaf material (Allan & Castillo 2007), which may vary depending on the effect of anoxic preconditioning in the presence of microorganisms necessary for the early stages of leaves degradation (Dieter *et al.* 2011). Likewise, changes in habitat availability could also reduce the presence of shredders MIB, which are essential in leaf degradation process in rivers (Allan & Castillo 2007; Datry *et al.* 2011). Otherwise, the absence of temperature differences between control and impact reach sections indicates the importance of the hydraulic parameters (current velocity and Froude number) in the sampling sites.

The current velocity is critical in the river ecosystem because interacts with the rocky bottom river bed to create hydraulic conditions that induce active or passive dispersal of MIB (Blanckaert *et al.* 2013; James *et al.* 2008; James *et al.* 2009). According to Brooks *et al.* (2005), the MIB shows high preference of low turbulence zones in the riffles related to the energetic exigences to mantain their position in the rocky bottom, but the decrease in the abundace and richness of MIB in the impact reach sections (Recinto and Dehesa, respectively) could be related to the decline in turbulent conditions with direct effects in disolved oxigen concentratrion and available habitats for MIB.

In general, the Mediterranean rivers are characterized by constant pressure on MIB composition due to temporal variations in water availability (Bonada & Resh 2013), predictable periods of drought and flood forces aquatic communities to acquire strategies to survive (Hershkovitz & Gasith 2012) which are related to the frequency and magnitude of disturbance (Lytle & Poff 2004), relevant aspect to validate the use of biological traits in the biomonitoring programs (Menezes *et al.* 2010).

In this study it was possible to determine the significance of 14 biological traits as potencial bioindicators. Only respiration, body form or armoring are related to the hydraulic parameters of the sampling sites. Unlike reported by Walters (2011), who determined the increase in organisms with high sclerotisation rate in low flow conditions, we only detect this relationship for organisms with soft body and the Froude number (turbulent conditions). For many families MIB, respiration through the tegument is a feature that allows them to tolerate the decrease of dissolved oxygen in areas with lower turbulence (Brooks *et al.* 2011). However, it was also possible to set some inconsistencies as the negative ratio of flattened bodies with water velocity and Froude number. The condition of a flattened body coincide with riffle sites, because this trait would resist the drag forces generated by the flow (Tomanova *et al.* 2008). However, the negative ratio in the present study established that indicate prevalence of these organisms in the areas of impact, due to a distribution of microhabitats available patch or the influence of drift (passive or active) in the spatial distribution (James *et al.* 2009).

Our results indicate that biological traits MIB would be a good tool for biomonitoring of changes in flow, mainly the body form. Also, the use of conventional methods such as abundance or richness of MIB could also support the observations of changes in river habitat. The combination of methods to assess the changes of flow have been proposed in other studies (Death *et al.* 2009; Dewson *et al.* 2007) and its efficiency lies in the power to explain the variations of the aquatic ecosystem exposed to multiple stressors. In Chile, the use of biological traits is a matter of incipient development, considering the lack of information on the MIB life cycle in its restricted range of latitudinal and altitudinal distribution and tolerance to various environmental conditions. Regard of this, the use of more specific taxonomic resolution (genus or species) could the evaluation of multiple environmental stressors in low order rivers. This study highlights the sensitivity of low order rivers, to future scenarios of water scarcity, increased water demand and increased environmental temperature for this region (Figueroa *et al.* 2013, Pedreros *et al.* 2013), which could cause significant losses in the composition or distribution of MIB, essential to the functioning of the aquatic ecosystem.

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DISCUSIÓN GENERAL

Los ríos mediterráneos constituyen una de las áreas de mayor interés para la conservación de la biota acuática, debido a que presentan una alta heterogeneidad ambiental (Bonada & Resh 2013). La constante interacción del caudal en los componentes abióticos y bióticos de los ríos propicia la variación de las características del hábitat fluvial (Lake 2000; Principe *et al.* 2007), lo cual se refleja en altos niveles de diversidad y endemismos de organismos acuáticos. Sin embargo, en estas áreas también es posible localizar una matriz de actividades económicas que intervienen los ríos y especialmente, el régimen natural del caudal (Dudgeon *et al.* 2006; Vörösmarty *et al.* 2010), lo cual pone en riesgo la integridad ecológica de estos ríos (Richter *et al.* 2003).

Variables ambientales

En particular para la zona mediterránea de Chile (32-40° S), la generación eléctrica y la extracción de agua para irrigación constituyen las principales amenazas al régimen natural del caudal (Figueroa *et al.* 2013). Diversos estudios han mostrado que la presencia de embalses y las fluctuaciones diarias en función de la demanda eléctrica modifican la dispersión o parámetros comunitarios de la biota acuática (García *et al.* 2011; Habit *et al.* 2007; Nilsson *et al.* 2005), sin embargo, la influencia de las bocatomas para actividades agrícolas es un tema de escaso desarrollo en el país. De acuerdo a Harden (2006) en las zonas montañosas de los Andes (excluyendo el territorio de Chile) es recurrente la presencia de estas estructuras las cuales generan cambios en la morfología del cauce debido a que reducen la capacidad de arrastre de los sedimentos en los ríos, situación que detectamos en el presente estudio, principalmente en Dehesa, donde las precarias estructuras para el desvío del caudal y reducciones > 90% del agua disponible favorecieron la acumulación de sedimentos. En otras zonas con régimen climático similar las bocatomas también han sido relacionadas a cambios en las características del hábitat fluvial e impactos en la comunidad de MIB (Brooks *et al.* 2011; Chessman *et al.* 2010; Dewson *et al.* 2007c; Dewson *et al.* 2007d; Walters 2011; Walters & Post 2011), lo cual no ha sido estudiado en Chile, siendo el presente estudio el primer registro sobre este tipo de impactos en los ecosistemas acuáticos del país.

Sin embargo, estos estudios resultan complejos de verificar cuando existen otras presiones sobre el sistema acuático. Asimismo, el estado previo de degradación de un río es fundamental para evaluar la afectación por extracción de agua, separando los efectos sinérgicos de los múltiples estresores (Matthaei *et al.* 2010). Por ejemplo, Walters & Post (2011) efectuaron un estudio dentro de una reserva forestal demostrando efectos sobre las comunidades de MIB, a pesar de no observar cambios en la calidad del agua; por el contario Dewson *et al.* (2007b) fueron capaces de observar cambios en los MIB, acompañadas de variaciones en la conductividad del agua en los puntos con mayor grado de degradación ambiental relacionada con la producción agrícola.

Las presiones que ejercen las actividades han sido analizadas en el capítulo 3 y 4 de esta tesis y han sido resumidas de la Figura 11 donde se establecen las diversas vías que pueden seguir los impactos identificados y los valores de correlación que han sido obtenidos en este estudio (Tabla 14). Los únicos parámetros químicos que mostraron diferencias entre los sectores de control e impacto fueron el pH y oxígeno disuelto, aunque el patrón no fue generalizado para la totalidad de los sitios. Los cambios en el pH podrían estar asociados a la variación de las características químicas del material foliar (Dieter *et al.* 2011), que se concentran al disminuir el caudal y además son mayormente expuesta al sol, lo cual tiende a afectar la capacidad para degradar por parte hongos o bacterias (Dewson *et al.* 2007d). Las variaciones del oxígeno disuelto se relacionarían con la modificación de las condiciones turbulentas (Gordon *et al.* 2004), aunque no se descarta la influencia de incremento en la demanda de oxígeno producto de la descomposición del material foliar.

La velocidad del agua y la turbulencia, son factores con alta incidencia en la comunidad de MIB. La turbulencia del agua también depende de la interacción de la velocidad de la corriente con la morfología del lecho rocoso, lo cual genera zonas de diferentes condiciones hidráulicas que inciden directamente en la composición y permanencia de los MIB. En este contexto, Brooks *et al.* (2005) detectaron la mayor diversidad de organismos en las zonas de menor turbulencia dentro de los rápidos de los ríos, sin embargo, la selección visual de las zonas de rápidos en los ríos ha sido cuestionada debido a que no suele coincidir con las características hidráulicas presentes en el lecho rocoso (Jowett 1993), afectando la correcta interpretación de los resultados.

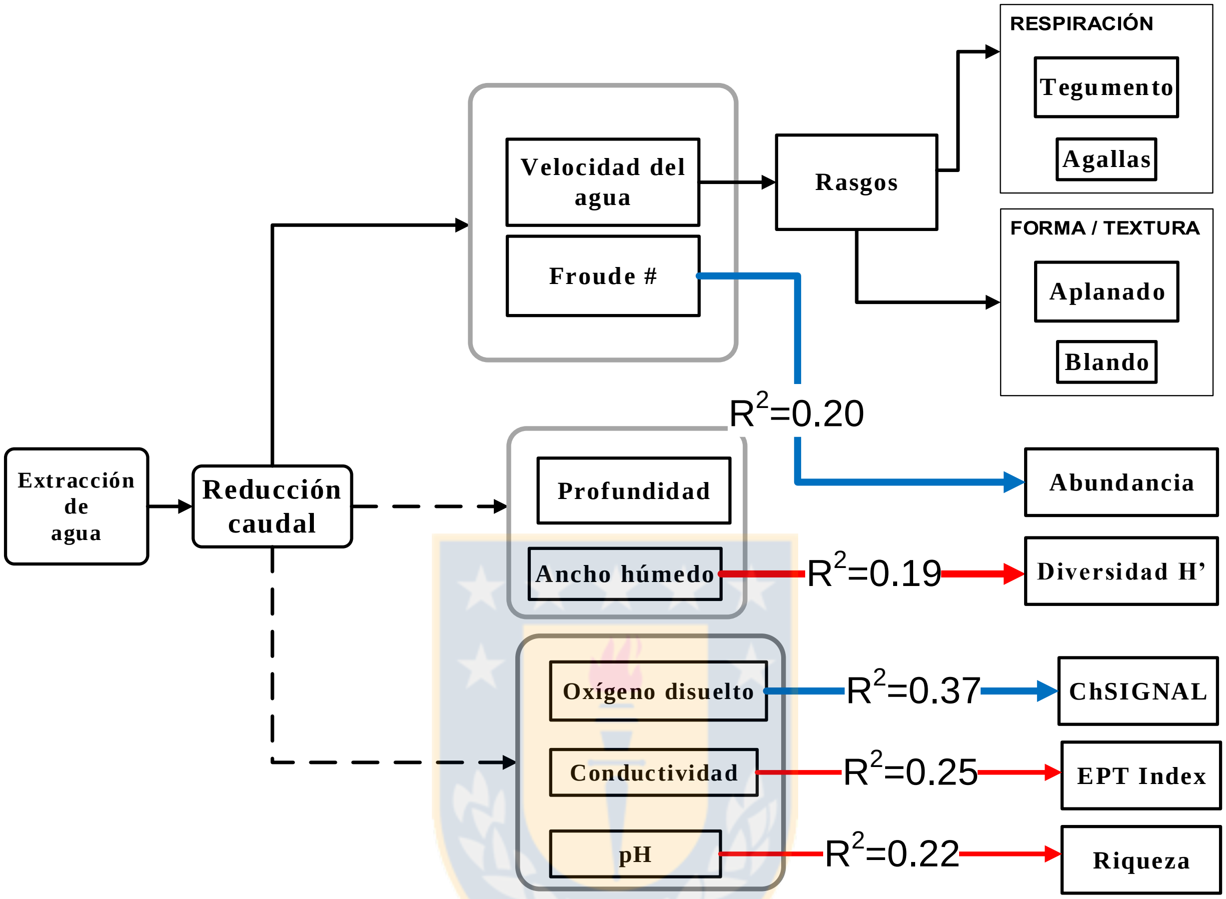

Figura 11. Influencia de las características del hábitat fluvial en los parámetros comunitarios, índices bióticos y rasgos de macroinvertebrados bentónicos. Línea roja: relación negativa, Línea azul: relación positiva, valores corresponden a R^2 (Capítulo 3).

Por otra parte, Blanckaert *et al.* (2013) establecieron la importancia de los peaks y temporalidad de la turbulencia para el desprendimiento de los MIB de su posición en el fondo rocoso, lo cual favorece la dispersión. En este sentido, la reducción del caudal podría ser más nociva en la distribución de los MIB debido a la combinación de aumento en la cantidad de sedimentos de las actividades agrícolas y su mayor acumulación en el fondo rocoso del río, reduciendo drásticamente la disponibilidad de microhábitats para la sobrevivencia de los MIB (Matthaei *et al.* 2010). Una posible medida de mitigación de este tipo de estresores ambientales es la conservación de la vegetación de ribera, la cual es capaz de retener el arrastre de sedimentos al río o de regular la penetración de la luz solar, y por ende mantener estable otros parámetros ambientales (Naiman *et al.* 2005).

Efectos sobre las comunidades de MIB

El principal indicador de cambios en la comunidad de MIB fue la abundancia (Fig. 12). El descenso de la abundancia ha sido observado en diversos estudios (Dewson *et al.* 2007a; Holmquist & Waddle 2013; Matthaei *et al.* 2010) y relacionado principalmente a la reducción en la disponibilidad del hábitat fluvial. Sin embargo, por su resistencia y adaptación a las variaciones ambientales, no fue posible detectar cambios en la riqueza de familias, siendo Diamphipnoidea (Plecoptera) y Glossosomatidae (Trichoptera) los grupos con relevancia como indicadores de zonas con escasa reducción del caudal. De hecho, la presencia de Diamphipnoidea ha sido reportada principalmente en sitios prístinos, con buena cobertura boscosa y escasa intervención en la composición físico química del agua de zonas montañosas (Miserendino *et al.* 2011), por lo cual el descenso en su abundancia o presencia podría ser utilizada como indicador de afectación del caudal.

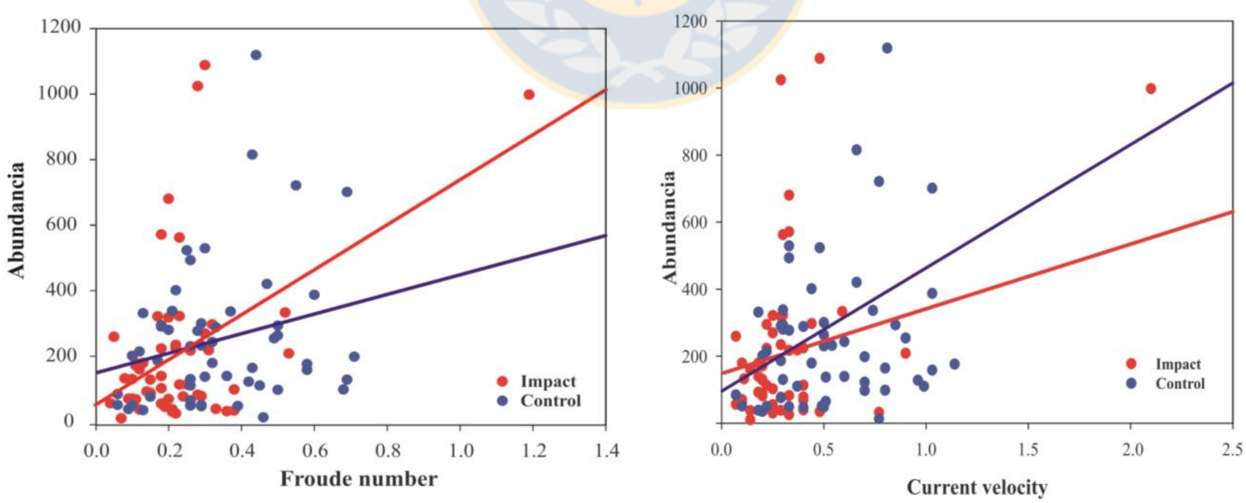

Figura 12. Relación entre la velocidad de la corriente y el número de Froude con la abundancia de macroinvertebrados bentónicos. Líneas corresponden a regresiones lineales

La leves diferencias en la comunidad de macroinvertebrados del presente estudio estarían relacionadas con la resistencia, para lo cual han desarrollado múltiples adaptaciones conductuales, morfológicas o fisiológicas. La principal adaptación conductual de los MIB es la deriva. El inicio activo o pasivo de la deriva de los MIB ha sido detectada en ríos con alteración del caudal, principalmente en el inicio de la perturbación como respuesta a la inmediata disminución de la disponibilidad de alimentos o cambios en la estructura del hábitat fluvial (James *et al.* 2008; James *et al.* 2009), sin embargo, este proceso también ha sido reportado como un método eficaz para la colonización o dispersión de la comunidad de MIB en ríos de la zona mediterránea de Chile (Figueroa *et al.* 2000; Figueroa *et al.* 2006), por lo cual no se puede descartar la presencia de un recambio de organismos provenientes de los sectores de control en los sitios de muestreo. En este sentido, se requiere cuantificar el aporte de este mecanismo de dispersión para lograr establecer la influencia real de la reducción del caudal, considerando que las estructuras hidráulicas básicas solo desvían agua, pero no ejercen retención de los organismos.

Las adaptaciones morfológicas y fisiológicas han sido recientemente utilizadas para evaluar los efectos de la reducción del caudal (Brooks *et al.* 2011; Walters 2011), dado que permiten evaluar múltiples estresores ambientales (Menezes *et al.* 2010). La utilización de rasgos ha mostrado ser muy útil con evaluaciones de mayor dispersión geográfica, en las cuales la reducción del caudal genera fuertes cambios en la heterogeneidad ambiental (Brooks *et al.* 2011; Tomanova & Usseglio-Polatera 2007), sin embargo, en otros estudios de menor escala geográfica no ha sido posible apreciar la utilidad dado el escaso recambio en la composición taxonómica (Walters 2011).

Por el contrario, el presente estudio permitió relacionar rasgos como Tipo de Respiración (Tegumento, Agallas y respiración por estigma), Forma del cuerpo (Aplanados) y Grado de Protección (Cuerpo suave) con las condiciones hidráulicas en los sitios de muestreo. La respiración mediante tegumento constituye en una ventaja para los MIB debido a que esta les permite ser más efectivos en la captura del oxígeno (Brooks *et al.* 2011), especialmente cuando éste es escaso, por lo cual sería común localizarlos en sectores con reducción del caudal (Tomanova *et al.* 2008), similar condición es esperable para la respiración con sifones (stigmata), ya que esta adaptación morfológica permite la captura de oxígeno atmosférico. El principal patrón obtenido fue la relación positiva de estos rasgos con el incremento en las condiciones hidráulicas, lo cual podría indicar la preferencia de los organismos en las zonas con mejor disponibilidad de hábitat.

A partir de los resultados de la presente investigación se puede indicar que los principales indicadores de alteración por reducción de caudal corresponden a los parámetros hidráulicos del río (velocidad de corriente y número de Froude); estos cambios en la hidráulica afectarían la disponibilidad de oxígeno disuelto, principalmente al reducirse las condiciones turbulentas, sin embargo, la capacidad de resistencia de la comunidad de MIB, reflejado en rasgos de tipo respiratorio o forma del cuerpo, permitirían sobrevivir a las nuevas condiciones ambientales.

En relación a los niveles taxonómicos, no se descarta que la selección del nivel de familia podrían tener repercusiones en la asignación de los rasgos, y por ende haber afectado en la determinación de los impactos. De hecho, es posible que no sea el más adecuado para Chile, debido a la baja dispersión geográfica y alto endemismo, que aunado al desconocimiento de aspectos autoecológicos, no facilitaría la asignación de las familias hacia un determinado rasgo biológico y su relación con otras variables físicos-químicas de calidad de agua o de las condiciones hidráulicas de los ríos. El avance en el conocimiento de las comunidades de MIB en Chile permitirá evaluaciones más precisas y la construcción de índices bióticos que tomen en consideración la sensibilidad de estos organismos antes las variaciones hidráulicas en los ríos del país.

CONCLUSIONES

1. La alta demanda de las actividades agrícolas y el marco legal actual de los derechos de agua, incentiva la extracción de agua en ríos de bajo orden de la zona mediterránea de Chile.

2. A pesar de la influencia de la demanda agrícola en la disponibilidad de agua de los ríos en la zona mediterránea de Chile, las investigaciones realizadas hasta el momento se han enfocado en los efectos de las variaciones del caudal, con escasa consideración de los escenarios futuros de escasez de agua o incremento en la temperatura del aire.

3. Los métodos tradicionales de construcción de las bocatomas con bolones, madera y sacos de arena, no permiten un control eficaz sobre la extracción de agua, observándose variaciones en la extracción del caudal entre 20% y 90% de la disponibilidad hídrica del cauce y los mayores efectos en Dehesa (> 70% en todos los muestreos).

4. La zona mediterránea chilena presenta una alta diversidad y endemismo, pero los especialista son escasos y la mayor información disponible no viene de estudios de biodiversidad, sino de tipo secundaria asociada a estudios de impacto ambiental. De acuerdo a esto, es necesario sistematizar los datos disponibles para la zona de mayor densidad poblacional y de actividades económicas del país, principalmente en las zonas de mayor sensibilidad ambiental como los ríos de bajo orden.

5. Los principales indicadores de perturbación ambiental producto del descenso en el caudal fueron los parámetros hidráulicos: velocidad de corriente y número de Froude. El cambio en estos parámetros hidráulicos se relacionó directamente con la concentración de oxígeno disuelto debido a la reducción en las condiciones turbulentas del agua.

6. Los parámetros comunitarios con diferencias significativas entre los sectores de

control e impacto fueron la abundancia (Recinto) y la riqueza (Dehesa). La mayoría de las familias de MIB mostraron amplia tolerancia a las variaciones en la velocidad de la corriente, siendo el límite inferior para la totalidad de ellas cercano a los 0.2 m/s.

7. Los bajos valores de abundancia de la familia Diamphipnoidea (Plecoptera) podrían ser un buen indicador biológico para perturbaciones ambientales por reducción del caudal.

8. Los rasgos biológicos de respiración (respiración tegumentaria, presencia de agallas), forma del cuerpo (cuerpo aplanado) y grado de esclerotización (cuerpo suave) se relacionaron con los parámetros hidráulicos, indicando su posible utilización como bioindicadores de la reducción del caudal en sistemas fluviales de bajo orden.

9. Se establecieron relaciones entre los rasgos biológicos y la extracción de agua para actividades agrícolas en el nivel taxonómico de familia, pero no se descarta que incrementando información de la autoecología de las especies, principalmente las de carácter endémico, se puedan detectar relaciones más significativas, permitiendo mejorar las herramientas de bioindicación.

10. El presente estudio constituye la primera aproximación de los efectos de la reducción del caudal generadas por las actividades agrícolas sobre las comunidades biológicas (MIB) y permite destacar la importancia de utilizar nuevos métodos para la bioindicación como los rasgos biológicos, considerando que los mayoría de los protocolos habituales para la gestión del agua incluyen la utilización de índices bióticos con escasa consideración del caudal en su construcción.

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