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Efectos del cambio climático sobre los hábitats de plantas de chile centro-sur, según su dependencia de las precipitaciones y sobre la conservación de sus hábitats en áreas protegidas

Tesis para optar al grado de Doctor en Ciencias Biológicas área Botánica

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TABLA DE CONTENIDO

ÍNDICE DE FIGURAS

ÍNDICE DE TABLAS

RESUMEN GENERAL

Las propiedades del nicho ecológico (*sensu* Hutchinson) de una especie, tales como su amplitud y posición relativa en gradientes ambientales, determinan su respuesta esperada ante cambio climático, en términos de la extensión de su hábitat y desplazamiento proyectado en dichos gradientes, con diferencias de nicho ecológico basadas en sus características morfológicas y fisiológicas específicas. Los análisis y modelos de nichos permiten comparar la condición presente contra cambios proyectados frente a escenarios de clima futuro, considerando las restricciones específicas de migración hacia nuevas zonas. Se prevé que los bosques templados de Sudamérica experimentarán cambios de precipitación contrastantes a lo largo de su distribución latitudinal y gradiente bioclimático, y cambios en temperatura más homogéneos y con posible mayor expresión en el gradiente altitudinal. Dado que es probable que diferentes grupos de especies que componen su diversidad estructural (*i.e*. árboles dominantes principales, codominantes, helechos epífitos y del sotobosque), respondan a distintos forzantes climáticos, en esta tesis se plantea que dichas diferencias pueden redundar en efectos contrastantes en sus hábitats ante cambio climático. En esta investigación se analizaron comparativamente las características constitutivas de los nichos de 118 especies de plantas que comparten distribución en dichos bosques distribuidos en Chile centro y sur e incorporando la capacidad de migración potencial futura específica, así aportando mayor realismo a los resultados, a diferencia de estudios previos que no lo consideran.

Los análisis permitieron establecer diferencias entre los nichos y los forzantes climáticos que los determinan para los grupos de plantas mencionadas, en relación a rasgos propios de cada grupo. Los resultados sugirieron un patrón descrito para otros ecosistemas, de relación inversa entre amplitud de nicho y magnitud de cambios en el gradiente altitudinal. No obstante, el patrón observado en relación al gradiente latitudinal fue directo, es decir contrario a lo observado para otros ecosistemas, constituye un patrón novedoso, relacionado a las condiciones particulares de transición bioclimática y proyecciones de cambio climático para la región respecto de otros ecosistemas análogos y por el efecto Rappoport observado en los nichos en las especies analizadas.

Esta tesis abordó además, un análisis de la extensión de los hábitats de las especies mencionadas que integran el *hotspot* de biodiversidad de Chile centro-sur, respecto de la representación bajo áreas de conservación. Constituye el primer análisis de este tipo a nivel de especies en plantas en Chile y que al contrastar con la distribución futura de las mismas, dio evidencias de efectos del cambio climático sobre la representación de los hábitats, considerando diferentes esquemas tanto de protección formal efectiva presente en Chile, como aquellos propuestos para una potencial incorporación futura. Lo anterior reveló que la localización de las áreas de protección oficial es útil ante cambio climático, pero insuficiente para el cumplimiento de metas globales de representación para la conservación *in situ*, y que el aporte de áreas de potencial incorporación futura (*i.e.* parques privados, sitios prioritarios a escala nacional y regionales) constituye una representación aditiva que virtualmente permitiría el cumplimiento de dichas metas tanto para el presente como para el escenario de cambio climático futuro.

ABSTRACT

The properties of ecological niche (*sensu* Hutchinson) of a species, such as its breadth and relative position within environmental gradients, may determine the expected response to climate change, in terms of habitat size and expected shift in those gradients, with differences in ecological niches based in their specific morphological and physiological traits. Niche modeling analyses are useful to compare a present condition with expected changes at future climate scenarios, considering specific migration constraints. It has been predicted that South American temperate forests will experience contrasting changes in precipitation across the latitudinal distribution and bioclimatic gradients, and more homogeneous changes in temperature with a possible greater expression in the elevational gradient. Given that different species groups that constitute a structural diversity for those forests (*i.e*. main dominant trees, co-dominant species, epiphytic ferns, ground ferns) may respond to different bioclimatic drivers, in this thesis is presented that mentioned differences may lead in contrasting effects in their habitats due to climate change. In this research the comparative niche characteristics were analyzed for 118 plant species that share their distribution in central and southern Chile, and considering specific migration constraints, thus having more realistic results, since previous similar studies do not consider it.

The analyses let to establish differences between niches and climatic drivers for mentioned plant groups, in relation to specific traits. Results suggested a pattern described for other ecosystems: an inverse relation between niche breadth and change magnitude in the elevational gradient. However, the observed pattern of relation between niche breadth and change magnitude in latitudinal gradient was direct, meaning contrary to formerly observed for other ecosystems, a novel pattern related to particular conditions of bioclimatic transition and climate change projections for the region, compared to other analogous ecosystems, and the Rappoport's effect found in the analyzed species niches.

This thesis also assessed the size habitat of mentioned plant species included in the biodiversity hotspot of central and southern Chile, related to the representation od their habitats under protected areas. It is the first analysis of this kind at a plant species level in Chile, and when contrasting with future distribution, showed the effect of climate change to habitat representation, considering different conservation schemes in Chile: effective official protected areas and different proposed categories for future implementation. It revealed that location of official protected areas are useful but insufficient to accomplish global representation goals, and that proposed categories are enough additive representation in order to virtually accomplish such goals, for the present as well as for the future climate change scenario.

INTRODUCCIÓN GENERAL

1. Nicho ecológico y distribución de especies ante cambio climático

El concepto de nicho ecológico *sensu* Hutchinson (1957) integra el conjunto de rangos de condiciones físicas y biológicas y de recursos limitantes, requeridos para que una especie mantenga o incremente su tamaño poblacional. Hutchinson se refirió al nicho como un hipervolumen de *n*-dimensiones, en el cual cada dimensión corresponde a una variable independiente física o biológica, o a la disponibilidad de un determinado recurso que en conjunto pueden afectar la abundancia de una especie determinada (Colwell & Rangel, 2009; Soberón & Nakamura, 2009). Dichas dimensiones integran un espacio ecológico en el cual puede desarrollarse una especie y que tiene su correlato en el espacio geográfico, según la combinación existente de variables ecológicas sobre la tierra, determinando así la distribución de la especie (Soberón & Nakamura, 2009). Es decir, el espacio geográfico ocupado por una especie refleja en gran medida sus requerimiento ecológicos o nicho.

En el caso de las plantas, el clima constituye uno de los factores principales que dirigen los patrones de distribución espacial de sus especies. Las variables que componen el clima, se relacionan con los rangos geográficos y ecológicos en los cuales las plantas se distribuyen, de acuerdo a las restricciones fisiológicas que ellas presentan, condicionando así la supervivencia y reproducción de las poblaciones de cada especie en un determinado lugar, de acuerdo a sus nichos ecológicos específicos (Woodward, 1987; Lomolino *et al*., 2010). Se reconoce que las especies durante períodos limitados de tiempo, presentan una tendencia a retener características ecológicas ancestrales. En tal sentido, existen rasgos que permiten a las especies persistir en determinados tipos de ambiente, atributos que se mantienen en el tiempo. Las características del nicho ecológico se encuentran dentro de dichos rasgos que tienden a conservarse, lo cual sirve de fundamento para evaluar efectos en las especies frente a cambios en el clima (Wiens & Graham, 2005; Ackerly, 2009; Wiens *et al*., 2010).

Existe amplia evidencia acerca de la naturaleza dinámica del clima, la cual ha impulsado a las especies a adaptarse a las condiciones cambiantes (Woodward, 1987; Petit *et al*., 1999). No obstante, la tasa de cambios que experimenta el clima en la actualidad ha sido muy superior al ritmo de los siglos anteriores. Este cambio climático ha sido presumiblemente gatillado por la alteración antropogénica del balance de gases de efecto invernadero de la atmósfera, y consta del aumento de la temperatura media global, aparejado de cambios heterogéneos a diversa escala regional y local, respecto de las extremas de temperatura junto a los montos y distribución de las precipitaciones (IPCC, 2013). Por consiguiente, el cambio climático observado durante las últimas décadas ha afectado la distribución de las especies de plantas, su fenología, las interacciones bióticas y la abundancia de sus poblaciones (Parmesan & Yohe, 2003; Parmesan, 2006; Kelly & Goulden, 2008; Bellard *et al*., 2012; Garcia *et al*., 2014; Parmesan & Hanley, 2015). Los desplazamientos futuros de distribución pueden ocurrir por reducciones en el rango de distribución actual, debido a que las condiciones futuras pueden llegar a ser inadecuadas para una especie en algunas partes de su presente distribución, o bien a la expansión de sus poblaciones hacia hábitats adecuados que recientemente se han hecho disponibles, sólo si la especie posee la capacidad de migrar de manera efectiva hacia ellas (Breshears *et al*., 2008; Engler *et al*., 2009; Garcia *et al*., 2014).

Algunas características claves del nicho ecológico son la amplitud que abarca el nicho de cada especie y su posición relativa en determinados gradientes ambientales. Las diferencias específicas en estas propiedades del nicho, constituyen factores que pueden explicar el amplio rango de posibles resultados en términos de desplazamientos futuros de distribución (Broennimann *et al*., 2006; Broennimann, 2008). Especies con posiciones de nicho contrastantes a lo largo de gradientes ambientales pueden mostrar respuestas disímiles de acuerdo a cambios en climas locales o regionales (Broennimann *et al*., 2006; Morin & Chuine, 2006; Kelly & Goulden, 2008). La base de las diferencias de nicho ecológico de las especies se halla en sus características morfológicas y fisiológicas específicas (Chase & Leibold, 2003; Colwell & Rangel, 2009). En tal sentido, por ejemplo, rasgos específicos como el tamaño máximo de los ejemplares, sistema vascular o atributos fisiológicos, pueden determinar diferencias de nicho entre helechos y angiospermas (Zotz *et al*., 2001; Brodribb *et al*., 2005; Kluge & Kessler, 2011), particularmente en relación con forzantes climáticos tales como la disponibilidad de agua que resulta clave en el ciclo de vida de los helechos (Qian *et al*., 2012), o rangos de temperatura como forzantes de nichos y de las diferencias en distribución en algunos grupos de angiospermas dominantes como árboles del género *Nothofagus* (Read, 1990; Box, 1995).

Se ha expuesto que las especies con nichos más amplios, y por ello con rangos mayores de distribución, podrían experimentar comparativamente menores efectos de cambio climático a lo largo de gradientes ambientales tales como altitud o latitud (Thuiller *et al*., 2004). En un análisis de plantas endémicas del sur de África, Broenimann *et al*. (2006) determinaron una relación inversa entre la amplitud de nichos y la magnitud del efecto del cambio climático en sus hábitats. Esta misma tendencia se concluye en los trabajos de Thuiller *et al*. (2005) en un análisis que incluyó 1200 especies de plantas de Europa, y en el de Botts *et al*. (2013) con 67 especies de anfibios en África. A escala de comunidad, pese a compartir ambientes, las respuestas de las especies producto del cambio climático pueden no ser homogéneas o integradas, ya que el nicho de cada especie es diferente (Engler *et al*., 2011; Angert *et al*., 2013; Gornish & Tylianakis, 2013).

En la literatura actual se encuentran numerosos ejemplos de desplazamientos observados y proyectados, generalmente hacia una mayor altitud y hacia mayores latitudes (Parmesan, 2006; Lenoir *et al*., 2008; Jump *et al*., 2009; Grabherr *et al*., 2010; Engler *et al*., 2011), pero también se reportan desplazamientos hacia direcciones inversas o diferentes (Lenoir *et al*., 2010; VanDerWal *et al*., 2012). Dentro de los ejemplos de cambios recientes observados, destaca el trabajo de Lenoir *et al*. (2008), quienes compararon la distribución altitudinal de 171 plantas de bosques de Europa occidental entre períodos 1905-1985 y 1986-2005, concluyendo que el cambio climático ha provocado un aumento en la elevación óptima de dichas especies en 29 m por década, con un efecto mayor para plantas restringidas a hábitats montañosos y para especies herbáceas que presentan un recambio poblacional más rápido. De igual forma, Bergamini *et al*. (2009) informan del aumento en altitud de la distribución en briófitas en Europa central, con un promedio de 24 m por década entre los períodos 1880-1920 y 1980-2005, asociado a cambios climáticos recientes.

Por otra parte, Jump *et al*. (2009) revisan diversas evidencias sobre la retracción en porciones bajas de los rangos de distribución de plantas del hemisferio norte, asociados a cambios climáticos de los últimos 50 años. Dentro de una especie determinada, se ha identificado que sus poblaciones marginales o correspondientes a los extremos de distribución, podrían ser las más susceptibles a frente al cambio climático (Angert, 2009). Frente a esta tendencia de cambios observados para las últimas décadas, se espera que en el futuro cercano las plantas continúen presentando distintos grados de desplazamiento de sus poblaciones en los gradientes ambientales, de acuerdo a los escenarios regionales de cambios futuros en el clima y de la capacidad de las especies de adaptarse según sus restricciones fisiológicas y de las capacidades de migración de sus poblaciones (IPCC, 2013; Garcia *et al*., 2014; Parmesan & Hanley, 2015).

Los análisis que permiten proyectar la distribución de las especies de acuerdo a información ambiental siguiendo los límites del nicho ecológico de las especies, se denominan modelos de nicho ecológico. Toman información espacialmente explícita de la distribución geográfica de las especies y conjuntos de variables ambientales, relacionándolos mediante protocolos estadísticos que generan un modelo predictivo de distribución (Guisan & Zimmermann, 2000; Araújo & Guisan, 2006; Austin, 2007; Elith & Leathwick, 2009; Wiens *et al*., 2009; Araújo *et al*., 2012; Anderson, 2013).

Los modelos de nicho ecológicos se basan en una serie de supuestos, siendo los más importantes: i) las especie a modelar se encuentra en equilibrio con su ambiente en un tiempo y área determinados, y que ya ha alcanzado su rango de distribución completo de acuerdo a la combinación de variables ecológicas en el espacio geográfico utilizado, ii) el nicho ajustado se conserva, es estable en el tiempo y espacio en el cual se considera la modelación, iii) las observaciones que se emplean para modelar son expresión del nicho observado, lo que implica la necesidad de considerar sus alcances, por ejemplo en el caso de limitaciones a la dispersión ante escenarios futuros de cambio climático, iv) la taxonomía de la especie está resuelta y v) las variables predictoras a emplear son ecológicamente significativas para la especie y se encuentran disponibles en su expresión geográfica (Guisan & Zimmermann, 2000; Guisan & Thuiller, 2005). Si bien existen casos en que no todas estas suposiciones se cumplen a cabalidad, en general hay buenas razones para su uso a pesar de los mencionados supuestos.

Es posible modelar la distribución futura de una especie, al considerar información proyectada de clima futuro y de esta forma determinar los desplazamientos esperados al contrastar las distribuciones resultantes para ambos escenarios temporales (*i.e*. presente y futuro con cambio climático) mediante el empleo de modelos de nicho ecológico (Guisan & Zimmermann, 2000; Hijmans & Graham, 2006; Wiens *et al*., 2009; Engler *et al*., 2009). Cabe señalar que las distribuciones futuras modeladas presentan incertidumbres acerca de la capacidad de las poblaciones de una especie de migrar hacia nuevos territorios e incorporarlos efectivamente como parte del hábitat (Thuiller *et al*., 2005; Araújo *et al*., 2007; Hannah *et al*., 2007; Engler *et al*., 2012, Araújo *et al*., 2011; D'Amen *et al*., 2011; Carvalho *et al*., 2011; Kuhlmann *et al*., 2012; Bateman *et al*., 2013). Para abordar este problema, se han desarrollado herramientas para tomar en cuenta la dispersión de los propágulos en el paisaje y las restricciones de migración, con el objeto de modelar distribuciones futuras más realistas para los escenarios de cambio climático (Engler *et al*., 2009; Summers *et al*., 2012; Engler *et al*., 2012; Bateman *et al*., 2013).

2. Representación de hábitats bajo conservación y cambio climático

La conservación *in situ* de especies, comunidades o ecosistemas es ampliamente reconocida como la base para una conservación efectiva de la biodiversidad (Rodríguez *et al*., 2004). El planeamiento sistemático para la conservación *sensu* Margules & Pressey (2000), considera metas de conservación, dentro de las cuales uno de los aspectos más importantes es la representación de los elementos de biodiversidad en sistemas de áreas protegidas, (Margules & Sarkar, 2007). En este concepto, la representación se entiende como una proporción de la ocurrencia de alguno de los objetos de conservación (*i.e*. poblaciones de especies, hábitat de especies), dentro de un conjunto de áreas protegidas en un contexto geográfico definido (Cabeza & Moilanen, 2013; Kukkala & Moilanen, 2013).

La Convención de la Diversidad Biológica y otras iniciativas globales, han recomendado un mínimo nivel de representación de ecosistemas y hábitats, entre un 10% y un 12% (Tear *et al*., 2005; Burguess *et al*., 2005). A partir de la Cumbre de Nagoya en 2010, se propuso elevar la meta de representación en áreas protegidas a un 17% para ecosistemas terrestres (UNEP/CBD, 2010; Moilanen *et al*., 2013). Debido a que la implementación de este tipo de políticas son temas a escala de cada país, pueden haber sesgos y artefactos de borde cuando los ecosistemas o especies se distribuyen en un amplio número de países cercanos o limítrofes (Moilanen *et al*., 2013).

La persistencia en el largo plazo de la conservación de las especies, en términos de la representación de especies o ecosistemas pueden estar amenazados por el cambio climático como uno de los factores más importantes (Sala *et al*., 2000). A medida que se hacen más evidentes los cambios en el clima, se hace más importante el entender su impacto potencial sobre la conservación de los ecosistemas naturales (Wiens *et al*., 2009), particularmente en cómo el cambio climático podría afectar los niveles de representación de los hábitats de elementos clave de la biodiversidad bajo esquemas de conservación (Araújo *et al*., 2007; D'Amen, 2011), tanto bajo áreas de conservación formal, como bajo áreas propuestas para implementar su conservación en el futuro.

3. Plantas de los bosques templados de Sudamérica y cambio climático

Los bosques templados de Sudamérica se ubican principalmente en el centro y sur de Chile y también en el suroeste de Argentina (ver Fig. 1.1). Están dominados por árboles del género *Nothofagus* e incluyen numerosas especies leñosas que forman una diversa estructura vertical con un sotobosque rico en especies (Donoso, 1993; Armesto *et al*., 2001; Moreira-Muñoz, 2011), en el cual los helechos, incluyendo especies terrestres y epífitas, son un componente importante (Rodríguez, 1995; Rodríguez *et al*., 2009).

Estos bosques comprenden una transición norte-sur desde un bioclima de tipo Mediterráneo a Templado (Armesto *et al*., 2001; Luebert & Pliscoff, 2006), con un alto nivel de endemismo de especies y un alto uso humano, lo que llevó a que estos bosques fuesen clasificados como *hotspot* de biodiversidad global (Myers *et al*., 2000, Armesto *et al*., 2001). Estos bosques lluviosos crecen a lo largo de un amplio gradiente de elevación desde el nivel del mar hasta el límite altitudinal de la vegetación o *treeline* de la cordillera de los Andes, y a lo largo de un notable gradiente latitudinal desde los 33° S a 55° S (Donoso, 1993; Armesto *et al*., 2001), como se presenta en la Fig. 1.1. La parte norte y centro de los bosques templados de Sudamérica evidencian una disminución progresiva en precipitación (DMC, 2015) que se proyecta que continúe en el futuro, no obstante se espera un aumento en la precipitación hacia el extremo sur de estos bosques en la transición del bioclima templado hacia bioclima subantártico de acuerdo a las proyecciones de clima futuro (IPCC, 2013), generando un patrón de cambio heterogéneo para los montos de precipitación en relación a un aumento más homogéneo de la temperatura media en todo el gradiente. Dicho cambio de temperatura podría implicar un mayor cambio hacia mayores altitudes en porciones fuera de la influencia oceánica moderadora de la temperatura que puede coincidir con sectores de menor elevación.

Aunque los efectos proyectados del cambio climático en estos bosques han comenzado recién a ser evaluados, por ejemplo a nivel fisiológico para especies de árboles principales (Gutiérrez, 2010), no se han proyectado los patrones de desplazamiento potencial de sus poblaciones a lo largo de gradientes ambientales. Dado que estos bosques viven a lo largo de gradientes extensos en elevación y latitud, resulta un desafío poder evaluar y anticipar las respuestas de sus especies componentes, frente a los cambios climáticos que experimentan a través de su transición desde los ecosistemas Mediterráneo a Templado, transiciones que sí han sido evaluadas y se prevén con notorios efectos para gradientes análogos del hemisferio norte (Pauli *et al*., 2012).

Además, aún no se ha evaluado la representación en áreas protegidas a nivel de especies de plantas para este ecosistema, ni tampoco se ha evaluado el efecto que el cambio climático pueda implicar en dicha representación en un escenario futuro. Dado que los bosques templados del sur de Sudamérica se ubican principalmente en Chile, las plantas de estos bosques templados dominados por *Nothofagus* constituyen un buen caso de estudio para evaluar la representación de la red de áreas protegidas a escala de especies, minimizando así los sesgos descritos por Moilanen *et al*. (2013).

Pese a que en Chile el sistema nacional de áreas protegidas del estado (SNASPE) cubre más del 18% de la superficie del país (Pauchard & Villarroel, 2002), muestra un fuerte sesgo geográfico hacia el sur y hacia altas elevaciones en la Cordillera de los Andes (Armesto *et al*., 1998). Ha sido considerado como insuficiente para el logro representación mínima tanto a escala de ecosistemas o comunidades (Pliscoff & Fuentes-Castillo, 2011) y a nivel de especies, para vertebrados (Tognelli *et al*., 2008). Además del SNASPE, existen áreas de protección de propiedad privada, para las cuales su regulación legal se encuentra en desarrollo (Squeo *et al*., 2012), y otras categorías bajo la Estrategia Nacional para la Biodiversidad (CONAMA, 2005) que incluyen sitios prioritarios para la conservación, actualmente clasificados a escala nacional y a escala regional (CONAMA, 2005; MMA, 2014). Estas últimas categorías no han sido implementadas aún, y no se dispone de evaluaciones exhaustivas sobre cómo podrían ayudar en el logro de las metas frente al cambio climático.

4. Desafíos de estudio a través de la presente tesis

Se proyecta que los bosques templados de Sudamérica experimenten, por una parte, cambios de precipitación más heterogéneos que los cambios de temperatura en el gradiente bioclimático templado coincidente con el gradiente latitudinal (*i.e.* transición de bioclimas mediterráneo-templado-subantártico) y por otra parte en el gradiente altitudinal, estos cambios de temperatura sí se podrían manifestar de manera más marcada hacia una mayor elevación, en comparación a sectores más bajos y cercanos al litoral que pueden presentar una influencia oceánica moderadora de la temperatura. En este escenario de cambio climático futuro, la diversidad estructural de estos bosques templados permite estudiar los efectos diferentes en cada grupo de especies (*i.e.* árboles dominantes, especies codominantes, helechos terrestres del sotobosque, helechos epífitos), con características de nichos climáticos influenciados por forzantes climáticos diferentes (*i.e.* helechos presumiblemente regidos por cambios en precipitación versus árboles probablemente regidos por cambios en temperatura). Lo anterior permite analizar comparativamente los efectos proyectados de dicho cambio climático en la distribución de sus hábitats y en los desplazamientos esperados de sus distribuciones medias en diferentes gradientes ambientales (*i.e.* gradientes climáticos, gradientes de latitud, gradientes de altitud). Estos análisis requieren tomar en cuenta las diferencias entre propiedades claves de los nichos ecológicos de cada especie (*i.e.* amplitud de nichos, posición de nichos en gradientes ambientales), para así evaluar si hay relaciones entre dichas propiedades con los efectos evaluados, como se ha evidenciado para otros ecosistemas. De igual modo dichos grupos de especies permiten analizar comparativamente la representación de sus hábitats en áreas protegidas tanto para el presente como para un futuro sometido a cambio climático, considerando las restricciones específicas de migración futura.

Esta tesis pretende abordar los desafíos de estudio mencionados, con el objetivo general de evaluar los efectos del cambio climático en las especies de plantas que conviven en los bosques templados ubicados en Chile centro y sur, tomando como base las características constitutivas de los nichos de grupos de especies que integran la diversidad estructural de estos bosques. Se pretende abordar las preguntas respecto de cuáles podrían ser las particularidades de los nichos ecológicos en estas plantas de manera comparada entre grupos de especies, junto con proyectar los cambios esperados para la distribución de sus hábitat producto del cambio climático con restricciones específicas de migración, a fin de conocer posibles diferencias entre grupos de especies, en diferentes gradientes ambientales considerando la altitud y la latitud. Se busca también entender si los patrones de relación entre características de los nichos y los efectos esperados de cambio climático en la distribución de los hábitat con restricción específica de migración, siguen o no las tendencias que han sido proyectadas en otros ecosistemas, tomando en cuenta las condiciones particulares de transición bioclimática de las plantas que integran este *hotspot* de biodiversidad. Junto a lo anterior, esta tesis busca revelar las implicancias que el cambio climático produciría en la representación del hábitat de las especies de plantas mencionadas en áreas protegidas, considerando diferentes esquemas tanto de protección formal efectiva presente en Chile, como aquellos que han sido propuestos para una potencial incorporación futura.

HIPÓTESIS

1. Los nichos ecológicos de cada grupo de plantas que conviven en los bosques templados de Sudamérica son regidos por forzantes climáticos diferentes: árboles dominantes más relacionados a temperatura y helechos del sotobosque más relacionados a precipitación. Esto determina efectos contrastantes del cambio climático en sus hábitats: mayor desplazamiento altitudinal proyectado en árboles y mayor desplazamiento latitudinal proyectado en helechos.

2. En especies de plantas de los bosques templados de Sudamérica, la amplitud de sus nichos ecológicos está relacionada inversamente al desplazamiento esperado de sus hábitats producto del cambio climático en los gradientes a) altitudinal y b) latitudinal.

3. Los hábitats de especies de plantas de los bosques templados de Sudamérica se encuentran insuficientemente representados en las áreas de protección formal de Chile, tanto para el presente como para un futuro sometido a cambio climático con restricciones específicas de migración.

4. Los hábitats de especies de plantas de los bosques templados de Sudamérica pueden completar una suficiente representación en áreas protegidas al incorporar otras unidades propuestas (*i.e*. parques privados, sitios prioritarios para la conservación nacionales y regionales), tanto para el presente como para un futuro sometido a cambio climático con restricciones específicas de migración.

OBJETIVOS

1. Estudiar los nichos ecológicos de plantas de Chile centro y sur que integran la diversidad estructural de los bosques templados de Sudamérica (*i.e.* especies arbóreas dominantes, especies leñosas co-dominantes, helechos epífitos y terrestres del sotobosque), para evaluar diferencias entre sus propiedades en términos de la amplitud de sus nichos y en términos de posición relativa dentro de gradientes ambientales definidos por variables bioclimáticas.

2. Conocer la posible relación entre las propiedades de nicho de estas especies (*i.e.* amplitud, posición relativa), con los efectos esperados del cambio climático sobre la dirección y magnitud del desplazamiento de sus hábitats en términos de los amplios gradientes en los cuales se desarrollan (*i.e.* altitud y latitud).

3. Evaluar el grado de representación de los hábitat de estas especies bajo esquemas de conservación formal en Chile (*i.e.* SNASPE) y evaluar el efecto del cambio climático sobre la representación en un escenario futuro.

4. Evaluar el aporte aditivo en representación bajo esquemas de conservación que implica implementar categorías propuestas de conservación (*i.e.* parques privados, sitios prioritarios de conservacion a escala nacional y a escala regional) considerando tanto la situación de representación presente como la futura sometida a cambio climático.

ESTRUCTURA Y ESTADO DE LOS CAPITULOS

CAPITULO I "Ecological niches and expected elevational and latitudinal shifts due to climate change in South American temperate forest plants: are they related?"

Manuscrito enviado a la revista Journal of Biogeography (27/05/2016). Este capítulo ayuda a responder las hipótesis 1 y 2; y los objetivos 1 y 2 de la tesis.

CAPITULO II "In the right place at the right time: habitat representation in protected areas of South American *Nothofagus*-dominated plants after a dispersal constrained climate change scenario"

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Este capítulo ayuda a responder las hipótesis 3 y 4; y los objetivos 3 y 4 de la tesis.

CAPÍTULO I

Ecological niches and expected elevational and latitudinal shifts due to climate change in South American temperate forest plants: are they related?

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ABSTRACT

Aim

Niche properties such as breadth and position in environmental gradients are hypothesized to determine plant responses to climate change. We explored niche properties in plants of a temperate biodiversity hotspot, spanning different growth forms and wide ranges in elevation and latitude, to assess the relation between niche characteristics and the magnitude and direction of modelled climate-change shifts.

Location

South American temperate forests

Methods

Localities from the entire range of 118 plant species associated to these forests were considered to assess niche breadth and niche position for each species in environmental gradients through Outlying Mean Index (OMI) analyses. Both present and future distributions were modelled using BIOMOD, considering migration constraints with MIGCLIM. Relationships were explored by using general linear models with R tools.

Results

Niche differences were outlined by two bioclimatic dimensions: the first one correlated to mean temperature range and precipitation seasonality following the bioclimatic transition Mediterranean – Temperate – Sub-Antarctic; and the second one correlated to minimum winter temperature following a transition from oceanic-influenced habitats to coldest tree-line habitats. Modelled elevational shifts followed expectations with an inverse relation with niche breadth. Forecasted latitudinal shifts were directly related to niche breadth (opposite to expected trend), following a latitudinal-wise bioclimatic gradient of Temperate forests, and directly related to the latitudinal mean distribution of plants and also to their latitudinal range, following Rapoport's effect.

Main conclusions

Niches of studied plants were successfully discerned by OMI analyses. Niche differences could be associated to specific morphological or physiological traits. Elevational and latitudinal shifts for understorey species may not be in agreement with shifts of dominant trees neither in direction nor magnitude. South American temperate forests plants followed inverse relationship between niche breadth and elevational shifts, conversely to latitudinal shifts, possibly because niche drivers followed latitudinal orientation and the species showed Rapoport's effect.

KEYWORDS

BIOMOD, climate change, elevation, ferns, latitude, niche breadth, niche modelling, *Nothofagus*, Outlying Mean Index, temperate forests

INTRODUCTION

Climate change observed during last decades has affected plant species distribution, their phenology, biotic interactions and abundance (Parmesan & Yohe, 2003; Parmesan, 2006; Kelly & Goulden, 2008; Bellard *et al.*, 2012; Garcia *et al.*, 2014; Parmesan & Hanley, 2015). Future plant distributional shifts may be caused by reductions of the current distribution range occurring because future conditions may become inadequate in some parts of the current range, or due to expansions if the species has the ability to migrate to newly available suitable habitat, or both (Breshears *et al.*, 2008; Engler *et al.*, 2009; Garcia *et al.*, 2014). Current literature is plenty of examples of observed and expected distributional shifts towards higher elevations and greater latitudes (Parmesan, 2006; Lenoir *et al.*, 2008; Jump *et al.*, 2009; Grabherr *et al.*, 2010; Engler *et al.*, 2011), but also towards inverse or different directions (Lenoir *et al.*, 2010; VanDerWal *et al.*, 2012). These shifts may be assessed when present distribution models of target species are contrasted with future modelled distributions using various tools (Hijmans & Graham, 2006; Engler *et al.*, 2009).

Specific differences in niche properties, such as relative position and breadth, are among the factors that may explain the wide range of possible outcomes observed in future distributional shifts (Broennimann *et al.*, 2006; Broennimann, 2008). Species with contrasting niche positions along environmental gradients may show dissimilar responses according to changes in local or regional climes (Broennimann *et al.*, 2006; Morin & Chuine, 2006; Kelly & Goulden, 2008). Morphological and physiological characteristics of the species underlie such ecological niche differences (Chase & Leibold, 2003; Colwell & Rangel, 2009). For instance, contrasting traits like maximum size of individuals, vascular system or physiological attributes may determine niche differences between ferns and angiosperms, particularly in relation to climatic drivers such as water availability or temperature ranges (Zotz *et al.*, 2001; Brodribb *et al.*, 2005; Kluge & Kessler, 2011).

It has been suggested that species with broader niches, and hence wider distributions, could experience smaller climate change effects along environmental gradients such as elevation or latitude (Thuiller *et al.*, 2005; Broennimann *et al.*, 2006; Botts *et al.*, 2013). However, this suggestion does not take into account that niche breadth may increase with latitude because of more fluctuating environments at higher latitudes, as expected according to the Rapoport's effect for some species groups (Stevens, 1989; Vázquez & Stevens, 2004). Nevertheless, at a community level, species responses to climate change may not be homogeneous or integrated since each species' niche is different (Engler *et al*., 2011; Angert *et al*., 2013; Gornish & Tylianakis, 2013).

The South American temperate forests (SATF) are located mainly in the centre and south of Chile, also in the southwest of Argentina (Fig. 1.1). They are dominated by trees of genus *Nothofagus* and they include various woody species that form a diverse vertical structure with a species-rich understorey (Donoso, 1993; Armesto *et al*., 2001) in which fern species, including epiphytic ferns and ground ferns, are an important component (Rodríguez, 1995; Alarcón & Cavieres, 2015).

These forests comprise a north-south transition from Mediterranean-type to a Temperate bioclimate (Armesto *et al*., 2001; Luebert & Pliscoff, 2006), with a high level of species endemism and a high human use leading to the nomination of these forests as global biodiversity hotspots (Myers *et al*., 2000, Armesto *et al*., 2001). These rainforests grow along a wide elevational gradient from sea level up to high Andes mountain range tree-line, and along a large latitudinal gradient from 33° S to 55° S (Donoso, 1993; Armesto *et al*., 2001), as presented in Fig. 1.1.

The northern half of SATF shows evidence of a progressive decrease in precipitation (DMC, 2015) projected to continue in the future, but the southern extreme of these forests expects an increase in precipitation (IPCC, 2013). However, temperature is predicted to increase in the whole range according to future climatic projections (IPCC, 2013). Although the projected climate change effects on these forests have been assessed at a physiological level for main tree species (Gutiérrez, 2010), and at a level of habitat size and representation in protected areas (Alarcón & Cavieres, 2015), assessments of potential shifts of their species populations along environmental gradients have not been addressed. Since they live along extensive gradients in elevation and latitude, it is challenging to assess and anticipate their component species responses to the undergoing climatic changes through its transition from Mediterranean to Temperate ecosystems, as it has been assessed to experience striking effects in the analogous European gradients (Pauli *et al*., 2012).

Our aim here is to evaluate the differences between species properties such as niche breadth and niche position within environmental gradients, of four groups of plants that represent the structural diversity of SATF (i.e. dominant tree species, woody co-dominant species, understorey ground ferns and epiphytic ferns) and to determine possible relations of the aforementioned niche properties with the expected effects of climate change upon the habitats' shift direction and magnitude, along these noticeable elevational and latitudinal gradients.

MATERIALS AND METHODS

Plant species groups

Four groups of SATF plants were considered as components of their vertical structure: trees of genus *Nothofagus* with 9 dominant species, 27 co-dominant woody species, 55 ground ferns and 27 epiphytic fern species. The total 118 plant species share their distribution within elevational and latitudinal gradients with the dominant trees (Gajardo, 1994; Donoso, 1993). The nomenclature followed Zuloaga *et al.* (2008) for woody species and Rodríguez (1995) for ferns. We gathered all available species localities from the University of Concepción herbarium (CONC), with possible coordinate biases checked and corrected from their label information, and the Chilean national forest inventory for dominant trees validated in the field (CONAF-CONAMA-BIRF, 1999). The species list and their valid number of localities are shown in Table 1.S1, Supporting Information.

Bioclimatic information

From the Worldclim database (Hijmans *et al.*, 2005), eight bioclimatic variables were selected with the least correlation among them for the studied species range area: i) mean temperature range (bv02), ii) temperature seasonality (bv04), iii) maximum temperature of the warmest month (bv05), iv) minimum temperature of the coldest month (bv06), v) annual precipitation (bv12), vi) precipitation seasonality as a coefficient of variation (bv15), vii) precipitation of warmest quarter (bv18), and viii) precipitation of coldest quarter (bv19). The bioclimatic information from each species occurrences was obtained with tools from R Core Team (2015): raster (Hijmans, 2015) and rgdal (Bivand *et al*., 2015).

Ecological niche analyses

We used all the species localities and the corresponding bioclimatic information to perform Outlying Mean Index (OMI) analyses. This multivariate method separates species niches in axes that reflect environmental variables (Dodélec *et al*., 2000), and it does not consider *a priori* assumptions on the length of dimensions, giving equal weight to each site regardless of its local species richness. This make it suitable for measuring niche relative positions in environmental dimensions, and better for measuring comparative niche breadths, unlike other ordination methods that may generate biases (Thuiller *et al*., 2004; Kleyer *et al*., 2012; Meynard *et al*., 2012). OMI analyses were carried out with niche functions from ade4 R-package (Dray & Dufour, 2007), so the niche position and niche breadth were obtained for subsequent analyses considering all the species as a whole group, but also by each species group separately to assess the climatic variables driving the main differences within each group. Niche breadth indexes were calculated from the square root of the raw niche breadth values.

Species distribution models

The species distributions were modelled using BIOMOD R-package (Thuiller, 2003; Thuiller *et al*., 2009) through eight techniques: Artificial Neural Networks (ANN), Classification Tree Analysis (CTA), Flexible Discriminant Analysis (FDA), Generalised Additive Models (GAM), Generalised Boosting Models (GBM), Generalised Linear Models (GLM), Multivariate Adaptive Regression Splines (MARS), and Random Forest (RF), all explained by Thuiller (2003). The criteria for selecting each species' best model followed Alarcón & Cavieres (2015). Distribution models were projected in 30 arc-second grids with BIOMOD and areas with human land use were discounted from each model according to CONAF-CONAMA-BIRF (1999) using raster R-package (Hijmans, 2015).

Future distribution models and species migration constraints

Future climate data scenarios were taken from Ramirez & Jarvis (2008), selecting the most conservative scenario according to their least change on dominant *Nothofagus* distributions as explained in Alarcón & Cavieres (2015): CSIRO MK2 B2A, projecting each species future distributions with BIOMOD based on the specific best niche model. We deducted the potential future distributions according to the specific migration constraints applying the MIGCLIM R-package (Engler *et al*., 2012). This step considered dispersal kernels, potential propagule production, short-distance dispersal capacity and probability of long-distance dispersal, as developed by Alarcón & Cavieres (2015) for the same species set.

Expected shifts in elevational and latitudinal gradients

Mean distributions in elevation and latitude for each species were calculated from the projected grids using raster R-package (Hijmans, 2015). Scatterplots were performed contrasting elevational versus latitudinal shifts, in order to explore the extent of different direction responses within each species group. Responses were considered as stable if changes in mean elevation or latitude were less than 25 m a.s.l. and 0.1 latitudinal degree respectively. Both present mean distribution and future mean distribution were compared by fitting linear models (R Core Team, 2015) for both altitudinal and latitudinal gradients, to explore possible patterns in the shifts.

Indexes of change for both elevation and latitude were calculated using the square root of the absolute value of the difference between future mean distribution and present mean distribution. Other explored patterns included the possible relation between the niche position in each OMI axis and the indexes of change for both elevational and latitudinal gradients. Afterwards, we searched for possible relations between the niche breadth and the predicted shifts in each gradient as anticipated in literature, fitting general linear models that considered niche breadth indexes and the indexes of change. Also, the values of niche breadth for both the most shifted half and the less shifted half of species for each gradient were analysed if there were differences using Mann–Whitney *U*-test (R Core Team, 2015), as they did not follow normal distributions. Relationships between latitudinal parameters and niche properties were explored by linear general models in order to test if these temperate rainforests plants follow Rapoport's effect.

RESULTS

Niche analyses

The results of OMI analyses are shown in Table 1.1. When all species were considered, two principal axes aggregated 95.2% of the total variance, where OMI axis 1 explained 74.4% of the variance and it was mainly correlated with the mean temperature range (bv02, -79.9%). OMI axis 2 explained 20.9% of the variance where minimum temperature of the coldest month was the most correlated variable (bv06, -56.3%).

When OMI was applied only on *Nothofagus* species, two main axes accounted for 97.9% of the total variance; 73.3% was explained by axis 1, which was mainly correlated with maximum temperature of the warmest month (bv05, -77.4%) and 24.7% of the variance was explained by axis 2, with minimum temperature of the coldest month as the variable with the highest correlation (bv06, -52.9%). OMI analysis for co-dominant woody species showed two axes including 94.5% of the total variance, where axes 1 and 2 accounted for 85.1% and 9.4% of the variances, respectively. The bioclimatic variables with the highest correlations were precipitation seasonality (bv15, -80.3%) for axis 1 and minimum temperature in the coldest month (bv06, -45.2%) for axis 2.

For ground ferns species OMI analysis explained 85.7% of variance in two axes: 68.1% for axis 1 and 17.7% for axis 2. The most correlated variables were annual precipitation (bv12, +60.1%) for axis 1 and minimum temperature in the coldest month (bv06, -51.2%) for axis 2. Finally, the OMI analysis for epiphytic ferns accounted for 94.1% of the variance in two main axes: 63.7% for axis 1 and 30.4% for axis 2. Both the maximum temperature in the warmest month (bv05) and the minimum temperature in the coldest month (bv06) resulted as most correlated with axis 1 (+48.1%), while annual precipitation (bv12) was the most correlated with axis 2 (-37.7%).

The occupancy extent of each species group within the two main OMI bioclimatic gradients is shown in Fig. 1.2. The relative position of every species in each axis, along with the comparative niche breadths are shown in Fig. 1.3. In Tables 1.S1 and 1.S2 in Supporting Information, the same kind of results for separated analyses within each group of species can be found.

The lowest extreme of OMI axis 1 for all species (Fig. 1.2 and 1.3) included niches outlined by a greater mean temperature range, a sharp seasonality of rainfall towards winter, higher summer temperature and less annual precipitation. These conditions are distinctive of the transition from Temperate to Mediterranean climate of central Chile, inhabited by deciduous *Nothofagus* species like *N. glauca* or *N. obliqua* in the northern distribution of these temperate forests, co-dominant species belonging to sclerophyllous flora (like *Cryptocarya alba* or *Azara petiolaris*) and ground ferns particularly adapted to summer drought (including cheilanthoid ferns and *Adiantum excisum* or *Adiantum gertrudis*). An absence of epiphytic ferns in this climatic niche extreme was also observed, except for some species like *Polypodium feullei* with thick rhizomes that allow them to survive the dry season.

More humid and oceanic conditions prevailed in the upper extreme of OMI 1, associated to coastal and southern distribution of these temperate forests, with lower temperature amplitude, lower seasonality for both temperature and precipitation, and higher precipitation amounts, in a transition from Temperate to Sub-Antarctic bioclimate. Such niches corresponded to evergreen *Nothofagus* species such as *N. nitida* or *N. betuloides* with co-dominant trees adapted to conditions of highest precipitation within the temperate forest gradient, like *Pilgerodendron uviferum*, *Podocarpus nubigenus* or *Tepualia stipularis*, and ground ferns as *Gleichenia litoralis, Gleichenia quadripartita* or *Polystichum multifidum* and epiphytic ferns like *Hymenophyllum secundum*, *Hymenophyllum ferrugineum* and *Hymenophyllum tortuosum.*

In the middle position of OMI 1 axis, the niches of characteristic species from the central distribution of these temperate forests were found, such as *Nothofagus dombeyi* or *Eucryphia cordifolia*, along with several ground ferns and epiphytic ferns, especially Hymenophyllaceae filmy ferns.

The OMI 2 axis was mainly correlated to lowest winter temperature from less extreme conditions at its minor tip, with niches of ground ferns typical of thermally stable conditions like oceanic ferns *Adiantum obtusatum* or *Blechnum asperum*, or those unable to resist freezing as *Blechnum blechnoides* or *Trichomanes exsectum*. Besides, niches of a remarkable diversity of epiphytic ferns such as *Pleopeltis macrocarpa, Hymenophyllum cuneatum, Hymenophyllum dicranotrichum* and *Asplenium trilobum,* and many co-dominant species unable to tolerate extreme cold, like *Drimys winteri, Laurelia* *sempervirens* or *Aextoxicon punctatum* share their niches at this lower part of the secondary OMI axis.

At the top of OMI 2 gradient, niches of deciduous trees *Nothofagus pumilio* and *Nothofagus antarctica* were found since they are able to withstand the lowest temperatures of the gradient. They form the tree line through the major part of these temperate rainforests, accompanied with co-dominant species like *Maytenus disticha* and ground ferns capable of standing winter lowest temperatures as *Botrichium dusenii* and *Lycopodium alboffii,* and cold-hardy epiphytic ferns like *Grammitis poeppigiana.*

Expected shifts

The effect of climate change on projected shifts in the elevational and latitudinal gradients are shown in Fig. 1.4 and Table 1.2, where upward movements for their mean elevation and southward shifts (towards higher latitude) are expected for 41% of the studied species. Nevertheless, there were differences among species groups, especially when comparing trees versus ferns. Both dominant *Nothofagus* and co-dominant trees showed that on 56% of their species a relocation of their mean distribution to higher elevation and higher latitude would be expected. Ferns showed more heterogeneous effects. Among ground ferns, 38% of the species would shift towards higher elevation and southward latitude, whilst 16% of them were projected to move upward but to northward latitude. Regarding epiphytic ferns, models indicated 33% of species with elevational changes that are not strong, but with a tendency of their mean distribution to move southward and 26% of species projected a shift upward in elevation and southward to higher latitudes.

Present versus future elevational distribution linear models revealed slopes significantly different from 1 for all the species groups (Fig. 1.5a,b,c,d), with slopes greater than 1 for *Nothofagus* ($p<0.01$), co-dominant trees ($p<0.001$) and ground ferns ($p<0.001$). These results indicated that species with mean distributions located at higher elevations would have greater upward shifts in the elevation gradient, compared to those located at lower elevations. In contrast, epiphytic ferns showed a slope less than 1 ($p<0.01$), indicating that the species with lower mean elevational distributions are projected to shift upward in more magnitude than the epiphytic ferns with higher mean elevation distributions.

For the latitudinal gradient (Fig. 1.5e,f,g,h), slopes in the linear models were greater than 1 for *Nothofagus* ($p<0.01$) and co-dominant species ($p<0.001$), meaning that in general the southernmost mean distributions are expected to have greater southward latitudinal shifts. In contrast, slope for ground ferns was lower than 1 ($p<0.01$) suggesting that species with mean distribution located in the northern part of the latitudinal gradient would have greater shifts projected southwards. The epiphytic ferns group did not show a special pattern of different magnitude of forecasted latitudinal shift ($p=0.096$).

Shifts in relation to niche position and niche breadth

The location of all species at each main OMI axis was contrasted to the projected index for elevational change and latitudinal change (Fig. 1.6). The species located at the lower part of OMI axis 1 (Temperate transitioning towards Mediterranean bioclimate) are expected to have a greater ($p<0.001$) elevational change index than those located at its upper part with colder, more humid Temperate towards oceanic Sub-Antarctic bioclimate (Fig. 1.6a). The opposite relation was found ($p=0.0275$) when OMI axis 2 was considered (Fig. 1.6b), with larger elevational changes expected for species' niches corresponding to upper OMI 2 (colder winters) compared to the shifts at lower OMI 2 (moderate winter temperature).

No relation was found when we compared between latitudinal shifts and niche position in OMI axis 1 (Fig. 1.6c), but when considering OMI axis 2, a direct relation was found ($p=0.0026$). This indicated that species related to moderate winter temperatures may experience less latitudinal changes than species associated to colder winter temperature or tree line (Fig. 1.6d). No significant relationship was found when the elevational change index was contrasted to the niche breadth index at both OMI axes (Fig. 1.6e,f). However, when the species were split by the level of expected changes, least shifted half of species appeared with higher niche breadth index ($p=0.0358$) at OMI axis 1 compared to the most shifted half of species, suggesting an inverse relation between the changes in elevation and niche breadth in that axis (Fig. 1.7a).

When latitudinal change index was contrasted to niche breadth (Fig. 1.6g,h), direct relationships were found at both OMI axes 1 ($p=0.009$) and 2 ($p<0.001$). Similar trends appeared when we compared niche breadth indexes of both least latitude-shifted half of species and most latitude-shifted half of species, for OMI axes 1 (p=0.033) and 2 (p=0.047), as shown in Fig. 1.7(c,d).

Direct relationships were found after contrasting mean distribution by latitude and niche breadth index at both OMI axes (p=0.009 for OMI 1, p<0.001 for OMI 2) as shown in Fig. 1.8(a,b), as well as latitudinal range against niche breadth index for both OMI axes (p<0.001) displayed in Fig. 1.8(c,d). The same tendency was outlined between latitudinal mean and latitudinal range as shown in Fig. 1.8e (p=0.015). Finally the latitudinal change index related to latitude range resulted positive (p<0.001; Fig. 1.8f).

DISCUSSION

Niche differentiation

Our results showed a bioclimatic niche differentiation among SATF plants, mainly related to the mean temperature range and precipitation seasonality, following the ecological transition within Temperate bioclimate from central Chile's Mediterranean climate to Patagonia Sub-Antarctic climate (OMI axis 1) and secondly related to the minimum winter temperature following the transition from oceanic stable habitats to coldest Andes tree-line habitats (OMI axis 2). While bioclimatic classifications that have analysed these forests (Amigo & Ramírez, 1998; Luebert & Pliscoff, 2006) are focused in both temperature and precipitation as equally important factors, we found that variables related to energy resulted more relevant than water availability to discriminate ecological niches considering all studied plants. The same has been found in local Temperate to Mediterranean transition (Teneb *et al.*, 2004), and in a global-scale assessment of factors determining plant distributions (Box, 1995).

Interestingly, when OMI was analysed separately by plant group, key bioclimatic variables differed, somehow distinguishing morphological or physiological traits. Niches within *Nothofagus* were discriminated mainly by maximum temperature of the warmest month. Alberdi (1995) informed summer foliar TL50 temperatures for southernmost species including tree line-forming *Nothofagus*, following the concordant order found here in niche position: *N. dombeyi*, *N. pumilio*, *N. antarctica*, *N. nitida* and *N. betuloides* from lower to higher summer frost resistance, and the correlated niche position from higher to lower summer temperature. Further, these differences among niches could also be interpreted observing the species' ability to survive after germination: biggest seeds (*N. glauca*, *N. obliqua* or *N. alpina*) able to reach deeper soil moisture thus preventing desiccation (Donoso, 1993), were found at niches related to highest summer temperatures, while the opposite was found for smallest seeds (*N. betuloides*, *N. antarctica* or *N. nitida*) that could not need such strategy. Nevertheless, differences in niches of co-dominant species were driven mainly by precipitation seasonality, following the climatic transition from a dry summer condition to a full-year precipitation. Hence, foliar sclerophylly could be interpreted as being related: *Azara petiolaris*, *Cryptocarya alba*, *Persea lingue*, *Myrceugenia exsucca* or *Podocarpus salignus* with higher sclerophyly (Alberdi, 1995; Read *et al*., 2016) presented niche positions associated with summer drought, while *Drimys winteri*, *Tepualia stipularis*, *Weinmannia trichosperma* and *Laureliopsis philippiana* with lower sclerophylly (Alberdi, 1995) presented niche positions related to full-year precipitation.

Annual precipitation was the most important variable for terrestrial fern niches. With life cycles and distribution patterns ruled by water availability (Quian *et al*., 2012), niche differences in ground ferns were coherently related to adaptations to the amount of precipitation, from low-rainfall adapted cheilanthoid ferns to ground ferns specially adapted to more humid habitats (Rodríguez, 1995; Parra *et al*., 2015). Moreover, epiphytic ferns, within a smaller niche space compared to other groups according to the general OMI analysis, presented thermal extremes (maximum summer temperature, minimum winter temperature) as the most relevant niche-discriminating variables. Some species present poikilohydric strategies (absence of stomata, lack of main vacuoles in lamina cells) in most of *Hymenophyllum* ferns generally associated with coastal or southern habitats thermally stable (Ponce *et al*., 2012), while strategies like water-reserving rhizomes in *Polypodium feuillei* were found at wider thermal extremes in transition to Mediterranean bioclimate (Rodríguez, 1995).

Diverse shifts responses by species group

Even though most of the species showed shift effects towards higher elevation and higher latitude, the responses differed among species groups. More than half of studied trees showed these globally common trends: polewards and upwards (Jump *et al*., 2009;

Parmesan, 2015). Nevertheless, we realized that for both groups of understorey ferns, shift responses in elevation and in latitude were more diverse in direction and in magnitude than for dominant trees. These different responses in plants have been documented for other communities worldwide (Kelly & Woulden, 2008; Lenoir *et al*., 2010), but we found noticeably more diverse responses than those modelled by VanDerWal *et al*. (2012) for Australian temperate forests' species. The variation in responses to climate change for ground ferns and epiphytic ferns in this study could be linked to a more heterogeneous location of climatic niche positions compared to the trees, as displayed by OMI analysis (Fig. 1.2).

According to the linear models, we found different trends in elevational shifts: *Nothofagus* trees, co-dominant species and ground ferns projected in general greater shifts for their species located at higher elevations, than those at lower sites. However, this was an inverse pattern for epiphytic ferns, maybe related to a dissimilar occupancy of this species group along the elevational gradient: the mean elevation of epiphytic ferns species were restricted to lower than 600 m a.s.l. while other plant groups exceeded 1000 m a.s.l.

After the examination of the latitudinal gradient, the pattern of latitudinal shift could be related to the extent of the species' mean distributions. Wider presence was observed in ground ferns (mean latitudes between 25 and 50 southern degrees), and greater latitudinal shifts were expected for those with lower mean latitude. Conversely, *Nothofagus* and co-dominant (mean latitudes between 35 and 48 southern degrees) projected their greater latitudinal shifts for species located towards higher latitude.

Elevational and latitudinal shifts related to niche position and niche breadth

The relation found between changes in elevation and niche position revealed greater elevational shifts expected for plants associated with the bioclimatic transition Temperate to Mediterranean than Temperate to Sub-Antarctic. That is opposite to the European analogous bioclimatic gradient analysed by Pauli *et al*. (2012), with a greater elevational change for Temperate-Boreal plants than Mediterranean plants. The pattern we found here included niche segregation in a climate change scenario with decreasing precipitation in almost the entire Temperate gradient, while in Europe precipitation is expected to increase in the homologous biome (IPCC, 2013). Besides, in SATF the elevational gradient itself was wider at the transition from Temperate to Mediterranean bioclimate compared to the transition from Temperate to Sub-Antarctic bioclimate, enabling a greater potential for expressing the expected elevational changes due to climate change.

The expected changes in elevation and latitude were directly related to the species' position in the niche dimension regarding the thermal gradient from a moderate winter temperature to the coldest winter temperature. A possible explanation could be that the climate change is expected to increase the temperature throughout the SATF, and this may heighten the minimum thermal edge across the whole ecosystem, so that greater changes could be intensified towards Andean tree line and Patagonic boundary of SATF (coldest winters), compared to the thermally moderate oceanic-influenced Temperate portion.

Theory has stated an inverse relation between niche breadth and projected climate change effects (Thuiller *et al*., 2005). Our results suggested this trend regarding the impacts on the elevational gradient: plants with narrower niche breadth were linked to greater elevational shifts, at least for the main niche OMI dimension, in line with assessments in South Africa for plants (Broennimann *et al*., 2006), and amphibians (Botts *et al*., 2013). Here we showed that in South America, species with restricted niche presence across the Temperate gradient from Mediterranean to Sub-Antarctic bioclimate corresponded to the most shifted plants in terms of elevation due to climate change.

Forecasted plants' shifts within latitudinal gradient did not show the formerly stated inverse pattern when contrasted to niche breadth. Instead, latitudinal shifts were directly related to niche breadth for both analysed OMI dimensions, especially axis 1, which is correlated to a bioclimatic gradient oriented by latitude of Temperate forests from Mediterranean transition to Sub-Antarctic transition. To our knowledge, this is the first study showing this pattern.

Such results could be explained from the point of view of the widespread latitudinal gradient where SATF grow, also considering the direct pattern found between the plants' niche breadth (at both OMI dimensions) and their latitudinal mean distribution of species, showing wider niche breadth values towards higher latitude. Our results also showed the direct relation between the plants' mean latitude and their latitudinal range. These patterns corresponded to Rapoport's effect (Stevens, 1989), which was already described by Arroyo *et al*. (1996) for SATF plants as well.

The direct relation found between latitudinal shift and niche breadth could also be explained because plants with wider niche breadth in SATF are related to latitudinal ampler distributions, as well as the fact that the main climatic niche drivers presented a latitudinal-wise transition, and also that the projected changes for these climatic drivers have been forecasted with a gradient by latitude, and finally great changes of latitudinal extremes are not expected according to each species' dispersal mechanisms. All of them could help for instance to produce local extinction at the northern distribution and local spread towards southern distribution, not observed to be frequent in species with narrow latitudinal distributions.

CONCLUSIONS

Ecological niches of SATF plants were successfully discerned by OMI analyses to be distributed in two bioclimatic dimensions: one shaped by mean temperature range and seasonality of rainfall displayed in a Mediterranean – Temperate – Sub-Antarctic bioclimate transition, and the second one comprised of minimum temperature of coldest month in a transition from oceanic-influenced habitats towards Andean tree line and Patagonic edge.

Key bioclimatic variables for niches differed by species group: maximum temperature of the warmest month for dominant *Nothofagus*, precipitation seasonality for co-dominant species, annual precipitation for ground ferns and both maximum warmest month temperature and minimum coldest month temperature for epiphytic ferns. It is suggested that differences found could be due to morphological or physiological specific traits.

Elevational and latitudinal shifts in response to climate change for understorey species may not be assumed to be the same in direction or magnitude as for the trees that dominate these temperate forests. Most dominant and co-dominant trees were expected to shift towards higher elevation and latitude, while ferns groups were projected to display more diverse responses in direction, related to differences in niche characteristics. Shifts in magnitude differed among species groups as well, combining the niche segregation in the environmental dimensions.

Expected elevational changes were suggested to be inversely related to niche breadth as formerly stated. Latitudinal variation of studied species' niche breadth supported the Rapoport's effect, and this together with the unequal expression of climate change projection in the whole distribution of SATF may explain the fact that latitudinal changes showed a direct relation with niche breadth contrary to the expected by theory.

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TABLES

Table 1.1. Correlation values between bioclimatic variables and the two main axes from the Outlying Mean Index (OMI) analysed for all the species and also for each studied group separately. Proportion of the total variance explained by each OMI axis is also shown. Source: own elaboration.

Bioclimatic variable		All species		*Nothofagus*		Co-dominant		Ground ferns		Epiphytic ferns	
		OMI 1	OMI 2	OMI 1	OMI 2	OMI 1	OMI 2	OMI 1	OMI 2	OMI 1	OMI 2
bv02	Mean Temperature Range	**-0.799**	-0.019	**-0.762**	0.052	**-0.775**	0.098	**-0.555**	0.071	0.228	0.216
bv04	Temperature Seasonality	**-0.624**	0.191	**-0.510**	0.223	**-0.618**	0.163	-0.364	0.223	0.038	0.173
bv05	Max Temperature Warmest Month	**-0.743**	-0.285	**-0.774**	-0.198	**-0.793**	-0.103	**-0.511**	-0.291	**0.481**	0.088
bv06	Min Temperature Coldest Month	0.080	**-0.563**	-0.107	**-0.529**	-0.012	**-0.452**	-0.059	**-0.512**	**0.481**	-0.129
bv12	Annual Precipitation	**0.510**	-0.280	0.288	-0.402	**0.609**	-0.002	**0.601**	-0.139	0.116	**-0.377**
bv15	Precipitation Seasonality	**-0.752**	-0.216	**-0.764**	-0.113	**-0.803**	-0.082	**-0.577**	-0.201	**0.443**	0.124
bv18	Precipitation Warmest Quarter	**0.648**	-0.052	**0.559**	-0.198	**0.632**	0.138	**0.577**	0.024	-0.219	-0.276
bv19	Precipitation Coldest Quarter	0.101	-0.485	-0.171	-0.492	0.249	-0.251	0.480	-0.219	0.352	-0.307
% Explained:		74.4%	20.9%	73.3%	24.7%	85.1%	9.4%	68.1%	17.7%	63.7%	30.4%

Table 1.2. Proportion of each species group (%) and total species, according to the expected shift due to climate change in elevation and latitude. Species numbers are in parentheses. Source: own elaboration.

Expected change in:		*Nothofagus*	Co-dominant	Ground ferns	Epiphytic ferns	Total species
Elevation	Latitude					
Downward	Northward	-	-	4% (2)	4% (1)	3% (3)
Downward	Stable	-	4% (1)	4% (2)	-	3% (3)
Downward	Southward	-	-	9% (5)	4% (1)	5% (6)
Stable	Northward	-	4% (1)	4% (2)	7% (2)	4% (5)
Stable	Stable	22% (2)	4% (1)	-	11% (3)	5% (6)
Stable	Southward	11% (1)	11% (3)	13% (7)	**33% (9)**	**17% (20)**
Upward	Northward	-	7% (2)	**16% (9)**	7% (2)	11% (13)
Upward	Stable	11% (1)	15% (4)	13% (7)	7% (2)	12% (14)
Upward	Southward	**56% (5)**	**56% (15)**	**38% (21)**	**26% (7)**	**41% (48)**

FIGURES

Figure 1.1. Geographical distribution of southern South American rainforests with *Nothofagus* habitat according to Alarcón & Cavieres (2015), compared to elevational gradient along with latitudinal gradient and the bioclimatic transition from Mediterranean to Temperate bioclimates according to Luebert & Pliscoff (2006). Source: own elaboration.

Figure 1.2. Analysis of distribution of assessed species on niche axes from bioclimatic variables using the Outlying Mean Index (OMI) method. Source: own elaboration.

Figure 1.3. Niche position and niche breadth comparison for all species in both components of Outlying Mean Index (OMI): OMI axis 1 (left) and OMI axis 2 (right). Source: own elaboration.

Figure 1.4. Scattered plots of expected shifts in elevation (x axis) and latitude (y axis) for each species in a) *Nothofagus* dominant trees, b) co-dominant species, c) ground ferns, and d) epiphytic ferns. Histograms of species by expected shift are also shown above (by elevation) and right (by latitude) for each plot. Source: own elaboration.

Figure 1.5. Expected shifts by each species group in elevation (letters a to d) and in latitude (letters e to h). Each species is represented by circles, no change position is represented by diagonal green lines. Fitted linear models for each species group are shown in red lines. Source: own elaboration.

Figure 1.6. Relations for all the species between niche position and niche breadth and expected shifts: between niche position and elevational changes in a) OMI axis 1, and b) OMI axis 2; between niche position and latitudinal changes in c) OMI axis 1, and d) OMI axis 2; between niche breadth and elevational changes in e) OMI axis 1, and f) OMI axis 2; and between niche breadth and latitudinal changes in g) OMI axis 1, and h) OMI axis 2. Source: own elaboration.

Figure 1.7. Differences in niche breath index of species, between least shifted half of species and most shifted half of species in both elevation and latitude, considering both OMI 1 and OMI 2 niche axes. Source: own elaboration.

Figure 1.8. Relations for all species regarding latitudinal parameters: between niche breadth index and latitudinal mean for a) OMI 1, and b) OMI 2; between latitudinal range

and niche breadth for c) OMI 1, and d) OMI 2; e) between latitudinal range and latitudinal mean; and f) between latitudinal change index and latitudinal range. Source: own elaboration.

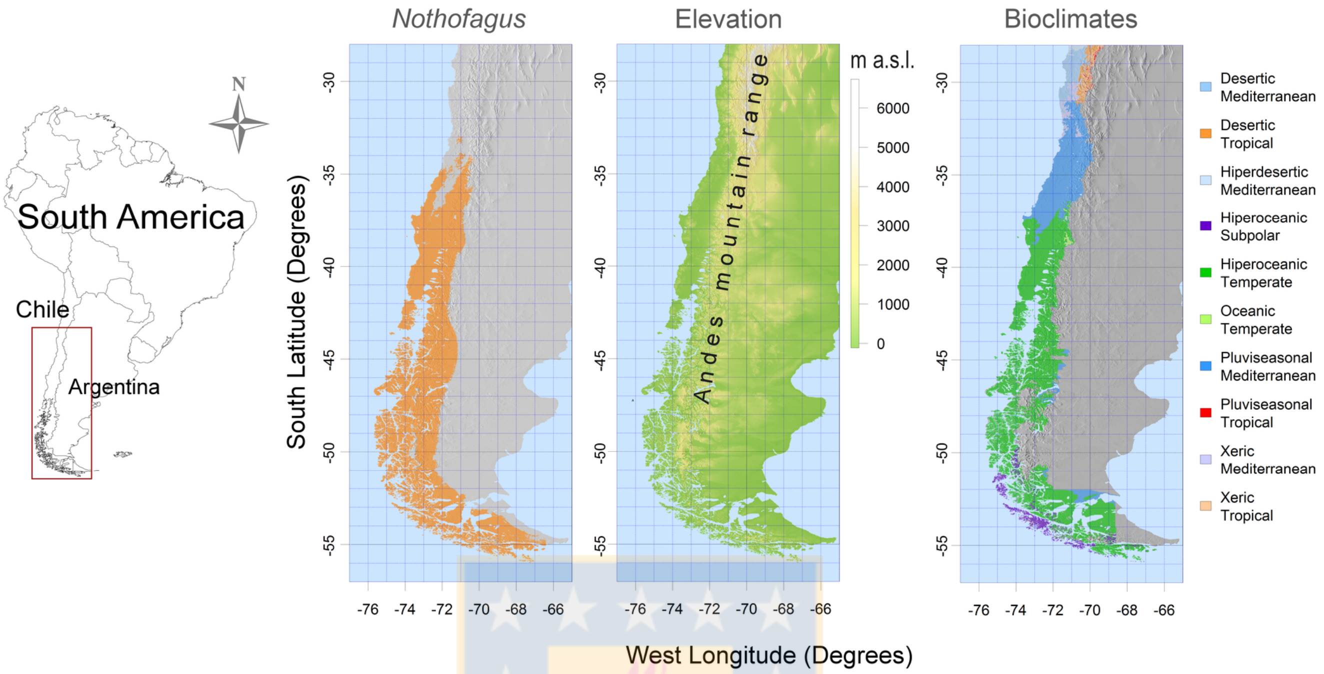

Figure 1.1. Geographical distribution of southern South American rainforests with *Nothofagus* habitat according to Alarcón & Cavieres (2015), compared to elevational gradient along with latitudinal gradient and the bioclimatic transition from Mediterranean to Temperate bioclimates according to Luebert & Pliscoff (2006). Source: own elaboration.

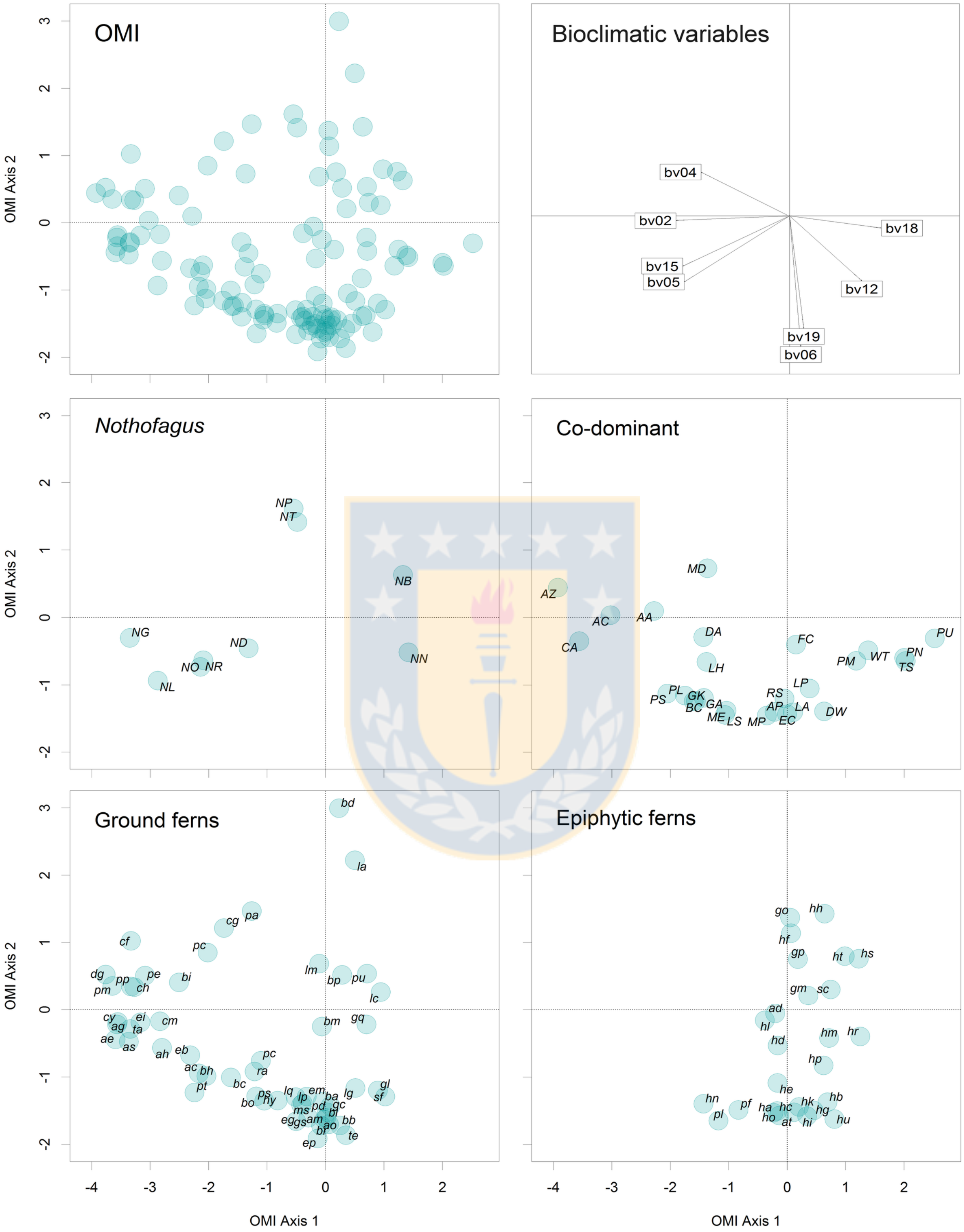

Figure 1.2. Analysis of distribution of assessed species on niche axes from bioclimatic variables using the Outlying Mean Index (OMI) method. Source: own elaboration.

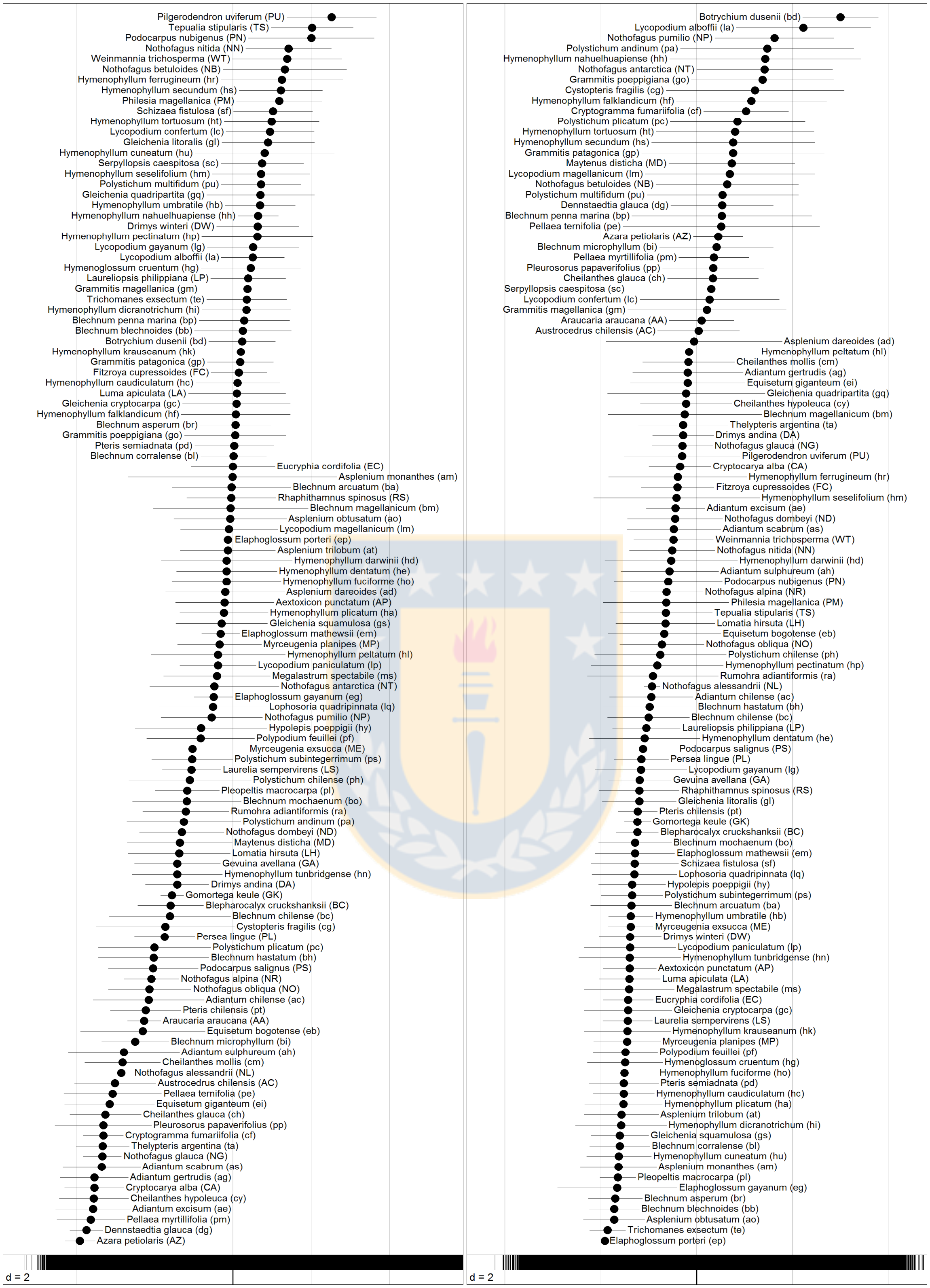

Figure 1.3. Niche position and niche breadth comparison for all species in both components of Outlying Mean Index (OMI): OMI axis 1 (left) and OMI axis 2 (right). Source: own elaboration.

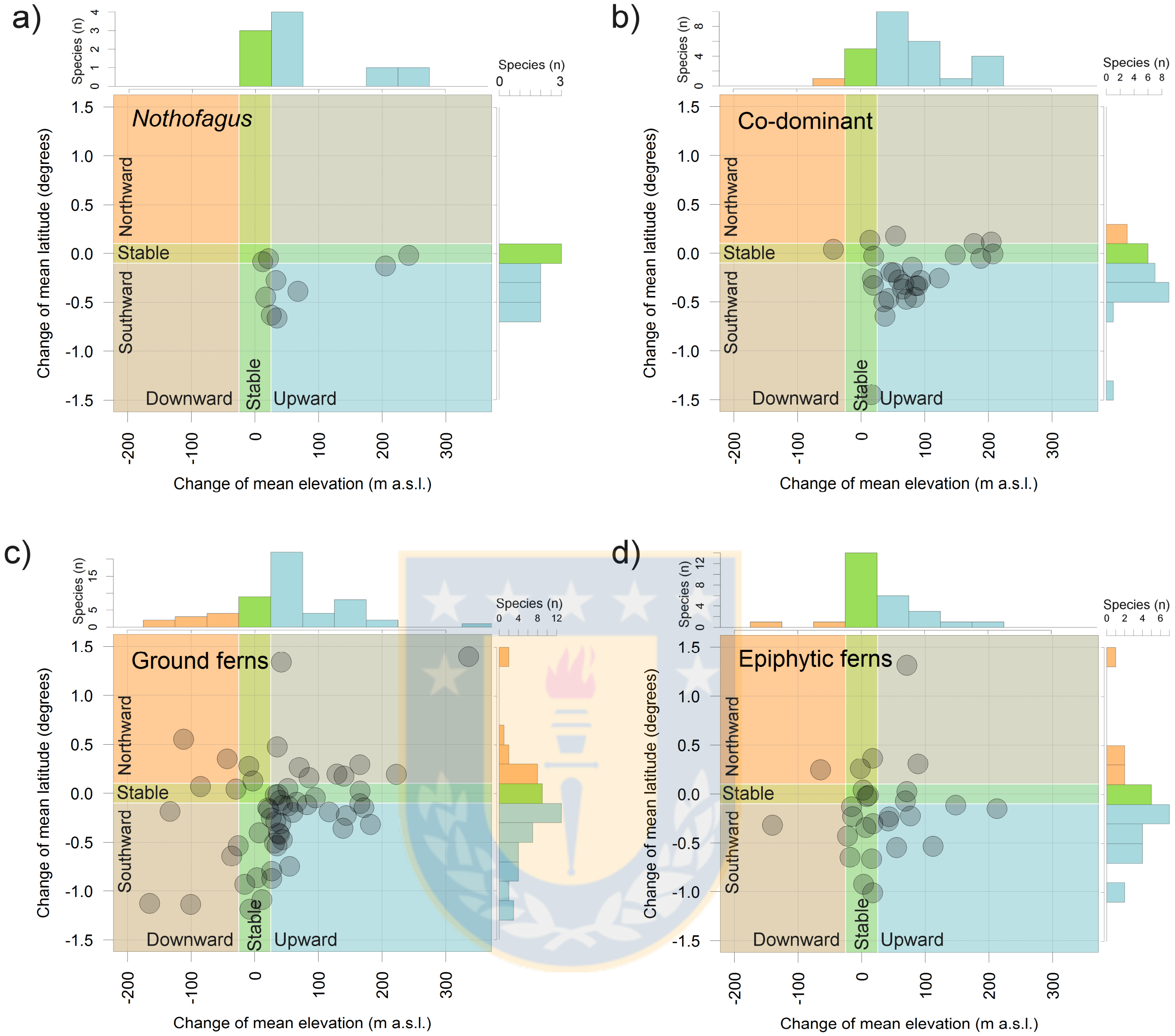

Figure 1.4. Scattered plots of expected shifts in elevation (x axis) and latitude (y axis) for each species in a) *Nothofagus* dominant trees, b) co-dominant species, c) ground ferns, and d) epiphytic ferns. Histograms of species by expected shift are also shown above (by elevation) and right (by latitude) for each plot. Source: own elaboration.

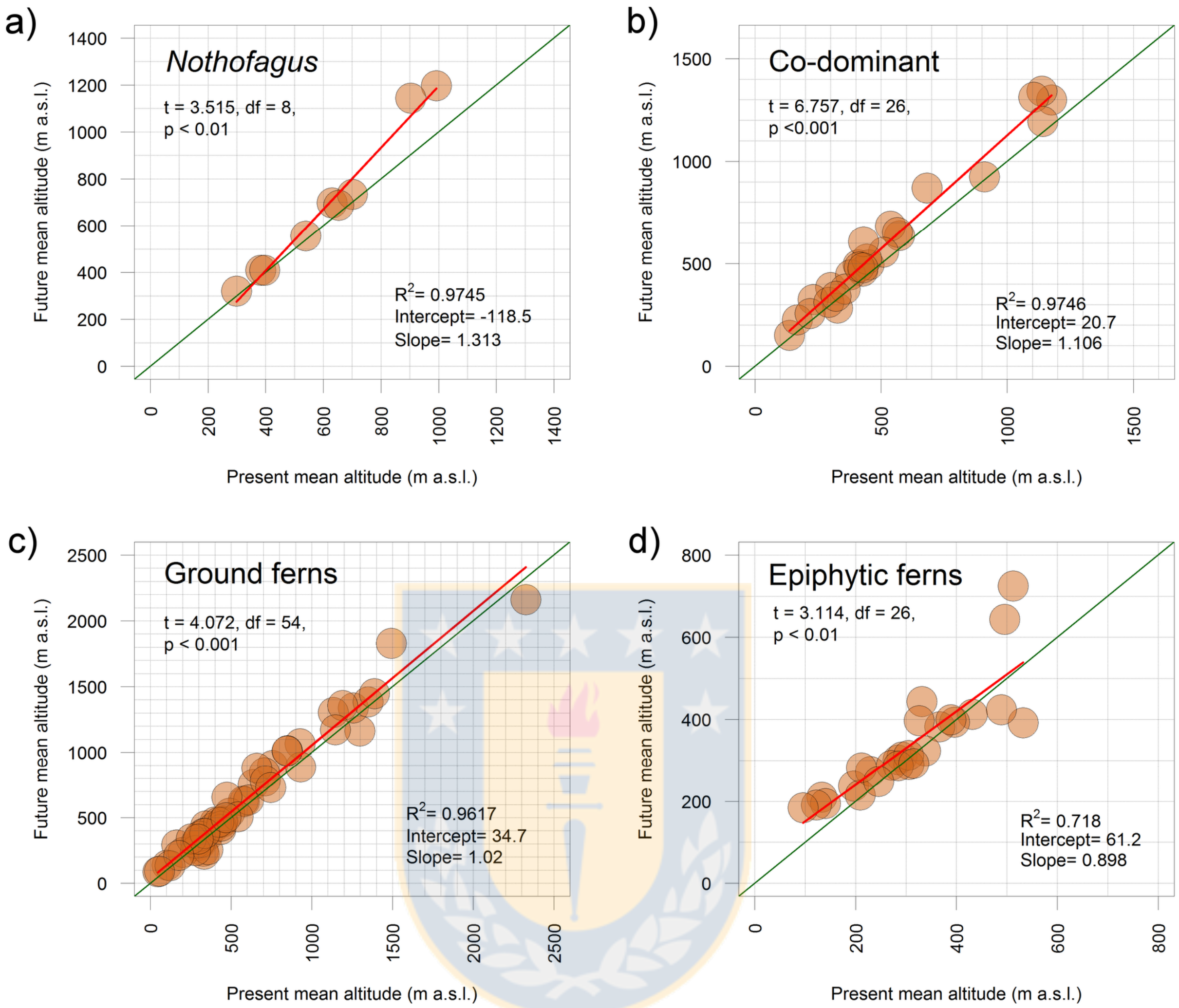

Figure 1.5. Expected shifts by each species group in elevation (letters a to d) and in latitude (letters e to h). Each species is represented by circles, no change position is represented by diagonal green lines. Fitted linear models for each species group are shown in red lines. Source: own elaboration.

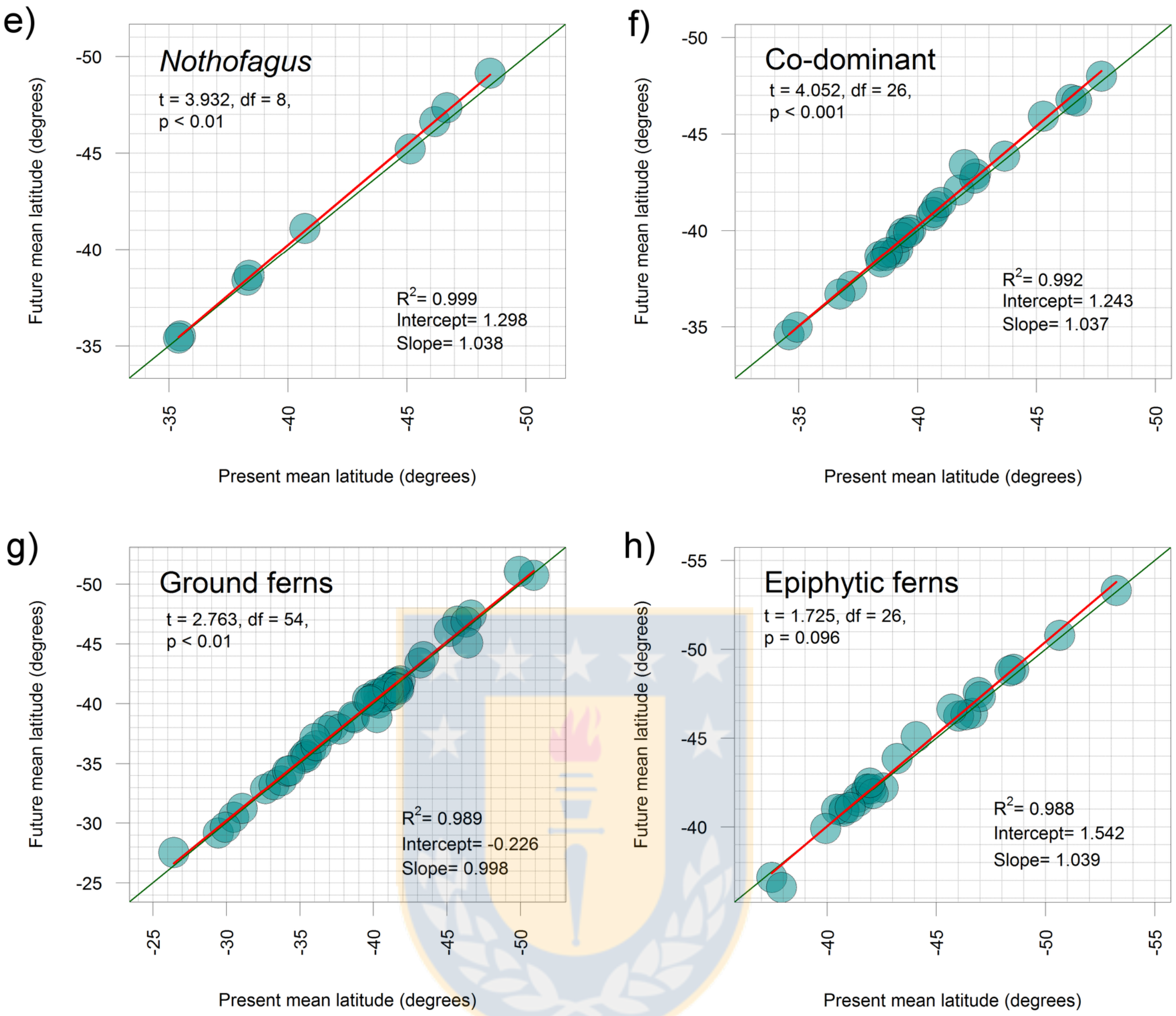

Figure 1.5. (continued). Expected shifts by each species group in elevation (letters a to d) and in latitude (letters e to h). Each species is represented by circles, no change position is represented by diagonal green lines. Fitted linear models for each species group are shown in red lines. Source: own elaboration.

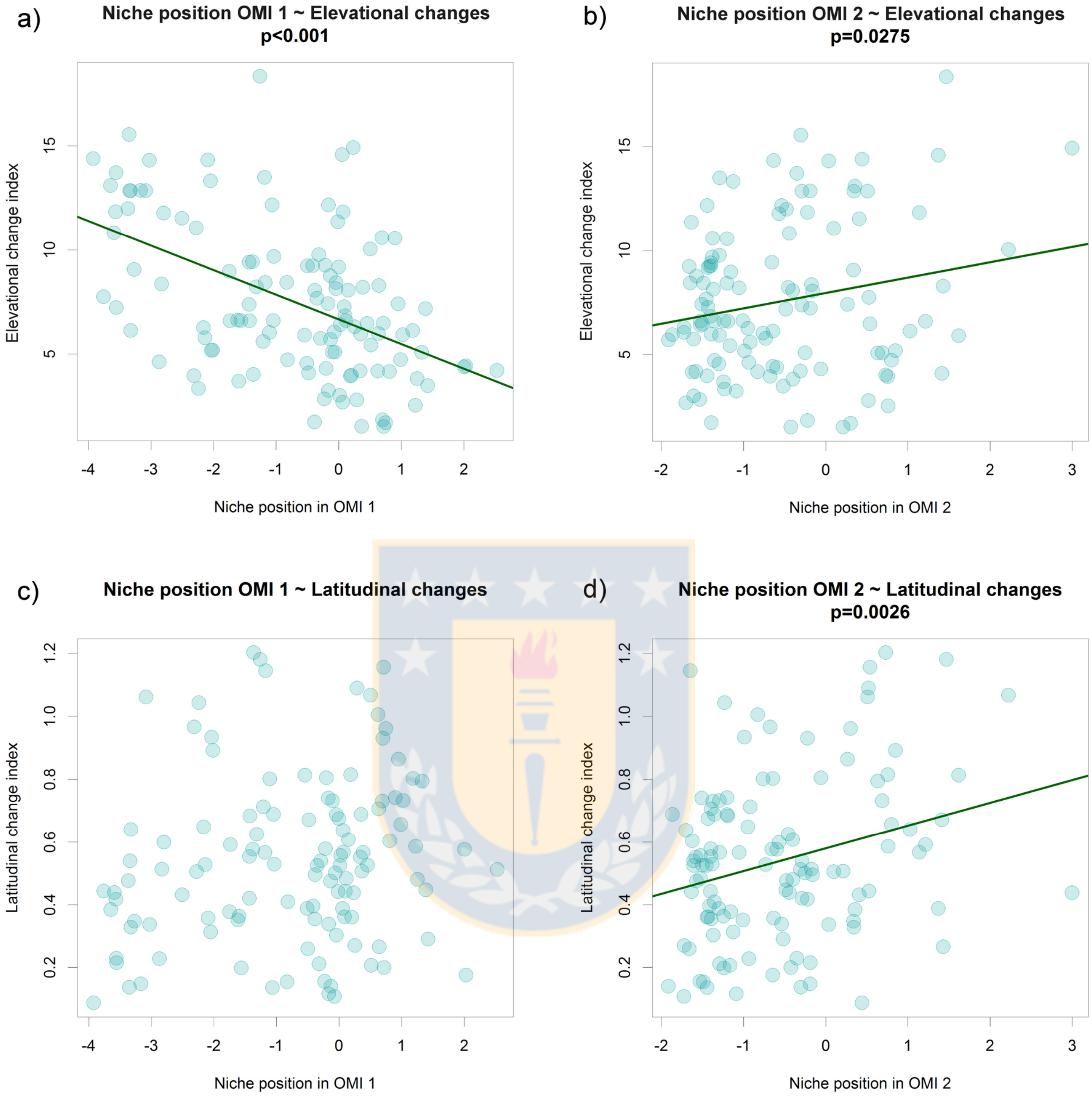

Figure 1.6. Relations for all the species between niche position and niche breadth and expected shifts: between niche position and elevational changes in a) OMI axis 1, and b) OMI axis 2; between niche position and latitudinal changes in c) OMI axis 1, and d) OMI axis 2; between niche breadth and elevational changes in e) OMI axis 1, and f) OMI axis 2; and between niche breadth and latitudinal changes in g) OMI axis 1, and h) OMI axis 2. Source: own elaboration.

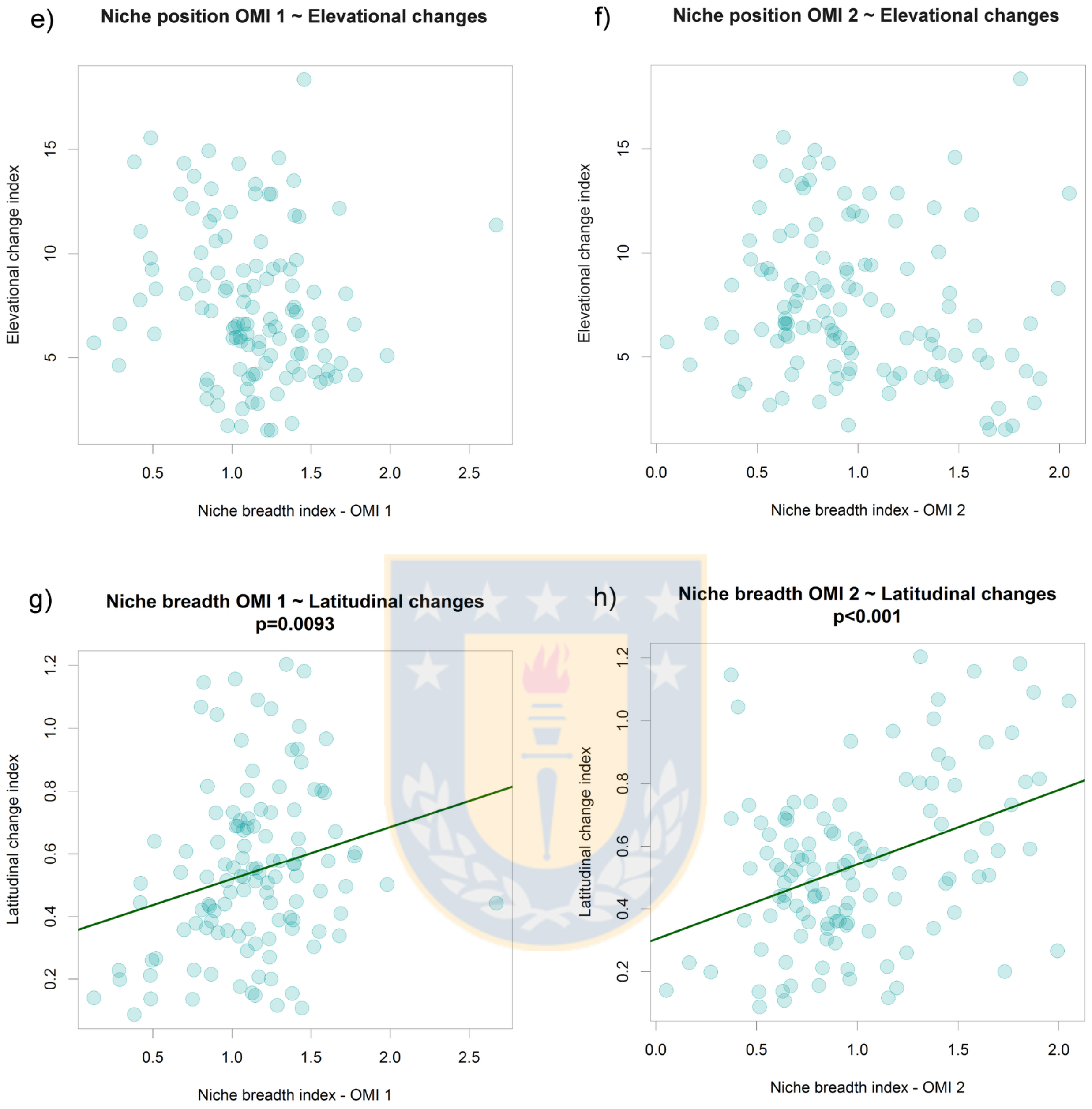

Figure 1.6. (continued). Relations for all the species between niche position and niche breadth and expected shifts: between niche position and elevational changes in a) OMI axis 1, and b) OMI axis 2; between niche position and latitudinal changes in c) OMI axis 1, and d) OMI axis 2; between niche breadth and elevational changes in e) OMI axis 1, and f) OMI axis 2; and between niche breadth and latitudinal changes in g) OMI axis 1, and h) OMI axis 2. Source: own elaboration.

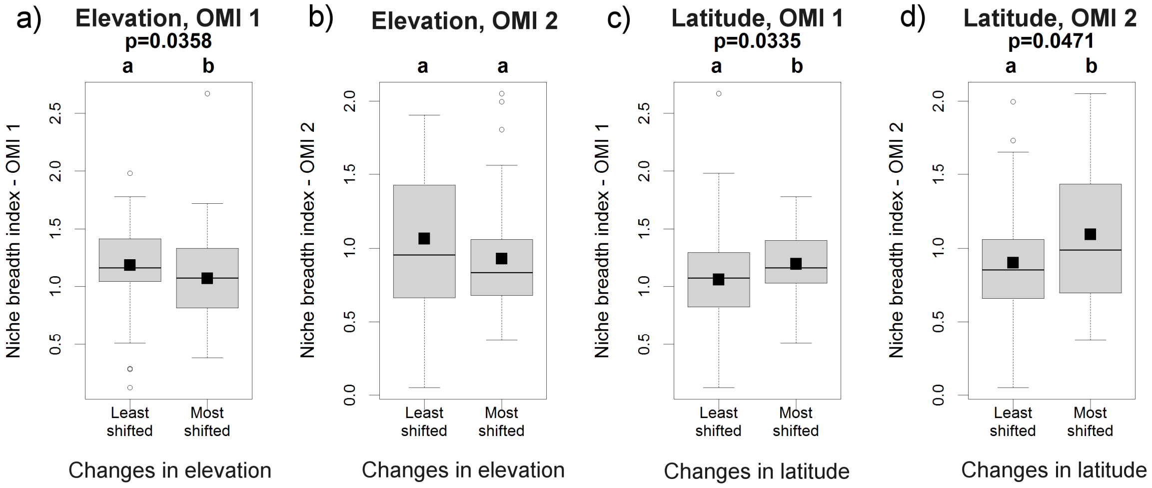

Figure 1.7. Differences in niche breath index of species, between least shifted half of species and most shifted half of species in both elevation and latitude, considering both OMI 1 and OMI 2 niche axes. Source: own elaboration.

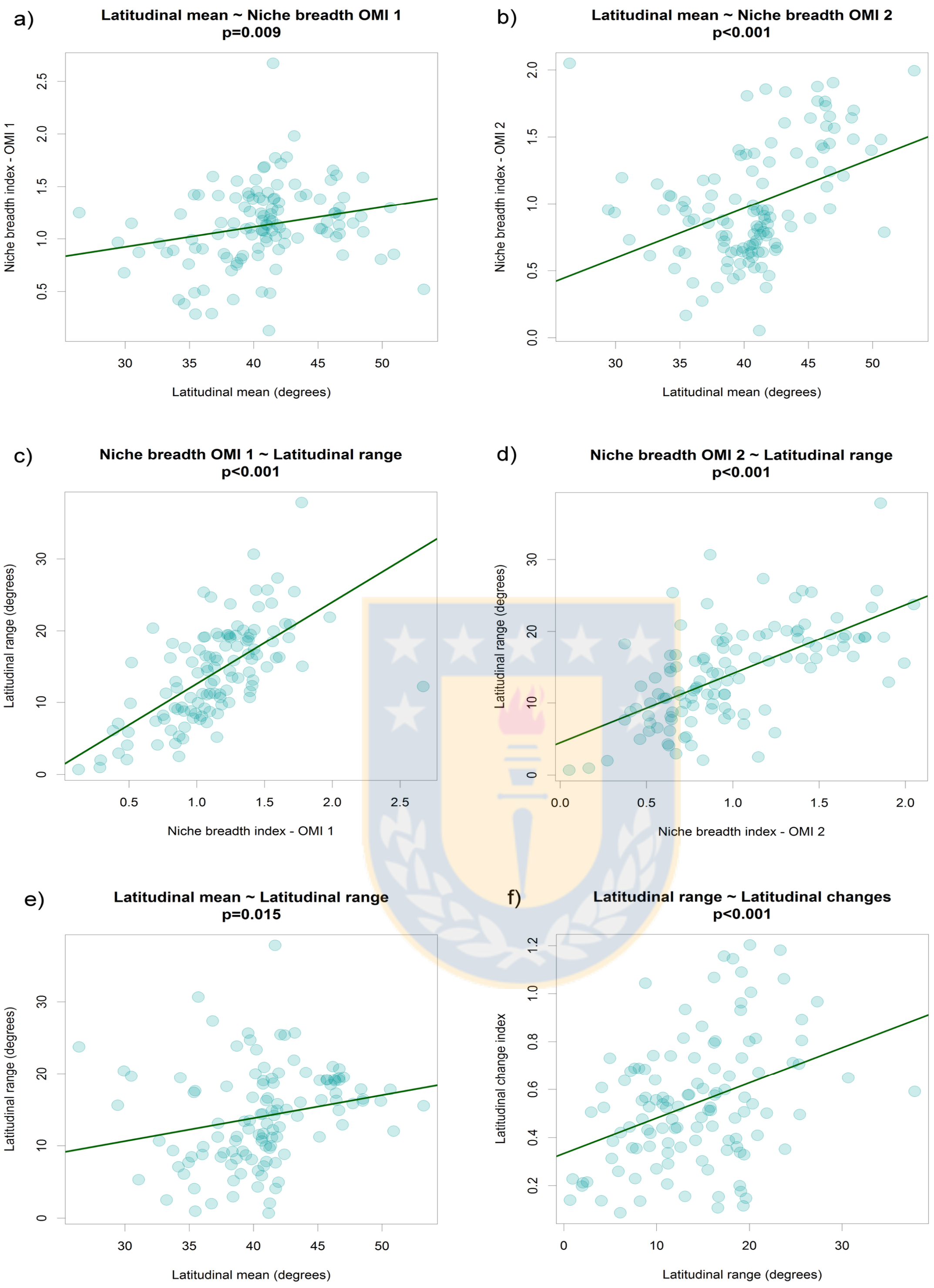

Figure 1.8. Relations for all species regarding latitudinal parameters: between niche breadth index and latitudinal mean for a) OMI 1, and b) OMI 2; between latitudinal range and niche breadth for c) OMI 1, and d) OMI 2; e) between latitudinal range and latitudinal mean; and f) between latitudinal change index and latitudinal range. Source: own elaboration.

SUPPORTING INFORMATION LEGENDS

Table 1.S1. Plant species information with elevational and latitudinal data. Source: own elaboration.

Figure 1.S1. Graphs of OMI analyses performed by species group. Distribution of species on niche axes using the Outlying Mean Index (OMI) method, considering each species group (upper graphs) and the variables correlated to each axis (lower graphs): a) *Nothofagus*, b) co-dominant species, c) ground ferns and d) epiphytic ferns. Source: own elaboration.

Figure 1.S2. Niche position and niche breadth comparison for species in both components of Outlying Mean Index (OMI) axis 1 at left and OMI axis 2 at right, by species group: a) *Nothofagus*, b) co-dominant species, c) ground ferns and d) epiphytic ferns. Source: own elaboration.

Table 1.S1. Plant species information with elevational and latitudinal data. Source: own elaboration.

Plant species	Family	Species group	Abbre-viation used in graphs	Number of occurrences	Niche breadth index (OMI 1)	Niche breadth index (OMI 2)	Niche position (OMI 1)	Niche position (OMI2)
Adiantum chilense Kaulf.	Pteridaceae	Ground fern	ac	297	1.4208	0.8687	-2.1642	-0.9479
Adiantum excisum Kunze	Pteridaceae	Ground fern	ae	78	0.9552	0.6118	-3.5900	-0.4429
Adiantum gertrudis Espinosa	Pteridaceae	Ground fern	ag	20	0.8689	1.1481	-3.5547	-0.1869
Adiantum scabrum Kaulf.	Pteridaceae	Ground fern	as	84	0.9915	0.9782	-3.3658	-0.4768
Adiantum sulphureum Kaulf.	Pteridaceae	Ground fern	ah	129	1.4229	1.0188	-2.7972	-0.5692
Aextoxicon punctatum Ruiz & Pav.	Aextoxicaceae	Co-dominant species	AP	3,391	1.2603	0.5512	-0.2158	-1.3971
Araucaria araucana (Molina) K. Koch	Araucariaceae	Co-dominant species	AA	6,946	0.4227	0.6717	-2.2773	0.0971
Asplenium dareoides Desv.	Aspleniaceae	Epiphytic fern	ad	162	1.5222	1.8350	-0.2026	-0.0591
Asplenium monanthes L.	Aspleniaceae	Ground fern	am	7	2.6702	0.7915	-0.0138	-1.6335
Asplenium obtusatum G. Forst. var. *sphenoides* (Kunze) C. Chr. ex Skottsb.	Aspleniaceae	Ground fern	ao	44	1.4424	0.6387	-0.0725	-1.7246
Asplenium trilobum Cav.	Aspleniaceae	Epiphytic fern	at	49	1.2192	0.7736	-0.1345	-1.5718
Austrocedrus chilensis (D. Don) Pic.Serm. & Bizzarri	Cupressaceae	Co-dominant species	AC	426	1.0421	0.8524	-3.0234	0.0357
Azara petiolaris (D. Don) I.M. Johnst.	Salicaceae	Co-dominant species	AZ	73	0.3830	0.5146	-3.9227	0.4430
Blechnum arcuatum J. Remy	Blechnaceae	Ground fern	ba	42	1.5178	0.8481	-0.0420	-1.3674
Blechnum asperum (Klotzsch) J.W. Sturm	Blechnaceae	Ground fern	br	15	0.9106	0.5627	0.0619	-1.7019
Blechnum blechnoides Keyserl.	Blechnaceae	Ground fern	bb	30	1.2376	0.5226	0.2513	-1.7212
Blechnum chilense (Kaulf.) Mett.	Blechnaceae	Ground fern	bc	133	1.5525	0.8516	-1.6173	-1.0078
Blechnum corralense Espinosa	Blechnaceae	Ground fern	bl	15	0.8418	0.6246	0.0124	-1.6077
Blechnum hastatum Kaulf.	Blechnaceae	Ground fern	bh	309	1.4141	0.9679	-2.0365	-0.9873
Blechnum magellanicum (Desv.) Mett.	Blechnaceae	Ground fern	bm	111	1.9819	1.6041	-0.0597	-0.2524
Blechnum microphyllum (Goldm.) C.V. Morton	Blechnaceae	Ground fern	bi	60	0.8586	1.1864	-2.5054	0.4081
Blechnum mochaenum G. Kunkel	Blechnaceae	Ground fern	bo	129	1.3915	0.7598	-1.1836	-1.2892
Blechnum penna-marina (Poir.) Kuhn	Blechnaceae	Ground fern	bp	146	1.1627	1.8755	0.2883	0.5190

Blepharocalyx cruckshanksii (Hook. & Arn.) Nied.	Myrtaceae	Co-dominant species	BC	253	0.8396	0.4390	-1.5982	-1.2431
Botrychium dusenii (H. Christ) Alston	Ophioglossaceae	Ground fern	bd	15	0.8533	0.7862	0.2322	2.9950
Cheilanthes glauca (Cav.) Mett.	Pteridaceae	Ground fern	ch	123	0.9121	0.9448	-3.2695	0.3365
Cheilanthes hypoleuca (Kunze) Mett.	Pteridaceae	Ground fern	cy	104	0.8892	0.9539	-3.5661	-0.2230
Cheilanthes mollis (Kunze) C. Presl	Pteridaceae	Ground fern	cm	98	0.9664	0.9550	-2.8313	-0.1744
Cryptocarya alba (Molina) Looser	Lauraceae	Co-dominant species	CA	11,386	0.7600	0.6452	-3.5566	-0.3508
Cryptogramma fumariifolia (Phil. ex Baker) H. Christ	Pteridaceae	Ground fern	cf	19	0.5107	0.8829	-3.3267	1.0253
Cystopteris fragilis (L.) Bernh.	Dryopteridaceae	Ground fern	cg	137	1.7734	1.8567	-1.7371	1.2145
Dennstaedtia glauca (Cav.) C. Chr. ex Looser	Dennstaedtiaceae	Ground fern	dg	20	0.4205	1.0642	-3.7603	0.5253
Drimys andina (Reiche) R. Rodr. & Quezada	Winteraceae	Co-dominant species	DA	38	0.8107	0.6354	-1.4334	-0.2900
Drimys winteri J.R. Forst. & G. Forst.	Winteraceae	Co-dominant species	DW	8,543	1.0506	0.6514	0.6333	-1.3911
Elaphoglossum gayanum (Fée) T. Moore	Lomariopsidaceae	Ground fern	eg	10	0.4950	1.2447	-0.4997	-1.6595
Elaphoglossum mathewsii (Fée) T. Moore	Lomariopsidaceae	Ground fern	em	11	0.4841	0.8280	-0.3201	-1.2913
Elaphoglossum porteri Hicken	Lomariopsidaceae	Ground fern	ep	5	0.1276	0.0520	-0.1333	-1.9134
Equisetum bogotense Kunth	Equisetaceae	Ground fern	eb	157	1.5951	1.1760	-2.3147	-0.6770
Equisetum giganteum L.	Equisetaceae	Ground fern	ei	65	1.1467	1.1959	-3.1666	-0.1902
Eucryphia cordifolia Cav.	Eucryphiaceae	Co-dominant species	EC	3,998	1.0734	0.5215	-0.0026	-1.4311
Fitzroya cupressoides (Molina) I.M. Johnst.	Cupressaceae	Co-dominant species	FC	6,158	0.7098	0.7595	0.1494	-0.4007
Gevuina avellana Molina	Proteaceae	Co-dominant species	GA	6,135	1.0953	0.6506	-1.4263	-1.1890
Gleichenia cryptocarpa Hook.	Gleicheniaceae	Ground fern	gc	63	1.3813	0.9107	0.0869	-1.4315
Gleichenia litoralis (F. Phil.) C. Chr.	Gleicheniaceae	Ground fern	gl	17	1.1836	0.7694	0.8989	-1.2009
Gleichenia quadripartita (Poir.) T. Moore	Gleicheniaceae	Ground fern	gq	82	1.3799	1.6407	0.7022	-0.2221
Gleichenia squamulosa (Desv.) T. Moore	Gleicheniaceae	Ground fern	gs	107	1.1725	0.6002	-0.2912	-1.6076
Gomortega keule (Molina) Baill.	Gomortegaceae	Co-dominant species	GK	66	0.2902	0.2726	-1.5633	-1.2371
Grammitis magellanica Desv.	Grammitidaceae	Epiphytic fern	gm	62	1.2255	1.6533	0.3652	0.2108
Grammitis patagonica (C. Chr.) Parris	Grammitidaceae	Epiphytic fern	gp	7	0.8451	1.9043	0.1848	0.7533
Grammitis poeppigiana (Mett.) Pic.Serm.	Grammitidaceae	Epiphytic fern	go	20	1.2982	1.4817	0.0536	1.3702

Hymenoglossum cruentum (Cav.) C. Presl	Hymenophyllaceae	Epiphytic fern	hg	70	1.2738	0.7828	0.4545	-1.4982
Hymenophyllum caudiculatum Mart.	Hymenophyllaceae	Epiphytic fern	hc	94	1.0748	0.6373	0.1161	-1.5241
Hymenophyllum cuneatum Kunze	Hymenophyllaceae	Epiphytic fern	hu	18	1.7801	0.6719	0.8107	-1.6238
Hymenophyllum darwinii Hook. f. ex Bosch	Hymenophyllaceae	Epiphytic fern	hd	20	1.6796	1.3782	-0.1623	-0.5351
Hymenophyllum dentatum Cav.	Hymenophyllaceae	Epiphytic fern	he	95	1.2870	1.1534	-0.1630	-1.0884
Hymenophyllum dicranotrichum (C. Presl) Hook. ex Sadeb.	Hymenophyllaceae	Epiphytic fern	hi	42	1.1326	0.9519	0.3422	-1.5806
Hymenophyllum falklandicum Baker	Hymenophyllaceae	Epiphytic fern	hf	20	1.3963	1.5651	0.0685	1.1396
Hymenophyllum ferrugineum Colla	Hymenophyllaceae	Epiphytic fern	hr	41	1.5600	1.4389	1.2527	-0.3997
Hymenophyllum fuciforme Sw.	Hymenophyllaceae	Epiphytic fern	ho	34	1.3936	0.6857	-0.1695	-1.5058
Hymenophyllum krauseanum Phil.	Hymenophyllaceae	Epiphytic fern	hk	62	1.1051	0.8981	0.2034	-1.4438
Hymenophyllum nahuelhuapiense Diem & J.S. Licht.	Hymenophyllaceae	Epiphytic fern	hh	5	0.5197	1.9935	0.6411	1.4281
Hymenophyllum pectinatum Cav.	Hymenophyllaceae	Epiphytic fern	hp	89	1.4247	1.3789	0.6241	-0.8271
Hymenophyllum peltatum (Poir.) Desv.	Hymenophyllaceae	Epiphytic fern	hl	56	1.7195	1.4557	-0.3822	-0.1592
Hymenophyllum plicatum Kaulf.	Hymenophyllaceae	Epiphytic fern	ha	62	1.1282	0.8085	-0.2305	-1.5314
Hymenophyllum secundum Hook. & Grev.	Hymenophyllaceae	Epiphytic fern	hs	71	1.0661	1.6984	1.2249	0.7584
Hymenophyllum seselifolium C. Presl	Hymenophyllaceae	Epiphytic fern	hm	61	1.2475	1.7324	0.7189	-0.4224
Hymenophyllum tortuosum Hook. & Grev.	Hymenophyllaceae	Epiphytic fern	ht	81	1.2122	1.6427	0.9880	0.7988
Hymenophyllum tunbrigense (L.) Sm.	Hymenophyllaceae	Epiphytic fern	hn	15	1.1544	1.0650	-1.4314	-1.3971
Hymenophyllum umbratile Diem & J.S. Licht.	Hymenophyllaceae	Epiphytic fern	hb	13	0.8983	0.4626	0.6908	-1.3752
Hypolepis poeppigii (Kunze) R. Rodr.	Dennstaedtiaceae	Ground fern	hy	105	1.6880	0.6986	-0.8178	-1.3527
Laurelia sempervirens (Ruiz & Pav.) Tul.	Monimiaceae	Co-dominant	LS	635	0.7513	0.5119	-1.0636	-1.4428

		species						
Laureliopsis philippiana (Looser) Schodde	Monimiaceae	Co-dominant species	LP	6,404	0.9570	0.7040	0.3853	-1.0518
Lomatia hirsuta (Lam.) Diels	Proteaceae	Co-dominant species	LH	1,136	1.3050	1.0357	-1.3797	-0.6560
Lophosoria quadripinnata (J.F. Gmel.) C. Chr.	Dicksoniaceae	Ground fern	lq	87	1.3867	0.8832	-0.5105	-1.2995
Luma apiculata (DC.) Burret	Myrtaceae	Co-dominant species	LA	6,713	1.2428	0.6391	0.1001	-1.4032
Lycopodium alboffii Rolleri	Lycopodiaceae	Ground fern	la	18	0.8048	1.4007	0.5049	2.2210
Lycopodium confertum Willd.	Lycopodiaceae	Ground fern	lc	22	1.1299	1.4510	0.9475	0.2652
Lycopodium gayanum J. Remy	Lycopodiaceae	Ground fern	lg	34	1.1707	0.9524	0.5135	-1.1628
Lycopodium magellanicum (P. Beauv.) Sw.	Lycopodiaceae	Ground fern	lm	104	1.2445	1.7654	-0.1047	0.6868
Lycopodium paniculatum Desv.	Lycopodiaceae	Ground fern	lp	69	0.9730	0.9521	-0.3861	-1.3924
Maytenus disticha (Hook. f.) Urb.	Celastraceae	Co-dominant species	MD	52	1.3437	1.3135	-1.3654	0.7295
Megalastrum spectabile (Kaulf.) A.R. Sm. & R.C. Moran	Dryopteridaceae	Ground fern	ms	83	1.3669	0.9422	-0.4155	-1.4128
Myrceugenia planipes (Hook. & Arn.) O. Berg	Myrtaceae	Co-dominant species	ME	829	1.4077	0.4682	-1.0364	-1.3805
Myrceugenia exsucca (DC.) O. Berg	Myrtaceae	Co-dominant species	MP	113	1.0749	0.6952	-0.3473	-1.4537
Nothofagus alessandrii Espinosa	Nothofagaceae	Dominant species	NL	64	0.2858	0.1655	-2.8691	-0.9355
Nothofagus alpina (Poepp. & Endl.) Oerst.	Nothofagaceae	Dominant species	NR	10,759	0.6975	0.7586	-2.0925	-0.6336
Nothofagus antarctica (G. Forst.) Oerst.	Nothofagaceae	Dominant species	NT	29,159	1.6541	1.4167	-0.4802	1.4140
Nothofagus betuloides (Mirb.) Oerst.	Nothofagaceae	Dominant species	NB	32,388	1.5859	1.4835	1.3255	0.6317
Nothofagus dombeyi (Mirb.) Oerst.	Nothofagaceae	Dominant species	ND	27,092	1.0785	0.9894	-1.3156	-0.4554
Nothofagus glauca (Phil.) Krasser	Nothofagaceae	Dominant species	NG	4,343	0.4874	0.6293	-3.3503	-0.3020
Nothofagus nitida (Phil.) Krasser	Nothofagaceae	Dominant species	NN	37,581	1.0973	0.8908	1.4210	-0.5173
Nothofagus obliqua (Mirb.) Oerst.	Nothofagaceae	Dominant species	NO	42,600	1.0575	0.8771	-2.1395	-0.7310
Nothofagus pumilio (Poepp. & Endl.) Krasser	Nothofagaceae	Dominant species	NP	28,747	1.3002	1.2418	-0.5470	1.6162
Pellaea myrtillifolia Mett. ex Kuhn	Pteridaceae	Ground fern	pm	22	0.8700	0.7300	-3.6450	0.3558

Pellaea ternifolia (Cav.) Link	Pteridaceae	Ground fern	pe	29	1.2475	2.0488	-3.0855	0.5081
Persea lingue (Miers ex Bertero) Nees	Lauraceae	Co-dominant species	PL	3,182	0.7726	0.5683	-1.7490	-1.1560
Philesia magellanica J.F. Gmel.	Philesiaceae	Co-dominant species	PM	72	1.0954	1.3101	1.1818	-0.6414
Pilgerodendron uviferum (D. Don) Florin	Cupressaceae	Co-dominant species	PU	20,591	1.1495	1.2086	2.5262	-0.3082
Pleopeltis macrocarpa (Bory ex Willd.) Kaulf.	Polypodiaceae	Epiphytic fern	pl	16	0.8213	0.3740	-1.1752	-1.6472
Pleurosorus papaverifolius (Kunze) Mett.	Aspleniaceae	Ground fern	pp	36	1.2354	1.0569	-3.3241	0.3439
Podocarpus salignus D. Don	Podocarpaceae	Co-dominant species	PN	19,391	1.6086	1.1278	2.0043	-0.5963
Podocarpus nubigenus Lindl.	Podocarpaceae	Co-dominant species	PS	99	1.1493	0.7201	-2.0492	-1.1240
Polypodium feuillei Bertero	Blechnaceae	Epiphytic fern	pf	136	1.3807	0.6689	-0.8313	-1.4884
Polystichum andinum Phil.	Dryopteridaceae	Ground fern	pa	38	1.4571	1.8065	-1.2605	1.4671
Polystichum chilense (H. Christ) Diels	Dryopteridaceae	Ground fern	ph	118	1.5671	1.3712	-1.1055	-0.7610
Polystichum multifidum (Mett.) H. Christ	Dryopteridaceae	Ground fern	pu	29	1.0199	1.5802	0.7138	0.5382
Polystichum plicatum (Poepp. ex Kunze) Hicken	Dryopteridaceae	Ground fern	pc	124	1.4387	1.4029	-2.0156	0.8488
Polystichum subintegerrimum (Hook. & Arn.) R. Rodr.	Dryopteridaceae	Ground fern	ps	22	1.0379	0.6403	-1.0478	-1.3530
Pteris chilensis Desv.	Pteridaceae	Ground fern	pt	33	0.9043	0.4076	-2.2412	-1.2314
Pteris semiadnata Phil.	Pteridaceae	Ground fern	pd	38	1.0094	0.7248	0.0274	-1.5234
Rhaphithamnus spinosus (Juss.) Moldenke	Verbenaceae	Co-dominant species	RS	3,398	1.1381	0.8326	-0.0446	-1.1996
Rumohra adiantiformis (G. Forst.) Ching	Dryopteridaceae	Ground fern	ra	78	1.1034	1.3625	-1.2107	-0.9182
Schizaea fistulosa Labill.	Schizaeaceae	Ground fern	sf	18	1.0074	0.9119	1.0224	-1.2923
Serpyllopsis caespitosa (Gaudich.) C. Chr.	Hymenophyllaceae	Epiphytic fern	sc	51	1.0601	1.7673	0.7468	0.3031
Tepualia stipularis (Hook. & Arn.) Griseb.	Myrtaceae	Co-dominant species	TS	25,869	1.0506	0.9626	2.0284	-0.6435
Thelypteris argentina (Hieron.) Abbiatti	Thelypteridaceae	Ground fern	ta	44	0.6772	0.9332	-3.3393	-0.2891
Trichomanes exsectum Kunze	Hymenophyllaceae	Ground fern	te	17	1.0241	0.3734	0.3509	-1.8633
Weinmannia trichosperma Cav.	Cunoniaceae	Co-dominant species	WT	24,577	1.4063	0.8282	1.3861	-0.4842

Table 1.S1. (continued). Plant species information with elevational and latitudinal data. Source: own elaboration.

Plant species	Present mean elevation (m a.s.l.)	Future mean elevation (m a.s.l.)	Elevational change index	Present mean latitude (degrees)	Future mean latitude (degrees)	Latitudinal change index	Latitudinal range (degrees)	Elevational change direction	Latitudinal change direction	Elevational change group	Latitudinal change group
Adiantum chilense Kaulf.	582	621	6.2609	-35.7167	-36.1365	0.6479	30.6654	Upward	Southward	Least changed	Most changed
Adiantum excisum Kunze	637	754	10.8176	-32.6630	-32.8551	0.4383	10.6496	Upward	Southward	Most changed	Least changed
Adiantum gertrudis Espinosa	574	626	7.2227	-33.2380	-33.1919	0.2149	2.4999	Upward	Stable	Most changed	Least changed
Adiantum scabrum Kaulf.	756	900	11.9903	-35.1936	-35.4207	0.4765	8.4580	Upward	Southward	Most changed	Least changed
Adiantum sulphureum Kaulf.	706	845	11.7736	-35.3777	-35.7368	0.5992	17.3660	Upward	Southward	Most changed	Most changed
Aextoxicon punctatum Ruiz & Pav.	409	495	9.2534	-39.7061	-40.0400	0.5778	13.4995	Upward	Southward	Most changed	Most changed
Araucaria araucana (Molina) K. Koch	1176	1299	11.0673	-38.4187	-38.6739	0.5052	2.9499	Upward	Southward	Most changed	Least changed
Asplenium dareoides Desv.	432	413	4.3020	-43.2113	-43.8589	0.8048	25.6656	Stable	Southward	Least changed	Most changed
Asplenium monanthes L.	163	292	11.3636	-41.5083	-41.3138	0.4410	12.1995	Upward	Northward	Most changed	Least changed
Asplenium obtusatum G. Forst. var. *sphenoides* (Kunze) C. Chr. ex Skottsb.	103	140	6.0565	-41.1161	-41.1276	0.1074	16.5993	Upward	Stable	Least changed	Least changed
Asplenium trilobum Cav.	133	210	8.7530	-40.7825	-41.0081	0.4750	11.6829	Upward	Southward	Most changed	Least changed
Austrocedrus chilensis (D. Don) Pic.Serm. & Bizzarri	1137	1342	14.3006	-37.2250	-37.1119	0.3363	11.2079	Upward	Northward	Most changed	Least changed
Azara petiolaris (D. Don) I.M. Johnst.	1105	1312	14.3936	-34.5881	-34.5957	0.0870	6.0748	Upward	Stable	Most changed	Least changed
Blechnum arcuatum J. Remy	401	468	8.1283	-41.8273	-41.9191	0.3031	14.9077	Upward	Stable	Most changed	Least changed
Blechnum asperum (Klotzsch) J.W. Sturm	354	361	2.6815	-40.3623	-40.7676	0.6366	6.5414	Stable	Southward	Least changed	Most changed
Blechnum blechnoides Keyserl.	47	87	6.2971	-41.3455	-41.4182	0.2695	9.9913	Upward	Stable	Least changed	Least changed
Blechnum chilense (Kaulf.) Mett.	490	534	6.6234	-38.7014	-38.8248	0.3513	23.8574	Upward	Southward	Most changed	Least changed
Blechnum corralense Espinosa	296	286	3.0115	-40.3367	-40.0613	0.5248	4.3082	Stable	Northward	Least changed	Most changed
Blechnum hastatum Kaulf.	608	635	5.1696	-37.2508	-38.1233	0.9341	13.0911	Upward	Southward	Least changed	Most changed
Blechnum magellanicum (Desv.) Mett.	449	475	5.0887	-43.1619	-43.4126	0.5007	21.8741	Upward	Southward	Least changed	Least changed
Blechnum microphyllum (Goldm.) C.V. Morton	1297	1164	11.5335	-37.6989	-37.8848	0.4311	9.0246	Downward	Southward	Most changed	Least changed
Blechnum mochaenum G. Kunkel	474	656	13.4869	-38.6051	-38.9258	0.5663	10.6829	Upward	Southward	Most changed	Most changed
Blechnum penna-marina (Poir.) Kuhn	316	308	2.7893	-45.7154	-46.9023	1.0894	19.1576	Stable	Southward	Least changed	Most changed
Blepharocalyx cruckshanksii (Hook. & Arn.) Nied.	137	151	3.6899	-39.1677	-39.0357	0.3632	9.2413	Stable	Northward	Least changed	Least changed
Botrychium dusenii (H. Christ) Alston	658	881	14.9220	-50.9102	-50.7186	0.4377	12.0079	Upward	Northward	Most changed	Least changed
Cheilanthes glauca (Cav.) Mett.	1256	1338	9.0543	-35.4552	-35.5758	0.3472	17.6076	Upward	Southward	Most changed	Least changed

Cheilanthes hypoleuca (Kunze) Mett.	927	1067	11.8380	-33.7342	-33.5602	0.4171	9.3246	Upward	Northward	Most changed	Least changed
Cheilanthes mollis (Kunze) C. Presl	711	781	8.3590	-29.4356	-29.1726	0.5128	15.5994	Upward	Northward	Most changed	Least changed
Cryptocarya alba (Molina) Looser	682	870	13.7078	-34.9401	-34.9926	0.2291	7.6914	Upward	Stable	Most changed	Least changed
Cryptogramma fumariifolia (Phil. ex Baker) H. Christ	1348	1386	6.1262	-36.0919	-36.5009	0.6396	9.8579	Upward	Southward	Least changed	Most changed
Cystopteris fragilis (L.) Bernh.	932	888	6.5831	-41.6880	-41.3383	0.5913	37.8235	Downward	Northward	Least changed	Most changed
Dennstaedtia glauca (Cav.) C. Chr. ex Looser	1388	1448	7.7430	-34.1689	-34.3655	0.4435	7.0830	Upward	Southward	Most changed	Least changed
Drimys andina (Reiche) R. Rodr. & Quezada	1141	1195	7.3656	-39.0087	-38.8326	0.4197	6.1248	Upward	Northward	Most changed	Least changed
Drimys winteri J.R. Forst. & G. Forst.	427	463	5.9714	-42.4396	-42.9378	0.7058	25.3656	Upward	Southward	Least changed	Most changed
Elaphoglossum gayanum (Fée) T. Moore	329	243	9.2275	-40.6457	-40.5785	0.2593	5.8748	Downward	Stable	Most changed	Least changed
Elaphoglossum mathewsii (Fée) T. Moore	342	438	9.7663	-41.2708	-41.3155	0.2114	2.0499	Upward	Stable	Most changed	Least changed
Elaphoglossum porteri Hicken	392	425	5.6979	-41.1845	-41.2041	0.1399	0.6666	Upward	Stable	Least changed	Least changed
Equisetum bogotense Kunth	745	730	3.9512	-36.8251	-37.7588	0.9663	27.3406	Stable	Southward	Least changed	Most changed
Equisetum giganteum L.	849	1014	12.8679	-30.4954	-30.4737	0.1475	19.6409	Upward	Stable	Most changed	Least changed
Eucryphia cordifolia Cav.	300	384	9.1757	-40.8040	-41.2591	0.6747	7.2080	Upward	Southward	Most changed	Most changed
Fitzroya cupressoides (Molina) I.M. Johnst.	573	637	8.0597	-41.7332	-42.1025	0.6077	4.0832	Upward	Southward	Most changed	Most changed
Gevuina avellana Molina	451	495	6.5822	-39.4171	-39.8843	0.6835	8.7246	Upward	Southward	Least changed	Most changed
Gleichenia cryptocarpa Hook.	327	380	7.2685	-41.5506	-41.6809	0.3609	18.6576	Upward	Southward	Most changed	Least changed
Gleichenia litoralis (F. Phil.) C. Chr.	333	221	10.5703	-41.2553	-40.7052	0.7417	9.6496	Downward	Northward	Most changed	Most changed
Gleichenia quadripartita (Poir.) T. Moore	306	309	1.8291	-45.1688	-46.0345	0.9304	19.0659	Stable	Southward	Least changed	Most changed
Gleichenia squamulosa (Desv.) T. Moore	202	235	5.7404	-40.6568	-40.9474	0.5391	10.6579	Upward	Southward	Least changed	Most changed
Gomortega keule (Molina) Baill.	327	283	6.5961	-36.7306	-36.6914	0.1980	1.9749	Downward	Stable	Least changed	Least changed
Grammitis magellanica Desv.	396	394	1.5123	-46.6624	-46.4058	0.5065	19.4242	Stable	Northward	Least changed	Least changed
Grammitis patagonica (C. Chr.) Parris	367	382	3.9400	-46.9249	-47.5882	0.8144	12.8912	Stable	Southward	Least changed	Most changed
Grammitis poeppigiana (Mett.) Pic.Serm.	512	725	14.5818	-50.6446	-50.7952	0.3880	17.7910	Upward	Southward	Most changed	Least changed
Hymenoglossum cruentum (Cav.) C. Presl	196	237	6.4551	-41.8802	-42.1565	0.5256	15.7994	Upward	Southward	Least changed	Most changed
Hymenophyllum caudiculatum Mart.	230	273	6.5998	-41.4372	-41.6708	0.4833	14.8411	Upward	Southward	Least changed	Least changed
Hymenophyllum cuneatum Kunze	284	301	4.1559	-42.5682	-42.2041	0.6034	14.9994	Stable	Northward	Least changed	Most changed
Hymenophyllum darwinii Hook. f. ex Bosch	496	644	12.1659	-40.7699	-40.8842	0.3380	19.0076	Upward	Southward	Most changed	Least changed

Hymenophyllum dentatum Cav.	389	400	3.2463	-41.4308	-41.4443	0.1160	19.3576	Stable	Stable	Least changed	Least changed
Hymenophyllum dicranotrichum (C. Presl) Hook. ex Sadeb.	292	309	4.1848	-41.8189	-42.1228	0.5513	11.2162	Stable	Southward	Least changed	Most changed
Hymenophyllum falklandicum Baker	532	392	11.8320	-47.0141	-47.3356	0.5671	19.4992	Downward	Southward	Most changed	Most changed
Hymenophyllum ferrugineum Colla	338	324	3.8134	-46.0163	-46.2473	0.4805	18.4493	Stable	Southward	Least changed	Least changed
Hymenophyllum fuciforme Sw.	140	195	7.4140	-40.4420	-40.9899	0.7402	11.5162	Upward	Southward	Most changed	Most changed
Hymenophyllum krauseanum Phil.	306	290	3.9744	-42.0192	-42.1487	0.3599	12.5995	Stable	Southward	Least changed	Least changed
Hymenophyllum nahuelhuapiense Diem & J.S. Licht.	122	191	8.2828	-53.2385	-53.3092	0.2659	15.5327	Upward	Stable	Most changed	Least changed
Hymenophyllum pectinatum Cav.	271	288	4.1705	-44.0865	-45.0982	1.0058	20.1575	Stable	Southward	Least changed	Most changed
Hymenophyllum peltatum (Poir.) Desv.	489	424	8.0476	-42.1184	-41.8730	0.4954	25.4406	Downward	Northward	Most changed	Least changed
Hymenophyllum plicatum Kaulf.	305	313	2.8404	-41.0570	-41.0811	0.1552	13.0578	Stable	Stable	Least changed	Least changed
Hymenophyllum secundum Hook. & Grev.	209	215	2.5333	-48.5364	-48.8793	0.5856	16.4577	Stable	Southward	Least changed	Most changed
Hymenophyllum seselifolium C. Presl	285	287	1.5113	-46.3583	-46.3185	0.1994	18.9742	Stable	Stable	Least changed	Least changed
Hymenophyllum tortuosum Hook. & Grev.	315	293	4.7287	-48.3712	-48.8011	0.6557	17.8410	Stable	Southward	Least changed	Most changed
Hymenophyllum tunbrigense (L.) Sm.	96	184	9.4084	-37.4767	-37.1704	0.5534	8.4330	Upward	Northward	Most changed	Most changed
Hymenophyllum umbratile Diem & J.S. Licht.	331	444	10.5923	-41.9549	-42.4878	0.7300	4.9665	Upward	Southward	Most changed	Most changed
Hypolepis poeppigii (Kunze) R. Rodr.	282	304	4.7086	-40.8313	-40.9985	0.4089	20.8825	Stable	Southward	Least changed	Least changed
Laurelia sempervirens (Ruiz & Pav.) Tul.	537	685	12.1655	-38.6732	-38.6917	0.1359	8.2163	Upward	Stable	Most changed	Least changed
Laureliopsis philippiana (Looser) Schodde	379	446	8.1919	-42.4008	-42.7209	0.5658	8.8080	Upward	Southward	Most changed	Most changed
Lomatia hirsuta (Lam.) Diels	564	653	9.4219	-39.3147	-39.6471	0.5765	13.3828	Upward	Southward	Most changed	Most changed
Lophosoria quadripinnata (J.F. Gmel.) C. Chr.	445	466	4.5427	-41.6102	-41.7604	0.3876	14.1994	Stable	Southward	Least changed	Least changed
Luma apiculata (DC.) Burret	509	556	6.8329	-40.5866	-40.7825	0.4426	14.3578	Upward	Southward	Most changed	Least changed
Lycopodium alboffii Rolleri	357	256	10.0345	-49.9174	-51.0566	1.0673	16.1910	Downward	Southward	Most changed	Most changed
Lycopodium confertum Willd.	305	359	7.4048	-46.6527	-47.3990	0.8639	14.8994	Upward	Southward	Most changed	Most changed
Lycopodium gayanum J. Remy	279	249	5.4206	-41.4343	-41.3918	0.2063	11.1496	Downward	Stable	Least changed	Least changed
Lycopodium magellanicum (P. Beauv.) Sw.	437	411	5.0883	-46.2986	-46.8338	0.7316	19.1992	Downward	Southward	Least changed	Most changed
Lycopodium paniculatum Desv.	439	436	1.7231	-41.0160	-40.8907	0.3540	7.8080	Stable	Northward	Least changed	Least changed
Maytenus disticha (Hook. f.) Urb.	909	925	4.0135	-41.9694	-43.4153	1.2025	20.0742	Stable	Southward	Least changed	Most changed
Megalastrum spectabile (Kaulf.) A.R. Sm. & R.C. Moran	253	339	9.2318	-40.7406	-40.5841	0.3956	18.5493	Upward	Northward	Most changed	Least changed
Myrceugenia planipes (Hook. & Arn.)	231	324	9.6791	-39.6261	-39.9059	0.5290	12.3328	Upward	Southward	Most changed	Most changed

O. Berg											
Myrceugenia exsucca (DC.) O. Berg	168	226	7.6622	-40.6741	-40.9495	0.5248	11.0579	Upward	Southward	Most changed	Least changed
Nothofagus alessandrii Espinosa	299	321	4.6130	-35.4749	-35.5268	0.2279	0.9500	Stable	Stable	Least changed	Least changed
Nothofagus alpina (Poepp. & Endl.) Oerst.	992	1197	14.3215	-38.2819	-38.4093	0.3569	7.3830	Upward	Southward	Most changed	Least changed
Nothofagus antarctica (G. Forst.) Oerst.	540	556	4.0921	-46.1738	-46.6236	0.6706	21.0075	Stable	Southward	Least changed	Most changed
Nothofagus betuloides (Mirb.) Oerst.	383	409	5.0764	-48.5001	-49.1307	0.7941	16.1910	Upward	Southward	Least changed	Most changed
Nothofagus dombeyi (Mirb.) Oerst.	630	698	8.2130	-40.7071	-41.0973	0.6246	14.3994	Upward	Southward	Most changed	Most changed
Nothofagus glauca (Phil.) Krasser	903	1145	15.5451	-35.3984	-35.4172	0.1371	4.0582	Upward	Stable	Most changed	Least changed
Nothofagus nitida (Phil.) Krasser	397	409	3.4697	-45.1366	-45.2209	0.2903	11.2246	Stable	Stable	Least changed	Least changed
Nothofagus obliqua (Mirb.) Oerst.	700	734	5.7706	-38.3724	-38.6503	0.5271	9.1913	Upward	Southward	Least changed	Most changed
Nothofagus pumilio (Poepp. & Endl.) Krasser	653	688	5.9035	-46.6819	-47.3429	0.8130	20.6658	Upward	Southward	Least changed	Most changed
Pellaea myrtillifolia Mett. ex Kuhn	1133	1305	13.0985	-31.0649	-31.2124	0.3841	5.2998	Upward	Southward	Most changed	Least changed
Pellaea ternifolia (Cav.) Link	2326	2160	12.8530	-26.4252	-27.5522	1.0616	23.7241	Downward	Southward	Most changed	Most changed
Persea lingue (Miers ex Bertero) Nees	442	522	8.9618	-38.7252	-38.8673	0.3770	11.2579	Upward	Southward	Most changed	Least changed
Philesia magellanica J.F. Gmel.	219	256	6.1178	-45.2830	-45.9275	0.8028	16.3410	Upward	Southward	Least changed	Most changed
Pilgerodendron uviferum (D. Don) Florin	293	311	4.2063	-47.7363	-47.9982	0.5118	15.8327	Stable	Southward	Least changed	Least changed
Pleopeltis macrocarpa (Bory ex Willd.) Kaulf.	326	397	8.4245	-37.9160	-36.6051	1.1450	18.2243	Upward	Northward	Most changed	Most changed
Pleurosorus papaverifolius (Kunze) Mett.	1191	1357	12.8553	-34.3150	-34.4227	0.3281	19.4409	Upward	Southward	Most changed	Least changed
Podocarpus salignus D. Don	358	377	4.3767	-46.4511	-46.7823	0.5756	16.2660	Stable	Southward	Least changed	Most changed
Podocarpus nubigenus Lindl.	430	608	13.3203	-38.4588	-38.3609	0.3129	5.1665	Upward	Stable	Most changed	Least changed
Polypodium feuillei Bertero	212	283	8.4294	-39.9417	-39.9181	0.1536	16.6827	Upward	Stable	Most changed	Least changed
Polystichum andinum Phil.	1493	1829	18.3354	-40.2317	-38.8366	1.1811	23.3407	Upward	Northward	Most changed	Most changed
Polystichum chilense (H. Christ) Diels	543	507	6.0265	-40.1659	-40.8081	0.8014	19.9742	Downward	Southward	Least changed	Most changed
Polystichum multifidum (Mett.) H. Christ	423	465	6.4717	-46.4210	-45.0836	1.1564	17.2826	Upward	Northward	Least changed	Most changed
Polystichum plicatum (Poepp. ex Kunze) Hicken	1146	1173	5.1750	-39.5927	-40.3878	0.8917	25.6573	Upward	Southward	Least changed	Most changed
Polystichum subintegerrimum (Hook. & Arn.) R. Rodr.	337	380	6.6007	-39.8624	-40.3364	0.6885	8.0997	Upward	Southward	Least changed	Most changed
Pteris chilensis Desv.	122	133	3.3399	-36.0184	-37.1069	1.0433	8.7997	Stable	Southward	Least changed	Most changed
Pteris semiadnata Phil.	295	336	6.3984	-40.9690	-41.2785	0.5563	9.9579	Upward	Southward	Least changed	Most changed
Rhaphithamnus spinosus (Juss.) Moldenke	413	484	8.4216	-40.9897	-41.4620	0.6872	16.2410	Upward	Southward	Most changed	Most changed

Rumohra adiantiformis (G. Forst.) Ching	468	500	5.5945	-39.7411	-40.2485	0.7123	24.6990	Upward	Southward	Least changed	Most changed
Schizaea fistulosa Labill.	177	212	5.9250	-43.4146	-43.9515	0.7328	14.0911	Upward	Southward	Least changed	Most changed
Serpyllopsis caespitosa (Gaudich.) C. Chr.	246	249	1.6966	-45.7195	-46.6433	0.9611	19.1159	Stable	Southward	Least changed	Most changed
Tepualia stipularis (Hook. & Arn.) Griseb.	322	341	4.4318	-46.6825	-46.7135	0.1760	19.0826	Stable	Stable	Least changed	Least changed
Thelypteris argentina (Hieron.) Abbiatti	846	1011	12.8528	-29.9266	-29.6357	0.5394	20.3575	Upward	Northward	Most changed	Most changed
Trichomanes exsectum Kunze	56	92	5.9510	-41.7119	-41.2378	0.6885	7.6330	Upward	Northward	Least changed	Most changed
Weinmannia trichosperma Cav.	429	480	7.1694	-43.6584	-43.8576	0.4464	16.0243	Upward	Southward	Most changed	Least changed

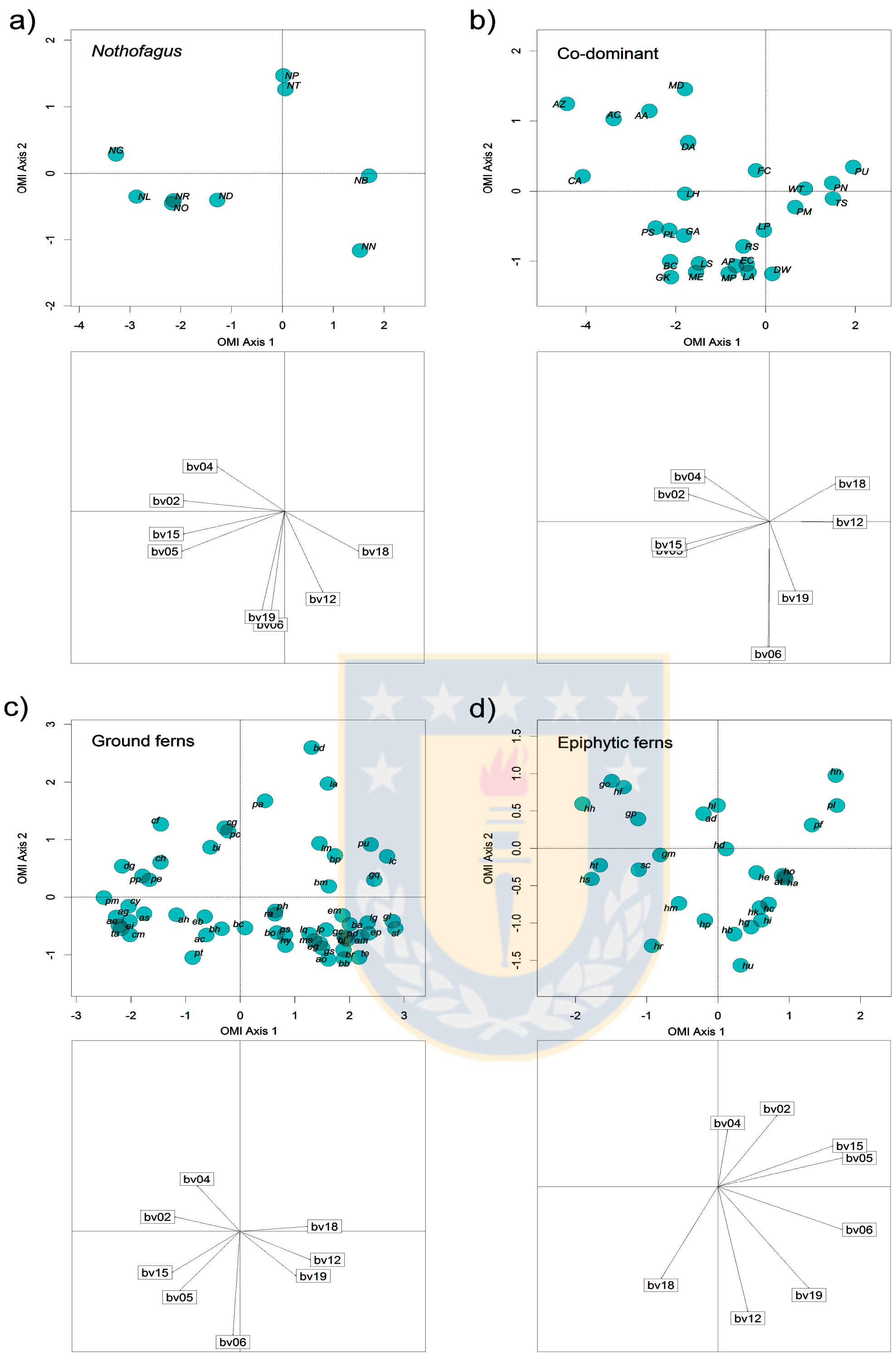

Figure 1.S1. Graphs of OMI analyses performed by species group. Distribution of species on niche axes using the Outlying Mean Index (OMI) method, considering each species group (upper graphs) and the variables correlated to each axis (lower graphs): a) *Nothofagus*, b) co-dominant species, c) ground ferns and d) epiphytic ferns. Source: own elaboration.

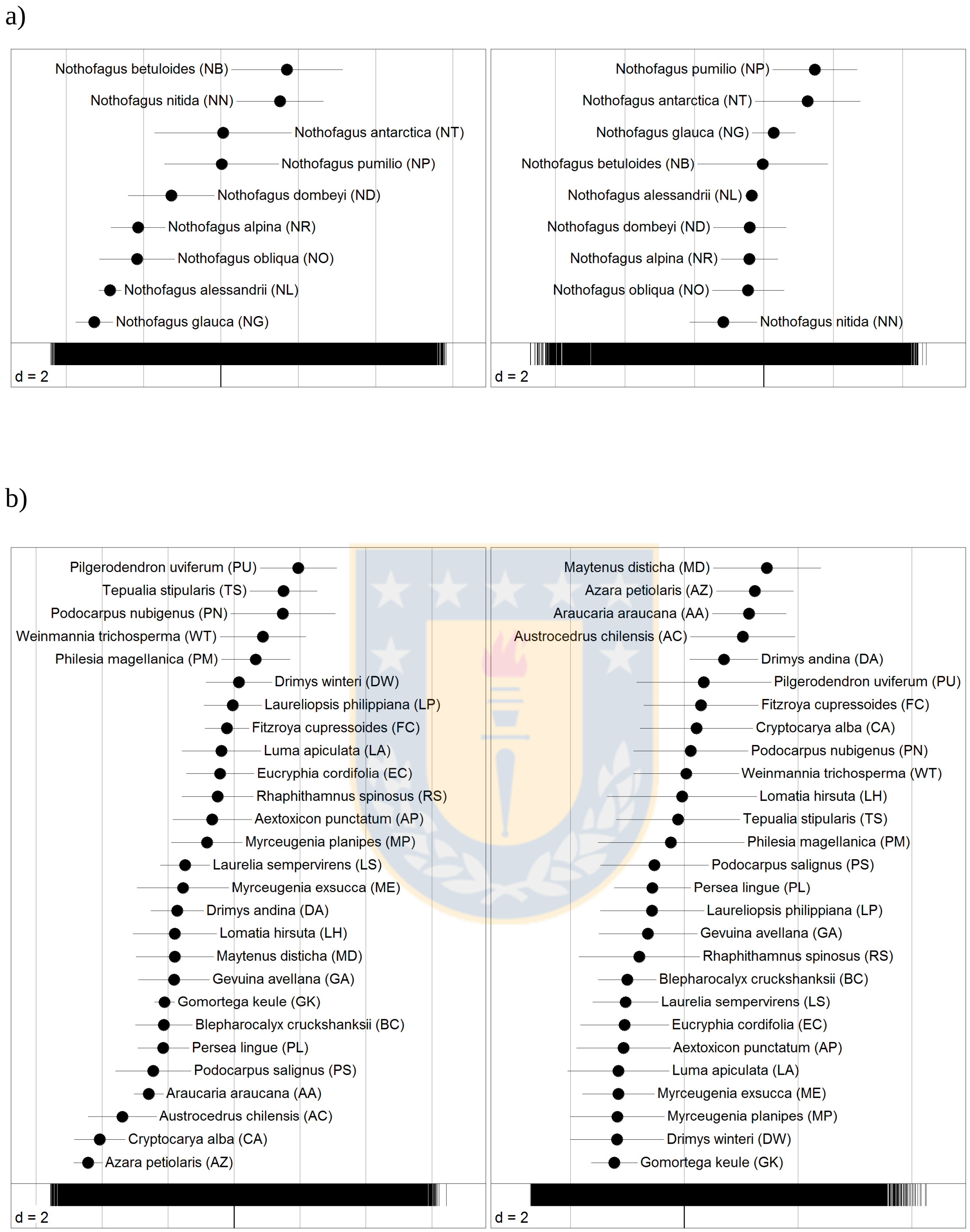

Figure 1.S2. Niche position and niche breadth comparison for species in both components of Outlying Mean Index (OMI) axis 1 at left and OMI axis 2 at right, by species group: a) *Nothofagus*, b) co-dominant species, c) ground ferns and d) epiphytic ferns. Source: own elaboration.

c)

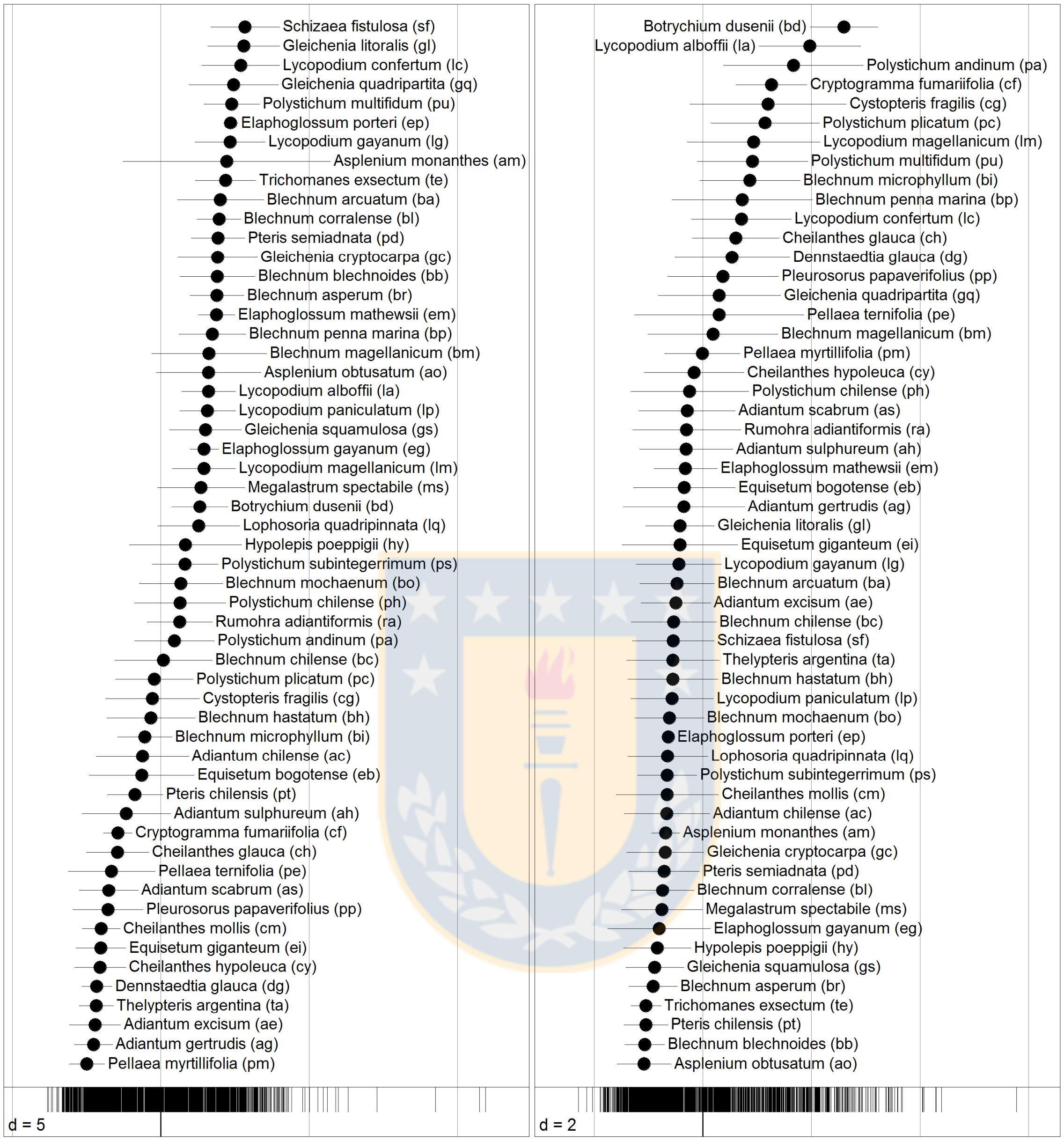

Figure 1.S2. (continued). Niche position and niche breadth comparison for species in both components of Outlying Mean Index (OMI) axis 1 at left and OMI axis 2 at right, by species group: a) *Nothofagus*, b) co-dominant species, c) ground ferns and d) epiphytic ferns. Source: own elaboration.

d)

Figure 1.S2. (continued). Niche position and niche breadth comparison for species in both components of Outlying Mean Index (OMI) axis 1 at left and OMI axis 2 at right, by species group: a) *Nothofagus*, b) co-dominant species, c) ground ferns and d) epiphytic ferns. Source: own elaboration.

CAPÍTULO II

In the right place at the right time: habitat representation in protected areas of South American *Nothofagus*-dominated plants after a dispersal constrained climate change scenario

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ABSTRACT

In order to assess the effects of climate change in temperate rainforest plants in southern South America in terms of habitat size, representation in protected areas, considering also if the expected impacts are similar for dominant trees and understory plant species, we used niche modeling constrained by species migration on 118 plant species, considering two groups of dominant trees and two groups of understory ferns. Representation in protected areas included Chilean national protected areas, private protected areas, and priority areas planned for future reserves, with two thresholds for minimum representation at the country level: 10% and 17%. With a 10% representation threshold, national protected areas currently represent only 50% of the assessed species. Private reserves are important since they increase up to 66% the species representation level. Besides, 97% of the evaluated species may achieve the minimum representation target only if the proposed priority areas were included. With the climate change scenario representation levels slightly increase to 53%, 69% and 99%, respectively to the categories previously mentioned. Thus, the current location of all the representation categories is useful for overcoming climate change by 2050. Climate change impacts on habitat size and representation of dominant trees in protected areas are not applicable to understory plants, highlighting the importance of assessing these effects with a larger number of species. Although climate change will modify the habitat size of plant species in South American temperate rainforests, it will have no significant impact in terms of the number of species adequately represented in Chile, where the implementation of the proposed reserves is vital to accomplish the present and future minimum representation. Our results also show the importance of using migration dispersal constraints to develop more realistic future habitat maps from climate change predictions.

INTRODUCTION

In situ conservation of species, communities or ecosystems is widely recognized as the basis for effective biodiversity conservation (Rodriguez *et al*., 2004). The systematic conservation planning (*sensu* Margules & Pressey, 2000), considers measurable conservation goals in which the representation of biodiversity in reserves is one of the most important issues (Margules & Sarkar, 2007). Here, representation is understood as the proportion of occurrence of a conservation target within a set of protected areas (Cabeza & Moilanen, 2013), considering species populations, communities or ecosystems within a geographical context (Kukkala & Moilanen, 2013).

The Convention on Biological Diversity and other worldwide initiatives recommended a minimum representation level of ecosystems and habitats between 10% and 12% (Tear *et al*., 2005; Burguess *et al*., 2005). After the Nagoya Summit in 2010, the aim for representation in protected areas (PA) was increased to 17% for terrestrial ecosystems (UNEP/CBD, 2010; Moilanen *et al*., 2013). Since the implementation of these policies is a national scale issue, biases and edge artifacts have been found for ecosystems or species distributed in several countries, leading to inefficiencies when establishing protected areas at a continental scale (Moilanen *et al*., 2013). Furthermore, the long-term persistence of current representation levels of species or ecosystems may be threatened by human-derived global changes, of which climate change is considered one of the most important (Sala *et al*., 2000). As changes become more evident, understanding their potential impact on natural ecosystems will turn to be increasingly important (Wiens *et al*., 2009), particularly how the representation level of key biodiversity habitats will be affected by projected climate conditions under different conservation schemes.

The temperate rainforests of southern South America are located in central and southern Chile with a lesser extent in neighboring areas in southwest Argentina (Donoso, 1993), see Fig. 2.1. They are considered one of the most threatened biodiversity hotspots (Myers *et al*., 2000), including different forest communities with high levels of endemism, most of which are dominated by the genus *Nothofagus* trees (Moreira-Muñoz, 2011; Donoso, 1993). Representation assessments have not been carried out for this ecosystem at the plant species level, while proper thresholds for them should consider the national conservation goal of 10% (CONAMA, 2005) or the Nagoya Summit suggestion of 17% (UNEP/CBD, 2010).

Since southern South American temperate rainforests are mainly located in Chile, the *Nothofagus*-dominated temperate rainforest plants constitute a good case study for assessing the representation of the PA network at a species level, minimizing the biases found by Moilanen *et al*. (2013) in their representation assessments for species and ecosystems located in several countries. These rainforests have several dominant tree species coexisting with a rich understory including ground and epiphytic plants, allowing comparisons among different plant groups in terms of climate change effects on their habitats and representation in PA as well.

The official Chilean national system of protected areas (NPA or SNASPE) includes national parks and reserves covering more than 18% of the country (Pauchard & Villarroel, 2002). However, the NPA shows a strong geographical bias towards the south of the country and high altitudes in the Andes (Armesto *et al*., 1998), see Fig. 2.1, and it has been considered insufficient to achieve minimum objectives for conservation at ecosystem or community scales (Pliscoff & Fuentes-Castillo, 2011) and at the species level for vertebrates (Tognelli *et al*., 2008). Besides NPA, there are privately owned reserves (PPA), for which a legal regulation is still being developed (Squeo *et al*., 2012). Moreover, the Chilean national biodiversity strategy (CONAMA, 2005) proposed in 2005 a set of prioritized sites for biodiversity conservation in order to strengthen their protection. A new legislation for protected areas and biodiversity issues is currently under debate and from the former set, only a subset is now considered as priority sites for biodiversity conservation at the national level (SBN). The rest of the formerly prioritized sites are now regarded as biodiversity conservation sites at the Chilean regional administration level (SBR) (CONAMA, 2005; MMA, 2014), see their location in Fig. 2.1). However, none of the two categories of priority sites have yet been implemented, and there are no comprehensive assessments on how they could help to accomplish conservation goals both currently and in the future. Further, it is known that conclusions about representation levels of protected areas change with the target species or ecosystems (Tognelli *et al*., 2008; Andrew *et al*., 2014). Thus, proper evaluations of present and future representation levels should consider assessments with multiple conservation targets (i.e. species).

Niche modeling is the most commonly used method for species distribution projections (Guisan *et al*., 2000; Wiens *et al*., 2009; Zimmermann *et al*., 2009). As a set of probabilistic analyses that uses statistical methods linked to geographic information systems, niche modeling depicts the relationships among species spatial distributions and a series of biotic and abiotic variables related to those spatial distributions (Guisan & Zimmermann, 2000; Anderson *et al*., 2003; Guisan *et al*., 2006). Niche modeling generates species distribution maps, allowing species distributions to be compared at different times if habitat conditions were to change. This has led to a fruitful discussion about the expected spatial shifts in species distribution due to climate change. Several studies in plants have found that species habitats will move towards higher latitudes or altitudes as a result of climate change (Guisan *et al*., 2000; Jump *et al*., 2009). Interestingly, this has started to be corroborated in the field (Walther, 2003; Lenoir *et al*., 2008).

However, most of potential future distribution maps produced through niche modeling methods have included uncertainties regarding the capability of species populations to effectively migrate to new territories and become part of the species habitat in this new timeframe (Thuiller *et al*., 2005; Araújo *et al*., 2007; Hannah *et al*., 2007; Engler *et al*., 2012, Araújo *et al*., 2011; D'Amen *et al*., 2011; Carvalho *et al*., 2011; Kuhlmann *et al*., 2012; Bateman *et al*., 2013). Depending on the species, full-migration scenarios might be unrealistic because of biological limits for propagule dispersal across landscapes with spatial barriers, and the effective availability of new territories due to increasing human land use changes (Engler *et al*., 2009; Summers *et al*., 2012). Different tools have been developed to take these migration constraints on species into account, and hence produce more realistic future distributions for expected climate change scenarios (Engler *et al*., 2012; Bateman *et al*., 2013).

Here we took advantage of modern tools for species distribution models and assessed the representation potential of Chilean protected areas (NPA and PPA) and proposed sites (SBN and SBR), for plant species in southern South American temperate rainforests comparing two groups of dominant trees and two groups of understory plants, using niche modeling tools and considering climate change impact under a future migration constrained scenario.

MATERIALS AND METHODS

Species selection and data sources

We selected 118 South American temperate rainforest plant species in four groups: a) *Nothofagus* tree species that dominate most of the South American temperate rainforest (n=9); b) co-dominant tree and woody species (n=27) from vegetation communities along with *Nothofagus*, according to Gajardo (1994); c) ground ferns, considered as understory species which share their distribution with *Nothofagus* (n=55) and d) epiphytic fern species which grow in *Nothofagus* forests (n=27). The nomenclatural lists are based on Zuloaga *et al*. (2008) for trees and shrubs, and Rodríguez (1995) for ferns. Species localities for trees were taken from the Chilean national forest inventory (CONAF/CONAMA/BIRF, 1999), and the Universidad de Concepción Herbarium (CONC), the most complete collection of Chilean plants. The list of species and the number of valid occurrences for each species is shown in 2.S1 Table included in Supporting Information.

Selection of climate variables and data sources

Eight variables with the lowest correlations among them were selected from the WorldClim global climate database (Hijmans *et al*., 2005) corresponding to the present climate conditions with a 30 arc-second resolution. Four of them were related to energy constraints: a) mean diurnal temperature range; b) temperature seasonality; c) maximum temperature in the warmest month and d) minimum temperature in the coldest month. The other four variables were directly related to water availability: e) annual precipitation; f) precipitation seasonality; g) precipitation in the warmest quarter and h) precipitation in the coldest quarter.

Modeling methods and present climate models

Plant species distributions were modeled using eight techniques available through the BIOMOD R-package (Thuiller, 2003; Thuiller *et al*., 2009; R Core Team, 2012): ANN for Artificial Neural Networks, CTA for Classification Tree Analysis, FDA for Flexible Discriminant Analysis, GAM for Generalized Additive Models, GBM for Generalized

Boosting Models, GLM for Generalized Linear Models, MARS for Multivariate Adaptive Regression Splines, and RF for Random Forest, details of which are explained in Thuiller (2003) and Thuiller *et al*. (2009). The best models according to AUC performance values, Kappa and True skill statistics were selected for each species. We chose the model indicated as the best by a majority of the three criteria. In the few cases where they fully disagreed, we opted for AUC as the selecting criteria (see 2.S2 Table in Supporting Information). A current distribution map was produced considering BIOMOD cut-off thresholds to project the best specific niche model. Areas that currently correspond to human land use within these distribution maps were determined by overlaying the models produced with CONAF/CONAMA/BIRF (1999) digital information.

Future climate data

We used future climate scenarios available from Ramirez & Jarvis (2008). Six future scenarios were initially tested for the year 2050: CCCMA CGCM2 B2A, CSIRO MK2 B2A, HCCPR HADCM3 B2A, CCCMA CGCM31 A1B, CSIRO MK30 A1B and UKMO HADCM3 A1B. The most conservative scenario was then chosen according to their least change on *Nothofagus* species distributions, which was CSIRO MK2 B2A. The future distribution for each species was projected using BIOMOD from the specific best niche model and the selected future climate data set.

Migration constraints

Once future distribution maps were drawn, migration for each species was modeled using the MIGCLIM R-package (Engler *et al*., 2012; R Core Team, 2012). MIGCLIM specific parameters to include dispersal kernels, potential propagule production, short-distance dispersal capacity (SDD) and probability for long-distance dispersal (LDD) were developed considering the literature available for each species (Tryon, 1970; Tryon , 1986; Armesto & Rozzi, 1989; Donoso & Lara, 1998; Cuevas, 2000; Loehle, 2000; Armesto *et al*., 2001; Figueroa, 2003; Hechenleitner *et al*., 2005; Donoso, 2006; Smith-Ramírez *et al*., 2007; Rodríguez *et al*., 2009; De Groot *et al*., 2012; Gillespie *et al*., 2012; Núñez-Ávila *et al*., 2013) related with propagule dispersal syndromes, probable initial and optimal maturity ages and relative abundance of their populations: see 2.S3 Table in Supporting Information for this data. As SDD and LDD are inferred values, a sensitivity analysis of these parameters was carried out to assess how changes in their values affected the predicted habitat size for each species. For this purpose, we performed new runs of every model for each species using new SDD values accounting for 25%, 50% and 200% of the initially inferred value. For LDD, new models were run using 10%, 25%, 50%, 200%, 400% and 1000%. We compared all the MIGCLIM outputs among them and against an unrealistic scenario with no restrictions to migration, observing that the changes included in SDD and LDD values did not generate important changes in habitat sizes, whereas the full migration scenario clearly exaggerated the habitat sizes (See 2.S4 Table and 2.S1 Fig. in Supporting Information for further details). Even though native forest substitution in central-south Chile reached an important magnitude during the decades of 1980s and 1990s (Echeverría *et al*., 2006; Aguayo *et al*., 2009; Echeverría *et al*., 2011), current assessments of land change made by the Chilean Secretary of Forests (MINAGRI, 2014; SINIA, 2012) show that this process is declining. In absence of spatial predictions for future land conversion in the whole distribution of these ecosystems, we utilized the current land use maps (CONAF/CONAMA/BIRF, 1999) as a conservative scenario to set the spatial barriers for future dispersion with MIGCLIM.

Protected areas

Both present and migration constrained future distribution outputs of studied species were overlaid on maps corresponding to the following categories of Chilean protected areas: a) the national system of protected wild areas (NPA) managed by the Chilean government; b) private protected areas (PPA) managed by private owners, c) prioritized sites for biodiversity conservation at national level (SBN) as a proposal for new protected areas according to CONAMA (2005), and d) prioritized sites for biodiversity conservation at each Chilean regional administration level (SBR), according to CONAMA (2005). Maps for the four categories were received from MMA (2014) and MINAGRI (2014) and non-governmental organizations such as Así Conserva Chile and World Wildlife Fund Chile, as shown in Fig.2.1.

Climate change effect assessment

Geographic information system (GIS) processes were performed using the raster R-based package (Hijmans & van Etten, 2012; R Core Team, 2012). Current and future distribution areas were compared by means of paired Student's t-test and fitting linear models, both of which utilized the stats R-based package (R Core Team, 2012). For assessing the climate change effect on the representation of every species habitats in protected areas, we compared the current and future representation in terms of the percentage of the habitat distribution for each time scenario. Achieving the minimum representation for each species was established according to two thresholds: 10% according to the Chilean national ecosystem representation goal for the year 2015 (CONAMA, 2005) and 17% in line with the Nagoya summit representation goal for the year 2025 (UNEP/CBD, 2010).

RESULTS

Expected effects of climate change on habitat size

Comparisons between present and the dispersal constrained future scenario for all the studied species showed that *Nothofagus* species significantly decreased ($p=0.0047$) their mean habitat size from an area of 98,553 ± 77,633 km^2 to 87,621 ± 72,320 km^2 in the future case (Fig. 2.2, and 2.S5 and 2.S6 Tables in Supporting Information). For the co-dominant species group, the mean habitat area (60,130 ± 47,082 km^2) showed no significant changes in their evaluation for the future scenario (60,095 ± 47,459 km^2). In contrast, ground ferns habitat size (34,619 ± 28,760 km^2) would increase in the future (45,423 ± 35,707 km^2, $p<0.0001$), whereas the epiphytic ferns showed in the present scenario a mean habitat size (39,034 ± 28,910 km^2) smaller ($p<0.0001$) than in the future (53,206 ± 37,833 km^2). Thus, the future climate change scenario predicted habitat size modifications for the studied plants, with expected increases for 73.7% of the species and shrinkage for 26.3% of them (Table 2.1). When both unconstrained and dispersal constrained future scenarios were compared, they differed in all the species groups ($p=0.0305$ in *Nothofagus* and $p<0.001$ in the rest of the groups, see Fig. 2.2 and 2.S6 Table in Supporting Information). Full migration scenario was significantly higher in habitat size (18.7% on average) than migration constrained models, which led us to use only the latter ones, since they consider biological bases for propagule dispersal capacity and life cycle delays, and they were very robust as indicated by the sensitivity analyses (See 2.S4 Table in Supporting Information).

To assess if changes in habitat size were equivalent among species irrespective of their current habitat size, we performed linear general models (LGM) between present and future habitat size for all the species groups (Fig. 2.3). For *Nothofagus*, the regression model slope was different (p=0.003) and lower than 1 (0.928); furthermore, its intercept value was negative, indicating decreases in habitat size where major reductions were observed in species with larger habitats. Co-dominant species proved to maintain their habitat size, or experience only insignificant reductions, since the slope (0.994) did not differ significantly from 1 (p=0.260). Both species groups, ground ferns and epiphytic ferns, showed linear regression slopes significantly (p<0.001) higher than 1 (1.212 and 1.267, respectively), accompanied by a positive intercept, indicating greater changes for those species with larger current habitats.

Expected changes in species representation in protected areas

For NPA areas, most of the species showed an increase in representation (70.3%) with climate change; only 29.7% of the studied species showed a decrease in their representation in NPA (Table 2.1). Considering species groups (Fig. 2.4), even though all *Nothofagus* species decreased their habitat size, their habitat representation in NPA increased. This is also seen in the fitted linear model shown in Fig. 2.4, where we found a positive intercept and a slope significantly (p=0.0128) greater than 1. Likewise, even though 51.9% of the co-dominant species decreased their habitat size, all of them increased their representation in NPA, as shown by the fitted linear model with a positive intercept and a slope larger than 1 (p<0.001). On the contrary, the habitat size of most ground ferns (90.9%) and epiphytic ferns (88.9%) showed increases in the future scenario. However, future representation in NPA increased by only 63.6% for ground ferns (fitted linear model showing a positive intercept and a slope higher than 1, p=0.035), versus a decreased future representation of 55.6% for epiphytic fern species, where the slope of the fitted linear model did not differ from 1 (p=0.270).

Changes in the representation of all the species in the assessed conservation schemes can be observed in Fig. 2.5. When a 10% threshold was used as a minimum representation in NPA, only 50% of the total species appeared as adequately protected by the NPA official system. In particular, 67% of *Nothofagus* species (Fig. 2.5a), 44% of co-dominant species (Fig. 2.5b), 38% of ground ferns (Fig. 2.5c) and 74% of epiphytic ferns (Fig. 2.5d) are represented in NPA. The NPA representation increased in the climate change scenario for co-dominant species from 44% to 48% of adequately protected species and for ground ferns from 38% to 42%, indicating an increase from 50% to 53%, looking at all the evaluated species (Fig. 2.6).

Considering the 17% threshold, Chilean national protected areas provided protection for only 30% of the total number of studied species: 44% of *Nothofagus* species, 30% of co-dominant species, 20% of ground ferns and 44% of epiphytic ferns. For the future scenario, 31% of all the studied species may be well represented in the NPA, with the same species number for *Nothofagus*, but a lower species number for epiphytic ferns (37%), and an increasing representation for co-dominant plants and ground ferns up to 37% and 22%, respectively.

The inclusion of private parks (PPA) significantly affected the minimum representation for some species, such as *Nothofagus alpina* and *Nothofagus dombeyi* in the future scenario when considering a 17% threshold, and co-dominant *Aextoxicon punctatum* and *Eucryphia cordifolia* with a 10% threshold. At least 11 species of ground ferns proved to be well represented as a result of the inclusion of PPA: *Gleichenia litoralis* for both thresholds, *Blechnum asperum* and *Megalastrum spectabile* for the 10% threshold, and *Blechnum penna-marina*, *Pteris semiadnata* and *Lycopodium paniculatum* for the 17% threshold. The addition of PPA also helped four more epiphytic fern species to be well represented, such as *Asplenium trilobum* and *Hymenophyllum plicatum* with the 10% threshold in both present and future scenarios; and for the 17% threshold , 6 and 10 species respectively for each time scenario, including species like *Hymenophyllum umbratile* and *Hymenophyllum dentatum*. The inclusion of PPA generated complementary protection to the NPA, aiding 19 more species to be well represented in the present scenario (for both the 10% and 17% thresholds) and 20 more species in the future scenario considering the 10% threshold, and 23 for the 17% threshold.

Prioritized sites for biodiversity conservation at Chilean national level (SBN) were crucial for achieving a satisfactory representation in most species. If the 10% threshold is considered and SBN were implemented at the present, 110 of the 118 evaluated species (93%) achieved enough representation while 95% of the assessed species would attain the minimum representation in the future scenario. When using 17% threshold, SBN could add up to 75% of the species as suitably represented under the present scenario and the SBN location may help to adequately represent up to 84% of the studied species.

The effect of including SBR after SBN is relevant when considering the 17% threshold, since the former could increase the species under proper representation from 75% up to 96% in the present scenario, and from 84% up to 95% for the future scenario, helping to achieve enough representation for co-dominants and ground ferns. However, when using the 17% threshold, 5 species would be currently underrepresented, and only 6 of the studied species would lack minimum representation in the future scenario. The species that would not be well represented under the 17% scenario, considering NPA and PPA, even if the SBN and SBR were implemented, include the endangered tree *Nothofagus alessandrii*, co-dominant *Blepharocalyx cruckshanksii*, ground ferns *Pteris chilensis*, *Cheilanthes mollis* and *Pellaea ternifolia* and epiphytic fern *Hymenophyllum tumbridgense*.

DISCUSSION

The current level of representation within the Chilean NPA at the plant species level can be considered low compared to other studies: only 50% of the species are minimally represented, compared to 100% in Western Europe and 89% in the South African Cape Region (Hannah *et al*., 2007). This may be due to the fact that NPA is strongly southward biased and it is not coincident with the greatest diversity of vascular plants located in the center-south of Chile (Armesto *et al*., 1998). Interestingly, our results showed that NPA will maintain or even increase the representation level of temperate rainforest plants in the climate change scenario by mid-century, reaching up to 52.5% of species in Chile. This contrasts with a projected decreasing representation of 94% for Western Europe plant species and 78% for species in the Cape Region, for the same 10% protection threshold (Hannah *et al*., 2007) and with some vertebrate species in Europe which are also expected to lose representation under climate change scenarios (D’Amen *et al*., 2011; Carvalho *et al*., 2011).

The future scenario for climate change indicated changes in the habitat size of the *Nothofagus*-dominated temperate rainforest of southern South America. Nevertheless, these changes are not predicted to be similar for each plant group, nor are the changes in habitat size necessarily in line with modifications in the representation level of their habitats in official areas such as NPA. For example, while the distributional habitat sizes for *Nothofagus* species are expected to decrease in the future, their representation level is projected to increase, suggesting that NPA reserves are located in useful areas for this species group in the long-term. In addition, NPA may include areas prone to be colonized by these species in a short-term future, according to the migration models. The same observation can be made with co-dominants; the species for which habitat sizes are projected to decrease (51.9% of species number) are expected to increase their representation levels in NPA. Furthermore, all of the species for which distribution size is anticipated to expand (48.1%) are expected to increase their representation proportion as well. Examples of this may be seen in species such as *N. alpina* and *N. dombeyi*, whose northern distribution and habitats at lower altitudes of the Andes mountain range are expected to be lost due to climate change. At the same time, their future habitats are expected to include present habitats that will persist in addition to new expanding zones, both coincident with the current location of NPA reserves at higher altitudes. The same situation may occur with co-dominant trees endemic to central-southern Chile that require high water availability, like *Laurelia sempervirens* and *Persea lingue*. These species are expected to decrease their northern lowland distributions where rainfall during the growing season is projected to decrease and this is coincident with areas where NPA reserves are scarce or non-existent. In addition, these species are expected to maintain their southern distributions or expand into areas close to their southern distributions, where more NPA reserves are located.

Understory ferns are expected to differ from the two groups mentioned above: 90.9% of ground fern species are projected to expand their habitat size, but only 63.6% will most likely increase their representation level in NPA. Nonetheless, the most striking difference is seen in epiphytic ferns; 88.9% of these species are expected to gain distribution area, but only 44.4% are anticipated to expand their representation proportion. This is most likely related to the fact that NPA units are geographically biased towards higher elevations, while a significant proportion of epiphytic fern species are prone to expand to lower altitude forests not included in NPA. The latter implies that the location of NPA reserves will continue to be useful in the future, except for one third (29.7%) of the total studied species for which new colonizable areas will not coincide with NPA or some habitats currently protected by NPA may not be climatically suitable in the future. Among these species we can mention a set of ground ferns distributed in the Mediterranean climate of central Chile, such as *Cheilanthes hypoleuca*, *Dennstaedtia glauca*, *Pteris chilensis* and *Thelypteris argentina*, whose future representation is expected to decrease because the few NPA units existing in central Chile may not be useful for the conservation of these ferns after climate change. Some other ground fern species with larger habitat distributions like *Blechnum magellanicum* and *Lycopodium magellanicum* are expected to have a distribution expansion outside NPA units, resulting in a decrease in their future representation. Other cases like *Elaphoglossum porteri* or *Elaphoglossum gayanum* have very small present distribution areas, and the decrease in their representation level can be attributed to the fact that their current distributions are mostly within NPA reserves, and in the future they would expand their populations to other places outside NPA. The ecological niches of both groups ground and epiphytic ferns resulted more heterogeneous compared to those of the dominant trees, with a differential response in habitat size changes also, and hence in their representation levels in the NPA system.

The current location of NPA parks and reserves assures enough future protection to maintain the same number of species of *Nothofagus* trees and epiphytic ferns. Thus, the current location of NPA reserves is important for current representation and it will continue to be important when temperate rainforest species face the expected climate change effects in the future. This suggests that any alterations to NPA units, such as clipping or area reduction for productive exploitations or changes in their main objectives to aims other than preserving habitat representation, are therefore strongly discouraged from the standpoint of biological resource policies for overcoming climate change. Despite the high proportion of Chilean land dedicated to NPA, representation goals are still not being met when biodiversity levels are considered, such as plant species levels, and future climate change for the region. Moreover, the current role of NPA in long-term biodiversity conservation is not fully assured yet since management plans have not been completed for all their units. In recent years, there has been a debate over redefining the main objectives of the NPA system and the government has included tourism among them, leading to building facilities in formerly fully preserved lands. Restricting grazing for the livestock of nearby communities, alien species control and setting maximum visitor limits inside reserves are among the challenges to be accomplished in order to assure the NPA long-term conservation role.

PPA reserves have not yet been fully formalized under law. However, our results showed that they would have a very positive complementary effect to official NPA, since PPA would add conserved habitats for 97.5% of the evaluated species, increasing additional conservation for 73.7% of the studied species in the future scenario. When minimum representation thresholds were considered, PPA reserves were shown to help 16.1% of the studied species to attain a well-conserved status, for both thresholds in the present scenario. Moreover, they could aid 16.9% of these species to obtain a well-represented future condition under the 10% threshold; this is 19.5% of the species if the 17% threshold were used for the future scenario. The positive effects of including PPA are more important for understory fern species than dominant tree species because the distribution of PPA areas is complementary to NPA in low elevations, where some understory ferns may tend to expand their distribution in the future. Since NPA reserves are located unevenly across the Chilean territory, proportionally more distributed towards southern and higher areas, PPA may spatially fit as a significant complement for NPA areas, in the same direction of those found by other evaluations of private reserves (Jackson & Gaston, 2008; Gallo *et al*., 2009).

As proposed for new protected areas under the Chilean national biodiversity strategy (CONAMA, 2005), the implementation of the SBN sites virtually completes the supplementary needs for minimum representation for most of the studied species after considering NPA and PPA, both in the present and future scenarios with a 10% threshold. The effect of including the SBR sites resulted important to accomplish satisfactory levels of species representation when applying the most restrictive threshold. This contrasts to the fact that Chilean environmental policy has recently considered most of these SBR areas in a low priority for being implemented as reserves, because they mostly comprised private properties. If the Nagoya summit threshold were applied, the set of species mentioned at the end of Results would still not achieve a minimum representation with NPA, PPA, SBN and SBR combined; most of them have habitats included in a Mediterranean-climate zone with scarce representation under conservation schemes, associated with high replacement due to human land-use. If SBN and SBR were carried out, it would be wise to include the habitat area of those species in the proposed reserves as well, especially for the endangered tree *Nothofagus alessandrii*, tree *Blepharocalyx cruckshanksii* and the ground fern *Pteris chilensis*.

Even though climate change is expected to affect the habitats of the evaluated plant species from these important South American temperate rainforests, the current location of the conservation units determines that there will be no significant change in terms of the number of species with a minimum representation for the evaluated future scenario. Analyzing climate change effects on habitat size and representation in parks, considering only the dominant trees as a basis may not be applicable to other species groups as it was the case for understory plants in this study. The evaluated groups are an example set of plants growing in a temperate rainforest, and their distributions are expected to react differently with climate change. Since their habitat representation may be achieved in a specific manner for every group, it is important to realize that this kind of assessment should consider a diverse and wide spectrum of species groups.

CONCLUSIONS

When applying the future scenario, most of the dominant tree species are expected to decrease in habitat size while their representation levels increase, but most of the understory plant species increased their habitat size, as well as their representation level in NPA. Contrary to former worldwide analyses, our study indicated that official Chilean NPA reserves are spatially arranged in a way which corresponds to areas prone to be maintained or expanded as useful habitats for most of the studied species after climate change. Our results highlight the need for strengthening NPA in order to contribute to overcome the climate change in South American temperate rainforest plants. Therefore, it is extremely important not to affect or reduce NPA units due to policy changes or productive purposes.

Private contributions to conservation through PPA reserves help official NPA to achieve minimum representation of most of the studied plant species. This will remain to be true or even increase in importance after climate change for many of the studied species. Implementing the prioritized SBN as formal reserves is also strongly recommended since they virtually complete the minimum representation needs for most of the studied plants in the present as well as the future climate-change scenario if the 10% threshold is observed. Considering an aggregated implementation of proposed SBR would be essential if 17% threshold was taken into account. The evaluated species were chosen because they represent some substantial structural elements of South American temperate rainforests; dominant elements such as *Nothofagus* tree species and co-dominant woody species are expected to react in their own specific way, different from understory components such as ground ferns and epiphytic ferns. Consequently, climate change assessments must be carried out on a species level and it is important not to assume that expected effects to dominant tree species are necessarily applicable to understory species. Finally, the use of migration dispersal constraints should always be included when more realistic future habitat maps are developed.

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TABLES

Table 2.1. Frequencies of expected effects after climate-change scenario (%) for each species group. Features in parenthesis indicate number of species. Source: own elaboration.

Effect in:		*Nothofagus*	Co-dominant	Ground ferns	Epiphytic ferns	Total species
Habitat size	Representation					
Decrease	Increase	100% (9)	51.9% (14)	7.3% (4)	11.1% (3)	25.4% (30)
Increase	Increase	-	48.1% (13)	56.4% (31)	33.3% (9)	44.9% (53)
Increase	Decrease	-	-	34.5% (19)	55.6% (15)	28.8% (34)
Decrease	Decrease	-	-	1.8% (1)	-	0.8% (1)

FIGURES

Figure 2.1. Location of *Nothofagus*-dominated temperate rainforests in South America and the geographical distribution of protected areas in Chile: national system of protected areas (NPA), private protected areas (PPA), prioritized sites for biodiversity conservation at national level (SBN) and proposed sites for biodiversity conservation at each Chilean regional administration level (SBR). Source: own elaboration.

Figure 2.2. Habitat size for each species group and modeled scenario. Top letters indicate significant differences within each species group according to paired t-tests in 2.S6 Table found in Supporting Information. Source: own elaboration.

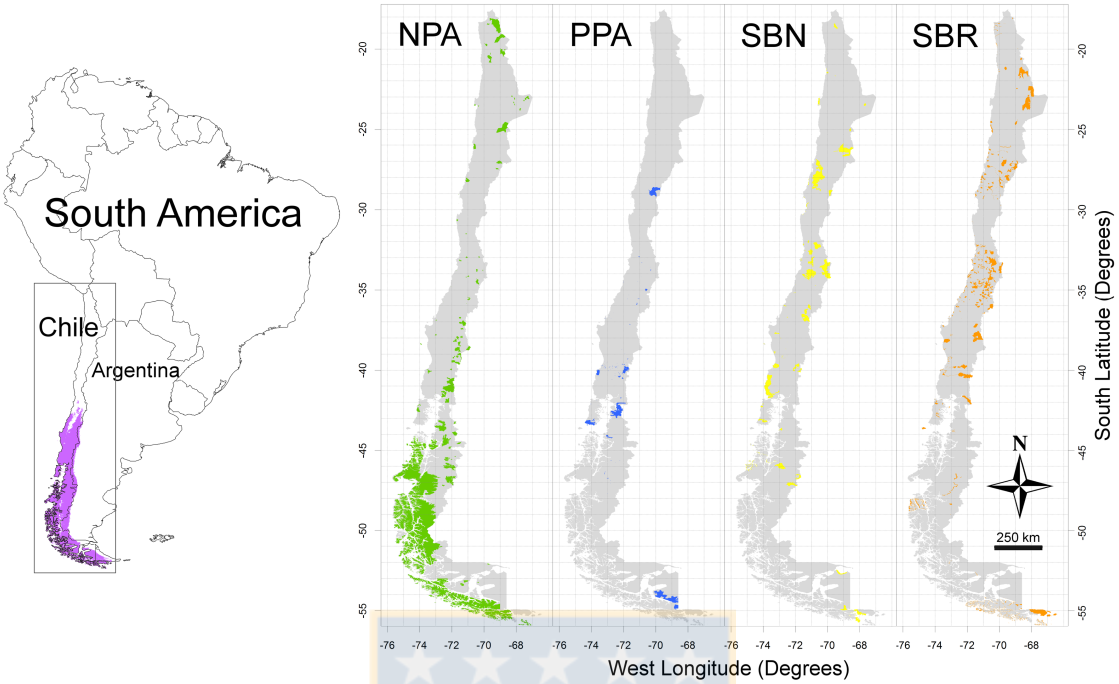
Figure 2.3. Expected changes in habitat area for all the species groups. Gray diagonal lines represent no change in habitat size; circles below the lines represent species with expected habitat size shrinkages, while circles above the lines represent species with expected habitat size increases. Red lines represent fitted linear models for each species group with their correlation, intercept and slope data. Source: own elaboration.

Figure 2.4. Expected changes for all the species group representation. Gray diagonal lines show no change in representation in NPA, circles under the lines represent expected shrinkages in NPA representation, while circles above the lines depict expected increases in representation in NPA. Red lines represent fitted linear models for each species group with their correlation, intercept and slope data. Source: own elaboration.

Figure 2.5. Present and future accumulated representation of a) *Nothofagus* tree species, b) co-dominant plant species, c) ground ferns and d) epiphytic ferns, in the Chilean national protected area system (NPA), private protected areas (PPA), prioritized sites for biodiversity conservation at national level (SBN) and proposed sites for biodiversity conservation at each Chilean regional administration level (SBR). Species lists in each group are hierarchically ordered by the representation of their present habitats in NPA official system. Continuous vertical lines indicate a 10% representation threshold and dotted lines indicate a 17% representation threshold. Source: own elaboration.

Figure 2.6. Accumulated proportion of species number with minimum representation in protected areas, considering: a) a 10% threshold as proposed by CONAMA (2005), and b) a 17% threshold as proposed by UNEP/CBD (2010) according to Chilean national protected

areas system (NPA), private protected areas (PPA), prioritized sites for biodiversity conservation at national level (SBN) and proposed sites for biodiversity conservation at each Chilean regional administration level (SBR). Features within strips indicate the aggregated number of species that achieve the minimum conservation target by each protection system. Source: own elaboration.



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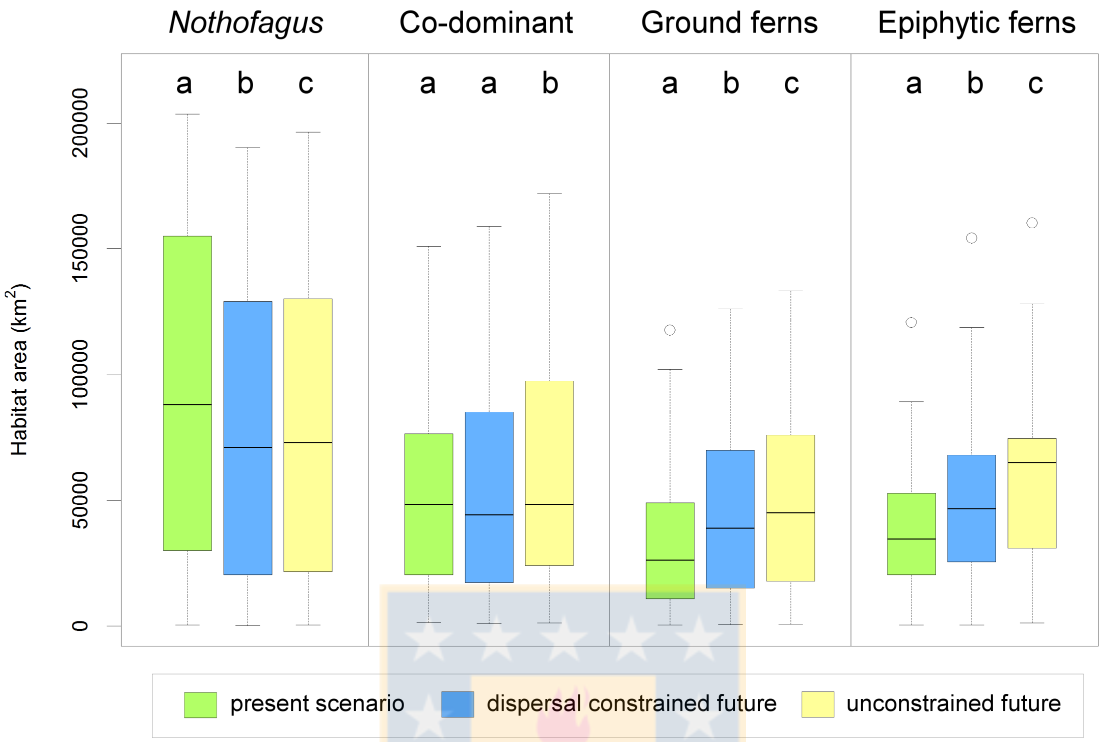

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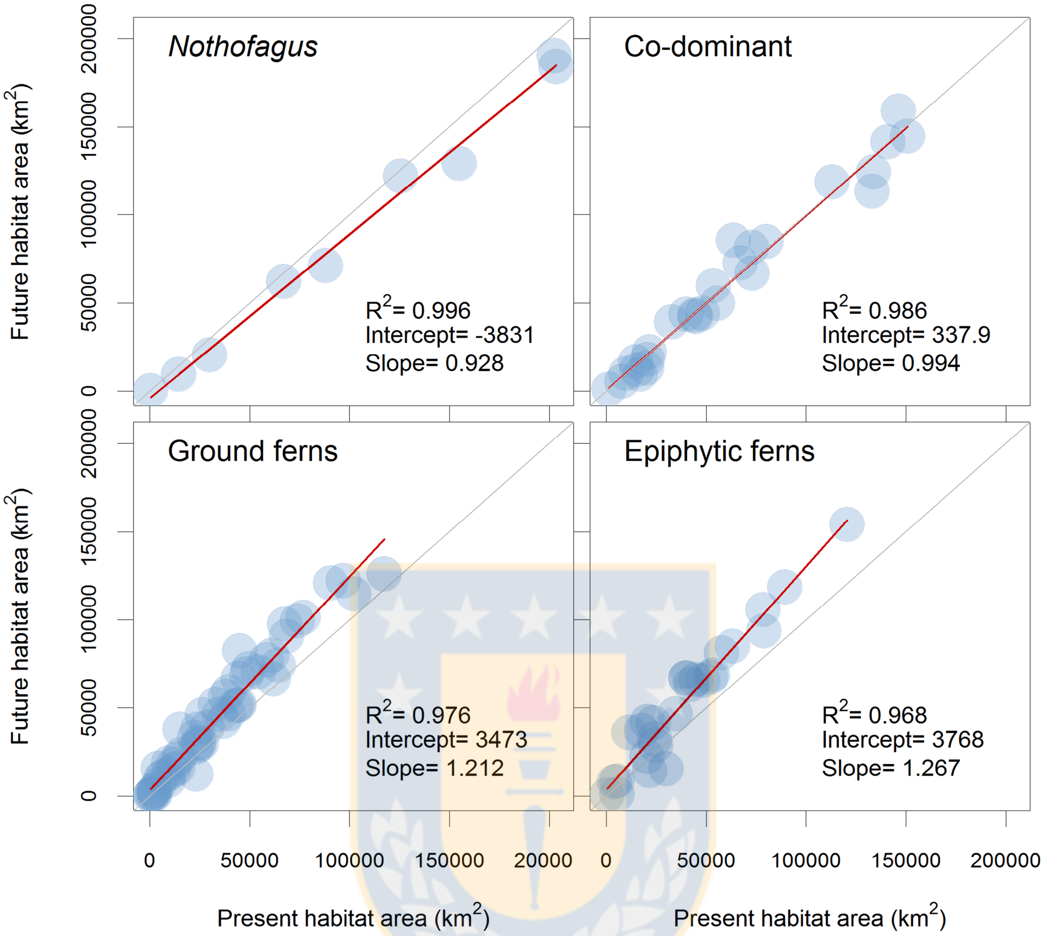
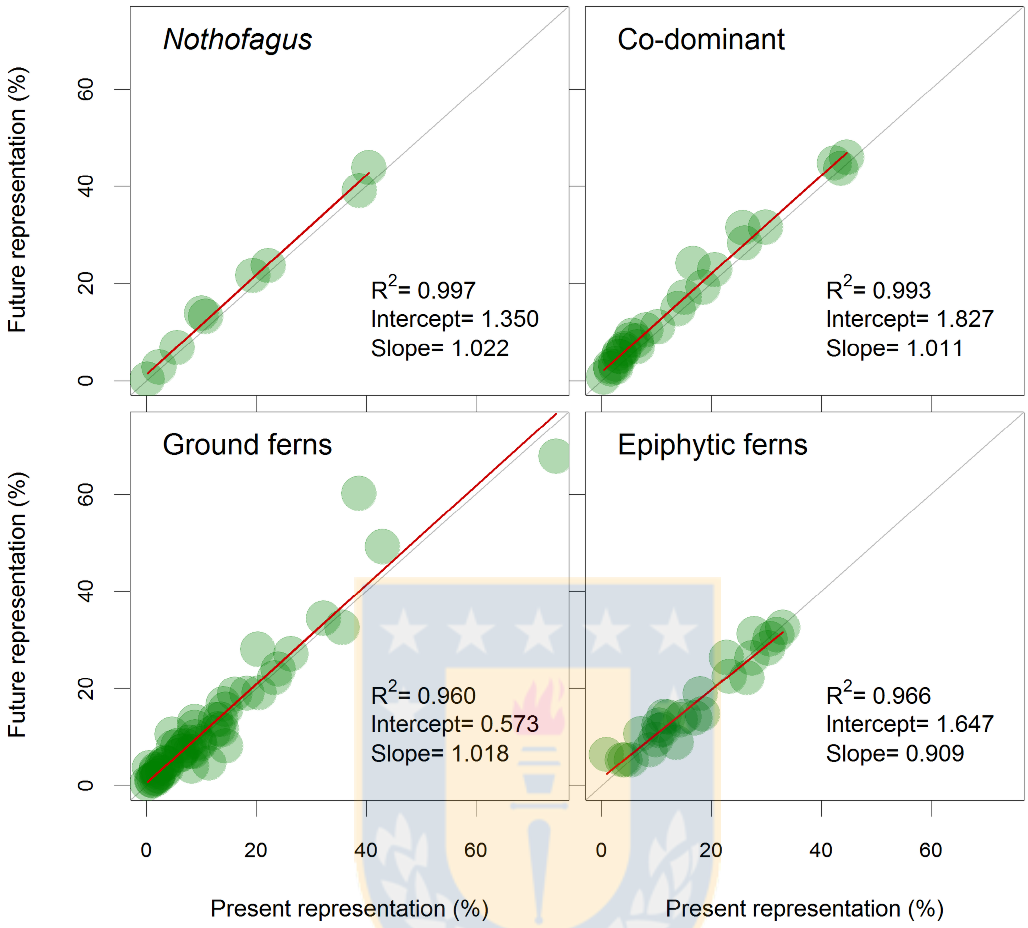


Figure 2.3. Expected changes in habitat area for all the species groups. Gray diagonal lines represent no change in habitat size; circles below the lines represent species with expected habitat size shrinkages, while circles above the lines represent species with expected habitat size increases. Red lines represent fitted linear models for each species group with their correlation, intercept and slope data. Source: own elaboration.



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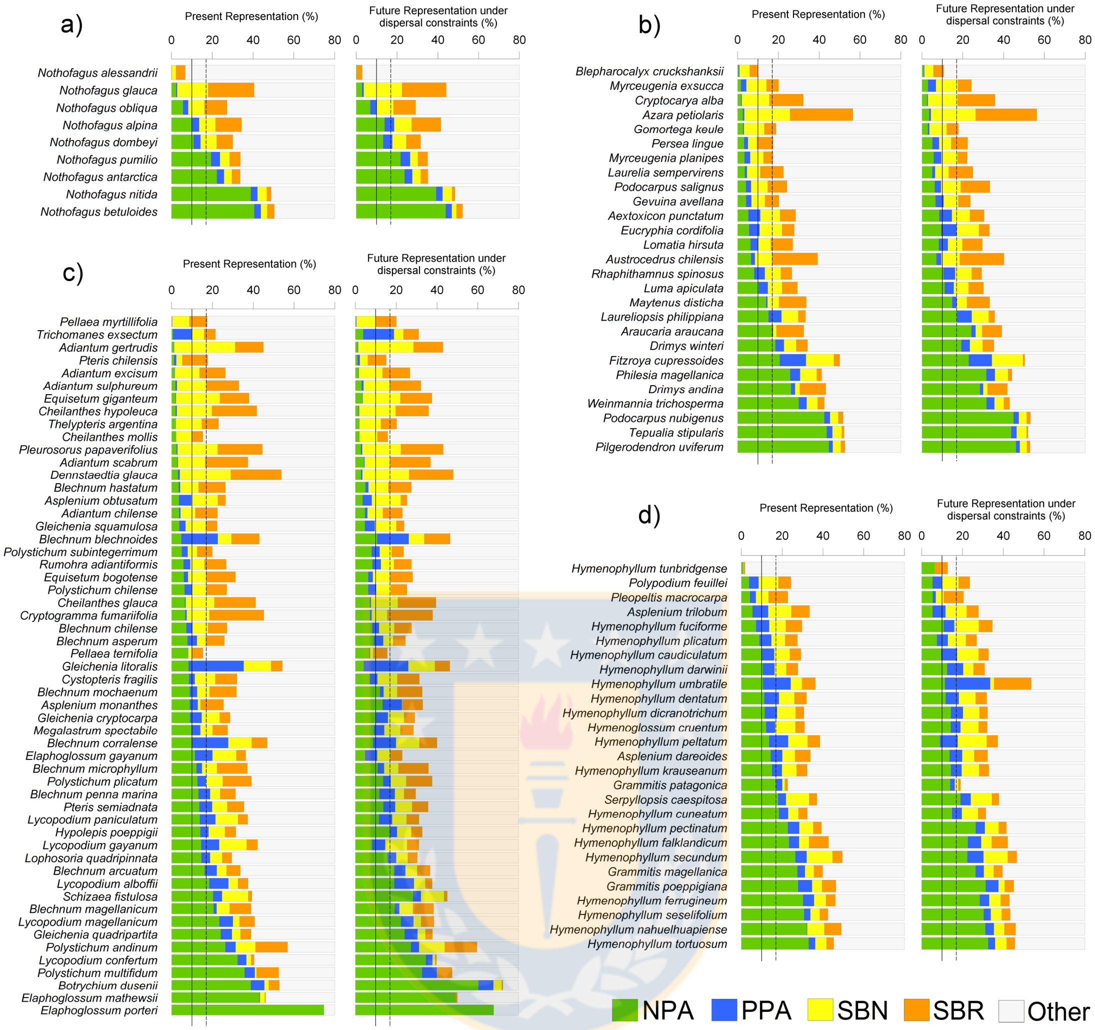

Figure 2.5. Present and future accumulated representation of a) *Nothofagus* tree species, b) co-dominant plant species, c) ground ferns and d) epiphytic ferns, in the Chilean national protected area system (NPA), private protected areas (PPA), prioritized sites for biodiversity conservation at national level (SBN) and proposed sites for biodiversity conservation at each Chilean regional administration level (SBR). Species lists in each group are hierarchically ordered by the representation of their present habitats in NPA official system. Continuous vertical lines indicate a 10% representation threshold and dotted lines indicate a 17% representation threshold. Source: own elaboration.

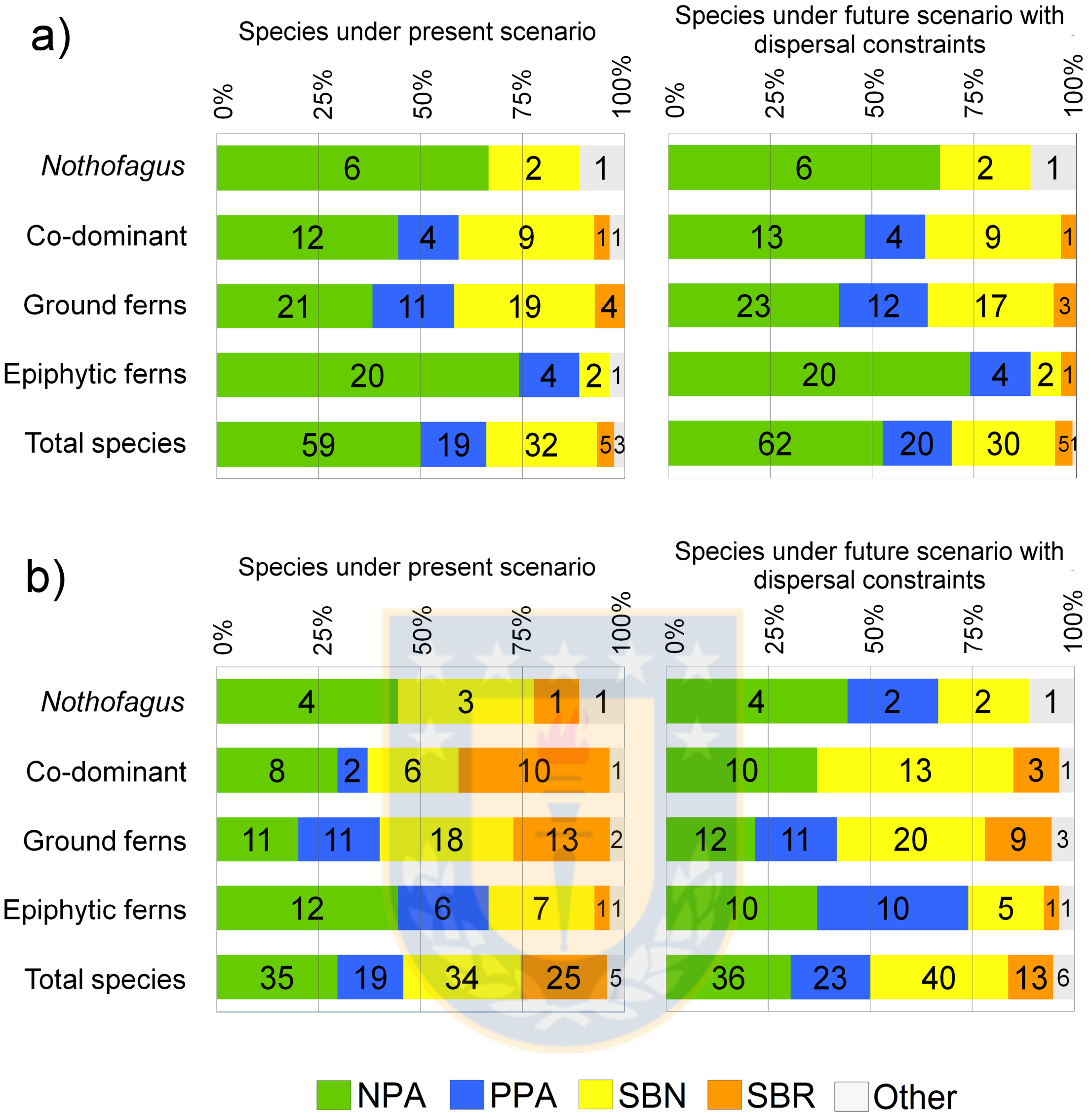

Figure 2.6. Accumulated proportion of species number with minimum representation in protected areas, considering: a) a 10% threshold as proposed by CONAMA (2005), and b) a 17% threshold as proposed by UNEP/CBD (2010) according to Chilean national protected areas system (NPA), private protected areas (PPA), prioritized sites for biodiversity conservation at national level (SBN) and proposed sites for biodiversity conservation at each Chilean regional administration level (SBR). Features within strips indicate the aggregated number of species that achieve the minimum conservation target by each protection system. Source: own elaboration.

SUPPORTING INFORMATION LEGENDS

Table 2.S1. Plant species list included in the assessment. Each species is presented according to taxonomic family, species group and endemism to South American temperate rainforests, and the number of valid occurrences used in niche modeling.

Table 2.S2. Parameter values (AUC, Kappa and TSS) to determine the best model for each species. The following modeling techniques were included: ANN for Artificial Neural Networks, CTA for Classification Tree Analysis, FDA for Flexible Discriminant Analysis, GAM for Generalized Additive Models, GBM for Generalized Boosting Models, GLM for Generalized Linear Models, MARS for Multivariate Adaptive Regression Splines, and RF for Random Forest.

Table 2.S3. Assumptions used for each species in order to set MIGCLIM parameters.

Table 2.S4. Sensitivity analysis of MIGCLIM parameters SDD (short distance dispersal) and LDD (probability for long distance dispersal) and their effects on the habitat area size for all the studied species: a) by species group, and b) by each species. A full migration scenario is also included as a comparison for habitat sizes without using MIGCLIM.

Table 2.S5. Modeled habitat area size (km^2) under assessed scenarios: present and future (year 2050) with modeled dispersal constraints for each species and their representation under different conservation schemes in Chile.

Table 2.S6. Habitat size comparisons among scenarios within species groups (obtained with paired t-tests).

Figure 2.S1. Sensitivity analysis of changes in MIGCLIM parameters SDD (short distance dispersal) and LDD (probability for long distance dispersal) and their effects on the habitat area size for all the studied species, following 2.S4 Table. Vertical red line represents 0% change in habitat size considering the parameters set in 2.S3 Table as 100% for both SDD and LDD. A full migration scenario is also included as a comparison for habitat sizes without using MIGCLIM.

Table 2.S1. Plant species list included in the assessment. Each species is presented according to taxonomic family, species group and endemism to South American temperate rainforests, and the number of valid occurrences used in niche modeling. Source: own elaboration.

Plant species	Family	Species group	Endemic to South American temperate rainforest [a]	Number of occurrences
Adiantum chilense Kaulf.	Pteridaceae	Ground fern	No	297
Adiantum excisum Kunze	Pteridaceae	Ground fern	Yes [b]	78
Adiantum gertrudis Espinosa	Pteridaceae	Ground fern	Yes	20
Adiantum scabrum Kaulf.	Pteridaceae	Ground fern	Yes	84
Adiantum sulphureum Kaulf.	Pteridaceae	Ground fern	Yes [b]	129
Aextoxicon punctatum Ruiz & Pav.	Aextoxicaceae	Co-dominant species	Yes	3,391
Araucaria araucana (Molina) K. Koch	Araucariaceae	Co-dominant species	Yes	6,946
Asplenium dareoides Desv.	Aspleniaceae	Epiphytic fern	Yes [b]	162
Asplenium monanthes L.	Aspleniaceae	Ground fern	No	7
Asplenium obtusatum G. Forst. var. *sphenoides* (Kunze) C. Chr. ex Skottsb.	Aspleniaceae	Ground fern	Yes [c]	44
Asplenium trilobum Cav.	Aspleniaceae	Epiphytic fern	Yes	49
Austrocedrus chilensis (D. Don) Pic.Serm. & Bizzarri	Cupressaceae	Co-dominant species	Yes	426
Azara petiolaris (D. Don) I.M. Johnst.	Salicaceae	Co-dominant species	Yes	73
Blechnum arcuatum J. Remy	Blechnaceae	Ground fern	Yes	42
Blechnum asperum (Klotzsch) J.W. Sturm	Blechnaceae	Ground fern	Yes	15
Blechnum blechnoides Keyserl.	Blechnaceae	Ground fern	Yes	30
Blechnum chilense (Kaulf.) Mett.	Blechnaceae	Ground fern	No	133
Blechnum corralense Espinosa	Blechnaceae	Ground fern	Yes	15
Blechnum hastatum Kaulf.	Blechnaceae	Ground fern	Yes [b c]	309
Blechnum magellanicum (Desv.) Mett.	Blechnaceae	Ground fern	Yes	111
Blechnum microphyllum (Goldm.) C.V. Morton	Blechnaceae	Ground fern	Yes	60
Blechnum mochaenum G. Kunkel	Blechnaceae	Ground fern	No	129
Blechnum penna-marina (Poir.) Kuhn	Blechnaceae	Ground fern	No	146
Blepharocalyx cruckshanksii (Hook. & Arn.) Nied.	Myrtaceae	Co-dominant species	Yes	253
Botrychium dusenii (H. Christ) Alston	Ophioglossaceae	Ground fern	Yes	15
Cheilanthes glauca (Cav.) Mett.	Pteridaceae	Ground fern	Yes [b]	123
Cheilanthes hypoleuca (Kunze) Mett.	Pteridaceae	Ground fern	Yes [b]	104
Cheilanthes mollis (Kunze) C. Presl	Pteridaceae	Ground fern	No	98
Cryptocarya alba (Molina) Looser	Lauraceae	Co-dominant species	Yes	11,386
Cryptogramma fumariifolia (Phil. ex Baker) H. Christ	Pteridaceae	Ground fern	Yes [b]	19
Cystopteris fragilis (L.) Bernh.	Dryopteridaceae	Ground fern	No	137
Dennstaedtia glauca (Cav.) C. Chr. ex Looser	Dennstaedtiaceae	Ground fern	No	20
Drimys andina (Reiche) R. Rodr. & Quezada	Winteraceae	Co-dominant species	Yes	38
Drimys winteri J.R. Forst. & G. Forst.	Winteraceae	Co-dominant species	No	8,543
Elaphoglossum gayanum (Fée) T. Moore	Lomariopsidaceae	Ground fern	No	10
Elaphoglossum mathewsii (Fée) T. Moore	Lomariopsidaceae	Ground fern	Yes	11
Elaphoglossum porteri Hicken	Lomariopsidaceae	Ground fern	Yes	5
Equisetum bogotense Kunth	Equisetaceae	Ground fern	No	157
Equisetum giganteum L.	Equisetaceae	Ground fern	No	65
Eucryphia cordifolia Cav.	Eucryphiaceae	Co-dominant species	Yes	3,998

Fitzroya cupressoides (Molina) I.M. Johnst.	Cupressaceae	Co-dominant species	Yes	6,158
Gevuina avellana Molina	Proteaceae	Co-dominant species	Yes	6,135
Gleichenia cryptocarpa Hook.	Gleicheniaceae	Ground fern	Yes	63
Gleichenia litoralis (F. Phil.) C. Chr.	Gleicheniaceae	Ground fern	Yes	17
Gleichenia quadripartita (Poir.) T. Moore	Gleicheniaceae	Ground fern	Yes	82
Gleichenia squamulosa (Desv.) T. Moore	Gleicheniaceae	Ground fern	Yes [c]	107
Gomortega keule (Molina) Baill.	Gomortegaceae	Co-dominant species	Yes	66
Grammitis magellanica Desv.	Grammitidaceae	Epiphytic fern	Yes [c]	62
Grammitis patagonica (C. Chr.) Parris	Grammitidaceae	Epiphytic fern	No	7
Grammitis poeppigiana (Mett.) Pic.Serm.	Grammitidaceae	Epiphytic fern	No	20
Hymenoglossum cruentum (Cav.) C. Presl	Hymenophyllaceae	Epiphytic fern	Yes [c]	70
Hymenophyllum caudiculatum Mart.	Hymenophyllaceae	Epiphytic fern	Yes [c]	94
Hymenophyllum cuneatum Kunze	Hymenophyllaceae	Epiphytic fern	Yes [c]	18
Hymenophyllum darwinii Hook. f. ex Bosch	Hymenophyllaceae	Epiphytic fern	Yes	20
Hymenophyllum dentatum Cav.	Hymenophyllaceae	Epiphytic fern	Yes	95
Hymenophyllum dicranotrichum (C. Presl) Hook. ex Sadeb.	Hymenophyllaceae	Epiphytic fern	Yes	42
Hymenophyllum falklandicum Baker	Hymenophyllaceae	Epiphytic fern	Yes [c]	20
Hymenophyllum ferrugineum Colla	Hymenophyllaceae	Epiphytic fern	No	41
Hymenophyllum fuciforme Sw.	Hymenophyllaceae	Epiphytic fern	Yes [c]	34
Hymenophyllum krauseanum Phil.	Hymenophyllaceae	Epiphytic fern	Yes	62
Hymenophyllum nahuelhuapiense Diem & J.S. Licht.	Hymenophyllaceae	Epiphytic fern	Yes	5
Hymenophyllum pectinatum Cav.	Hymenophyllaceae	Epiphytic fern	Yes [c]	89
Hymenophyllum peltatum (Poir.) Desv.	Hymenophyllaceae	Epiphytic fern	No	56
Hymenophyllum plicatum Kaulf.	Hymenophyllaceae	Epiphytic fern	Yes	62
Hymenophyllum secundum Hook. & Grev.	Hymenophyllaceae	Epiphytic fern	Yes [c]	71
Hymenophyllum seselifolium C. Presl	Hymenophyllaceae	Epiphytic fern	No	61
Hymenophyllum tortuosum Hook. & Grev.	Hymenophyllaceae	Epiphytic fern	Yes [c]	81
Hymenophyllum tunbrigense (L.) Sm.	Hymenophyllaceae	Epiphytic fern	No	15
Hymenophyllum umbratile Diem & J.S. Licht.	Hymenophyllaceae	Epiphytic fern	Yes	13
Hypolepis poeppigii (Kunze) R. Rodr.	Dennstaedtiaceae	Ground fern	Yes [b]	105
Laurelia sempervirens (Ruiz & Pav.) Tul.	Monimiaceae	Co-dominant species	Yes	635
Laureliopsis philippiana (Looser) Schodde	Monimiaceae	Co-dominant species	Yes	6,404
Lomatia hirsuta (Lam.) Diels	Proteaceae	Co-dominant species	No	1,136
Lophosoria quadripinnata (J.F. Gmel.) C. Chr.	Dicksoniaceae	Ground fern	No	87
Luma apiculata (DC.) Burret	Myrtaceae	Co-dominant species	Yes	6,713
Lycopodium alboffii Rolleri	Lycopodiaceae	Ground fern	Yes	18
Lycopodium confertum Willd.	Lycopodiaceae	Ground fern	Yes	22
Lycopodium gayanum J. Remy	Lycopodiaceae	Ground fern	Yes [c]	34
Lycopodium magellanicum (P. Beauv.) Sw.	Lycopodiaceae	Ground fern	Yes	104
Lycopodium paniculatum Desv.	Lycopodiaceae	Ground fern	Yes	69
Maytenus disticha (Hook. f.) Urb.	Celastraceae	Co-dominant species	Yes	52
Megalastrum spectabile (Kaulf.) A.R. Sm. & R.C. Moran	Dryopteridaceae	Ground fern	Yes	83
Myrceugenia planipes (Hook. & Arn.) O. Berg	Myrtaceae	Co-dominant species	Yes	829
Myrceugenia exsucca (DC.) O. Berg	Myrtaceae	Co-dominant species	Yes	113
Nothofagus alessandrii Espinosa	Nothofagaceae	Dominant species	Yes	64
Nothofagus alpina (Poepp. & Endl.) Oerst.	Nothofagaceae	Dominant species	Yes	10,759
Nothofagus antarctica (G. Forst.) Oerst.	Nothofagaceae	Dominant species	Yes	29,159
Nothofagus betuloides (Mirb.) Oerst.	Nothofagaceae	Dominant species	Yes	32,388
Nothofagus dombeyi (Mirb.) Oerst.	Nothofagaceae	Dominant species	Yes	27,092
Nothofagus glauca (Phil.) Krasser	Nothofagaceae	Dominant species	Yes	4,343
Nothofagus nitida (Phil.) Krasser	Nothofagaceae	Dominant species	Yes	37,581

Nothofagus obliqua (Mirb.) Oerst.	Nothofagaceae	Dominant species	Yes [d]	42,600
Nothofagus pumilio (Poepp. & Endl.) Krasser	Nothofagaceae	Dominant species	Yes	28,747
Pellaea myrtillifolia Mett. ex Kuhn	Pteridaceae	Ground fern	Yes [b]	22
Pellaea ternifolia (Cav.) Link	Pteridaceae	Ground fern	No	29
Persea lingue (Miers ex Bertero) Nees	Lauraceae	Co-dominant species	Yes	3,182
Philesia magellanica J.F. Gmel.	Philesiaceae	Co-dominant species	Yes	72
Pilgerodendron uviferum (D. Don) Florin	Cupressaceae	Co-dominant species	Yes	20,591
Pleopeltis macrocarpa (Bory ex Willd.) Kaulf.	Polypodiaceae	Epiphytic fern	No	16
Pleurosorus papaverifolius (Kunze) Mett.	Aspleniaceae	Ground fern	Yes [b]	36
Podocarpus salignus D. Don	Podocarpaceae	Co-dominant species	Yes	19,391
Podocarpus nubigenus Lindl.	Podocarpaceae	Co-dominant species	Yes	99
Polypodium feuillei Bertero	Blechnaceae	Epiphytic fern	Yes [b]	136
Polystichum andinum Phil.	Dryopteridaceae	Ground fern	Yes	38
Polystichum chilense (H. Christ) Diels	Dryopteridaceae	Ground fern	Yes	118
Polystichum multifidum (Mett.) H. Christ	Dryopteridaceae	Ground fern	Yes	29
Polystichum plicatum (Poepp. ex Kunze) Hicken	Dryopteridaceae	Ground fern	Yes [b]	124
Polystichum subintegerrimum (Hook. & Arn.) R. Rodr.	Dryopteridaceae	Ground fern	Yes	22
Pteris chilensis Desv.	Pteridaceae	Ground fern	Yes	33
Pteris semiadnata Phil.	Pteridaceae	Ground fern	Yes	38
Rhaphithamnus spinosus (Juss.) Moldenke	Verbenaceae	Co-dominant species	No	3,398
Rumohra adiantiformis (G. Forst.) Ching	Dryopteridaceae	Ground fern	No	78
Schizaea fistulosa Labill.	Schizaeaceae	Ground fern	Yes	18
Serpyllopsis caespitosa (Gaudich.) C. Chr.	Hymenophyllaceae	Epiphytic fern	Yes [c]	51
Tepualia stipularis (Hook. & Arn.) Griseb.	Myrtaceae	Co-dominant species	Yes	25,869
Thelypteris argentina (Hieron.) Abbiatti	Thelypteridaceae	Ground fern	No	44
Trichomanes exsectum Kunze	Hymenophyllaceae	Ground fern	Yes	17
Weinmannia trichosperma Cav.	Cunoniaceae	Co-dominant species	Yes	24,577

[a] South American temperate rainforest range includes central and southern Chile and neighboring areas in Argentina.

[b] Distribution also includes other small neighboring areas.

[c] Distribution also includes Juan Fernández Archipelago in the Pacific Ocean.

[d] This species includes formerly named *Nothofagus macrocarpa* (A. DC.) F.M. Vázquez & R. Rodr. populations following Vergara *et al*. (2014).

Table 2.S2. Parameter values (AUC, Kappa and TSS) to determine the best model for each species. The following modeling techniques were included: ANN for Artificial Neural Networks, CTA for Classification Tree Analysis, FDA for Flexible Discriminant Analysis, GAM for Generalized Additive Models, GBM for Generalized Boosting Models, GLM for Generalized Linear Models, MARS for Multivariate Adaptive Regression Splines, and RF for Random Forest. Source: own elaboration.

Species	AUC		Kappa		TSS		Final best model
	Best model	Value	Best model	Value	Best model	Value	
Adiantum chilense	RF	0.979	RF	0.835	RF	0.902	RF
Adiantum excisum	RF	0.978	RF	0.807	RF	0.910	RF
Adiantum gertrudis	GBM	0.979	RF	0.722	GBM	0.909	GBM
Adiantum scabrum	RF	0.950	RF	0.584	RF	0.832	RF
Adiantum sulphureum	RF	0.963	RF	0.668	RF	0.858	RF
Aextoxicon punctatum	RF	0.998	RF	0.950	RF	0.943	RF
Araucaria araucana	GAM	0.999	RF	0.992	GAM	0.989	GAM
Asplenium dareoides	RF	0.948	RF	0.697	GBM	0.820	RF
Asplenium monanthes	GBM	0.999	GBM	0.798	RF	0.830	GBM
Asplenium obtusatum var sphenoides	GBM	0.946	RF	0.697	GBM	0.841	GBM
Asplenium trilobum	RF	0.967	RF	0.626	RF	0.855	RF
Austrocedrus chilensis	RF	0.993	RF	0.923	RF	0.938	RF
Azara petiolaris	RF	0.994	RF	0.902	RF	0.957	RF
Blechnum arcuatum	GBM	0.904	GBM	0.625	GBM	0.720	GBM
Blechnum asperum	RF	0.998	RF	0.755	FDA	0.987	RF
Blechnum blechnoides	RF	0.977	RF	0.692	RF	0.919	RF
Blechnum chilense	RF	0.970	RF	0.736	RF	0.872	RF
Blechnum corralense	RF	0.964	RF	0.557	RF	0.924	RF
Blechnum hastatum	RF	0.980	RF	0.854	RF	0.902	RF
Blechnum magellanicum	RF	0.935	RF	0.552	RF	0.823	RF
Blechnum microphyllum	RF	0.943	MARS	0.575	GBM	0.791	RF
Blechnum mochaenum	RF	0.971	RF	0.757	RF	0.837	RF
Blechnum penna marina	RF	0.921	RF	0.552	RF	0.677	RF
Blepharocalyx cruckshanksii	RF	0.983	RF	0.864	RF	0.883	RF
Botrychium dusenii	RF	0.906	RF	0.598	RF	0.746	RF
Cheilanthes glauca	RF	0.958	RF	0.775	RF	0.782	RF
Cheilanthes hypoleuca	RF	0.961	RF	0.694	RF	0.826	RF
Cheilanthes mollis	RF	0.971	RF	0.730	RF	0.896	RF
Cryptocarya alba	RF	0.999	RF	0.979	RF	0.983	RF
Cryptogramma fumariifolia	RF	0.989	GBM	0.782	RF	0.963	RF
Cystopteris fragilis var apiiformis	RF	0.943	RF	0.639	RF	0.781	RF
Dennstaedtia glauca	RF	0.956	RF	0.450	RF	0.852	RF
Drimys andina	RF	0.989	RF	0.771	GLM	0.940	RF
Drimys winteri	RF	0.998	RF	0.941	RF	0.960	RF
Elaphoglossum gayanum	RF	0.994	GBM	0.676	RF	0.764	RF
Elaphoglossum mathewsii	RF	0.853	RF	0.698	GBM	0.713	RF
Elaphoglossum porteri	RF	0.999	ANN	0.999	RF	0.999	RF
Equisetum bogotense	RF	0.948	RF	0.705	RF	0.783	RF
Equisetum giganteum	RF	0.957	RF	0.678	RF	0.791	RF
Eucryphia cordifolia	RF	0.997	RF	0.971	RF	0.972	RF
Fitzroya cupressoides	RF	0.999	RF	0.977	RF	0.981	RF
Gevuina avellana	RF	0.998	RF	0.976	RF	0.972	RF
Gleichenia cryptocarpa	GBM	0.969	RF	0.654	GBM	0.880	GBM

Gleichenia litoralis	RF	0.960	RF	0.593	RF	0.862	RF
Gleichenia quadripartita	RF	0.917	RF	0.460	RF	0.739	RF
Gleichenia squamulosa	RF	0.965	RF	0.702	RF	0.874	RF
Gomortega keule	RF	0.999	RF	0.982	RF	0.998	RF
Grammitis magellanica	RF	0.928	RF	0.466	GBM	0.725	RF
Grammitis patagonica	GBM	0.973	GBM	0.395	GBM	0.953	GBM
Grammitis poeppigiana	GBM	0.948	RF	0.682	GBM	0.847	GBM
Hymenoglossum cruentum	RF	0.989	RF	0.740	GBM	0.889	RF
Hymenophyllum caudiculatum var productum	RF	0.954	RF	0.650	RF	0.834	RF
Hymenophyllum cuneatum	RF	0.975	RF	0.567	RF	0.842	RF
Hymenophyllum darwinii	GBM	0.932	RF	0.555	GBM	0.861	GBM
Hymenophyllum dentatum	RF	0.950	RF	0.702	RF	0.833	RF
Hymenophyllum dicranotrichum	GBM	0.925	RF	0.621	GBM	0.806	GBM
Hymenophyllum falklandicum	RF	0.909	RF	0.374	GBM	0.690	RF
Hymenophyllum ferrugineum	RF	0.958	RF	0.563	GBM	0.852	RF
Hymenophyllum fuciforme	RF	0.976	RF	0.607	RF	0.906	RF
Hymenophyllum krauseanum	RF	0.946	RF	0.586	RF	0.787	RF
Hymenophyllum nahuelhuapiense	ANN	0.997	RF	0.282	GBM	0.941	ANN
Hymenophyllum pectinatum	RF	0.949	RF	0.621	RF	0.790	RF
Hymenophyllum peltatum	RF	0.958	RF	0.585	RF	0.829	RF
Hymenophyllum plicatum	RF	0.950	RF	0.667	RF	0.867	RF
Hymenophyllum secundum	RF	0.926	RF	0.505	RF	0.755	RF
Hymenophyllum seselifolium	RF	0.939	RF	0.570	GBM	0.800	RF
Hymenophyllum tortuosum	RF	0.940	RF	0.573	RF	0.782	RF
Hymenophyllum tunbridgense	RF	0.919	MARS	0.567	RF	0.809	RF
Hymenophyllum umbratile	RF	0.979	RF	0.508	RF	0.957	RF
Hypolepis poeppigii	RF	0.942	RF	0.671	GBM	0.807	RF
Laurelia sempervirens	RF	0.998	RF	0.956	RF	0.960	RF
Laureliopsis philippiana	RF	0.999	RF	0.977	RF	0.961	RF
Lomatia hirsuta	RF	0.991	RF	0.924	RF	0.923	RF
Lophosoria quadripinnata	GBM	0.944	RF	0.575	GBM	0.768	GBM
Luma apiculata	RF	0.999	RF	0.966	RF	0.968	RF
Lycopodium alboffii	RF	0.972	RF	0.477	RF	0.741	RF
Lycopodium confertum	GBM	0.928	RF	0.167	GBM	0.776	GBM
Lycopodium gayanum	RF	0.937	RF	0.592	RF	0.774	RF
Lycopodium magellanicum	RF	0.941	RF	0.644	GBM	0.754	RF
Lycopodium paniculatum	RF	0.984	RF	0.750	RF	0.973	RF
Maytenus disticha	RF	0.986	RF	0.753	RF	0.924	RF
Megalastrum spectabile	RF	0.916	RF	0.610	RF	0.742	RF
Myrceugenia exsucca	RF	0.998	RF	0.951	RF	0.953	RF
Myrceugenia planipes	RF	0.986	RF	0.893	RF	0.937	RF
Nothofagus alessandrii	RF	0.999	RF	0.999	RF	0.999	RF
Nothofagus alpina	RF	0.999	RF	0.956	RF	0.974	RF
Nothofagus antarctica	RF	0.996	RF	0.929	RF	0.953	RF
Nothofagus betuloides	RF	0.994	RF	0.952	RF	0.967	RF
Nothofagus dombeyi	RF	0.999	RF	0.946	RF	0.961	RF
Nothofagus glauca	RF	0.999	RF	0.992	RF	0.992	RF
Nothofagus nitida	RF	0.999	RF	0.976	RF	0.991	RF
Nothofagus obliqua	RF	0.999	RF	0.974	RF	0.989	RF
Nothofagus pumilio	RF	0.994	RF	0.953	RF	0.958	RF
Pellaea myrtillifolia	RF	0.963	RF	0.510	RF	0.898	RF
Pellaea ternifolia	GBM	0.952	RF	0.426	GBM	0.843	GBM
Persea lingue	RF	0.999	RF	0.970	RF	0.973	RF
Philesia magellanica	RF	0.963	RF	0.623	RF	0.917	RF
Pilgerodendron uviferum	RF	0.996	RF	0.955	RF	0.960	RF
Pleopeltis macrocarpa	RF	0.990	RF	0.598	RF	0.987	RF
Pleurosorus papaverifolius	RF	0.959	RF	0.714	RF	0.867	RF
Podocarpus nubigenus	RF	0.990	RF	0.964	RF	0.956	RF
Podocarpus salignus	RF	0.983	RF	0.774	RF	0.930	RF

Polypodium feuillei	RF	0.967	RF	0.756	RF	0.782	RF
Polystichum andinum	RF	0.919	RF	0.490	GBM	0.815	RF
Polystichum chilense	RF	0.962	RF	0.726	RF	0.826	RF
Polystichum multifidum	RF	0.925	RF	0.390	RF	0.788	RF
Polystichum plicatum	RF	0.956	RF	0.713	RF	0.778	RF
Polystichum subintegerrimum	GBM	0.934	RF	0.386	GBM	0.824	GBM
Pteris chilensis	RF	0.970	RF	0.607	RF	0.885	RF
Pteris semiadnata	RF	0.966	RF	0.684	RF	0.777	RF
Rhaphithamnus spinosus	RF	0.997	RF	0.960	RF	0.957	RF
Rumohra adiantiformis	RF	0.971	RF	0.711	RF	0.892	RF
Schizaea fistulosa	GBM	0.985	ANN	0.747	GBM	0.951	GBM
Serpyllopsis caespitosa	RF	0.947	RF	0.523	GBM	0.923	RF
Tepualia stipularis	RF	0.996	RF	0.965	RF	0.974	RF
Thelypteris argentina	RF	0.987	RF	0.567	RF	0.815	RF
Trichomanes exsectum	RF	0.995	RF	0.765	RF	0.811	RF
Weinmannia trichosperma	RF	0.996	RF	0.964	RF	0.982	RF

Table 2.S3. Assumptions used for each species in order to set MIGCLIM parameters[a]. Source: own elaboration.

Species	Propagule dispersal syndrome				SDD: Short distance dispersal[b] (m)	LDD: Probability of long distance dispersal[c]	Initial maturity age (years)	Optimal maturity age (years)
	Barochory	Zoochory	Anemochory	Hydrochory				
Adiantum chilense			X		900	0.2	2	5
Adiantum excisum			X		900	0.1	2	5
Adiantum gertrudis			X		450	0.05	2	5
Adiantum scabrum			X		900	0.1	2	5
Adiantum sulphureum			X		900	0.2	2	5
Aextoxicon punctatum	X	X			225	0.1	20	25
Araucaria araucana	X	X			45	0.1	25	45
Asplenium dareoides			X		900	0.1	2	4
Asplenium monanthes			X		450	0.05	2	5
Asplenium obtusatum var sphenoides			X		900	0.1	2	5
Asplenium trilobum			X		900	0.1	2	4
Austrocedrus chilensis			X		450	0.1	20	35
Azara petiolaris		X			45	0.1	10	15
Blechnum arcuatum			X	X	900	0.05	5	8
Blechnum asperum			X		900	0.1	2	5
Blechnum blechnoides			X		900	0.1	2	5
Blechnum chilense			X		900	0.2	5	8
Blechnum corralense			X		225	0.05	2	5
Blechnum hastatum			X		900	0.2	2	5
Blechnum magellanicum			X		900	0.1	5	8
Blechnum microphyllum			X		900	0.1	2	5
Blechnum mochaenum			X		900	0.1	2	5
Blechnum penna marina			X		900	0.1	2	5
Blepharocalyx cruckshanksii		X			90	0.1	15	25
Botrychium dusenii			X		900	0.1	2	5
Cheilanthes glauca			X		900	0.1	2	5
Cheilanthes hypoleuca			X		900	0.1	2	5
Cheilanthes mollis			X		900	0.1	2	5
Cryptocarya alba	X	X			450	0.2	20	25
Cryptogramma fumariifolia			X		900	0.1	2	5
Cystopteris fragilis var apiiformis			X		900	0.1	2	5
Dennstaedtia glauca			X	X	900	0.05	5	8
Drimys andina		X			45	0.1	10	15
Drimys winteri		X			90	0.2	10	20
Elaphoglossum gayanum			X		225	0.05	2	5
Elaphoglossum mathewsii			X		225	0.05	2	5
Elaphoglossum porteri			X		225	0.05	2	5
Equisetum bogotense			X	X	900	0.2	2	5
Equisetum giganteum			X	X	900	0.05	5	8
Eucryphia cordifolia			X		450	0.05	15	20
Fitzroya cupressoides			X		450	0.1	30	50
Gevuina avellana	X	X			90	0.1	10	20
Gleichenia cryptocarpa			X		900	0.1	2	5
Gleichenia litoralis			X		900	0.1	2	5
Gleichenia quadripartita			X		900	0.1	2	5
Gleichenia squamulosa			X		900	0.1	2	5

Gomortega keule	X	X			45	0	18	28
Grammitis magellanica			X		900	0.1	2	4
Grammitis patagonica			X		900	0.1	2	4
Grammitis poeppigiana			X		900	0.1	2	4
Hymenoglossum cruentum			X	X	450	0.05	2	4
Hymenophyllum caudiculatum var productum			X	X	450	0.05	2	4
Hymenophyllum cuneatum			X	X	450	0.05	2	4
Hymenophyllum darwinii			X	X	450	0.05	2	4
Hymenophyllum dentatum			X	X	450	0.05	2	4
Hymenophyllum dicranotrichum			X	X	450	0.05	2	4
Hymenophyllum falklandicum			X	X	450	0.05	2	4
Hymenophyllum ferrugineum			X	X	450	0.05	2	4
Hymenophyllum fuciforme			X	X	450	0.05	2	4
Hymenophyllum krauseanum			X	X	450	0.05	2	4
Hymenophyllum nahuelhuapiense			X	X	450	0.05	2	4
Hymenophyllum pectinatum			X	X	450	0.05	2	4
Hymenophyllum peltatum			X	X	450	0.05	2	4
Hymenophyllum plicatum			X	X	450	0.05	2	4
Hymenophyllum secundum			X	X	450	0.05	2	4
Hymenophyllum seselifolium			X	X	450	0.05	2	4
Hymenophyllum tortuosum			X	X	450	0.05	2	4
Hymenophyllum tunbridgense			X	X	450	0.05	2	4
Hymenophyllum umbratile			X	X	450	0.05	2	4
Hypolepis poeppigii			X		900	0.1	5	8
Laurelia sempervirens			X		900	0.1	20	25
Laureliopsis philippiana			X		900	0.1	20	30
Lomatia hirsuta			X		450	0.05	5	15
Lophosoria quadripinnata			X		900	0.2	5	8
Luma apiculata		X			90	0.1	5	15
Lycopodium alboffii			X		900	0.1	2	5
Lycopodium confertum			X		900	0.1	2	5
Lycopodium gayanum			X		900	0.1	2	5
Lycopodium magellanicum			X		900	0.1	2	5
Lycopodium paniculatum			X		900	0.1	2	5
Maytenus disticha	X	X			225	0.05	10	15
Megalastrum spectabile			X		900	0.1	5	8
Myrceugenia exsucca		X			45	0.1	15	20
Myrceugenia planipes		X			45	0.1	10	20
Nothofagus alessandrii	X				90	0.01	20	30
Nothofagus alpina			X		450	0.05	20	30
Nothofagus antarctica			X		450	0.05	20	30

Nothofagus betuloides			X		450	0.05	20	30
Nothofagus dombeyi			X		450	0.05	15	25
Nothofagus glauca	X	X			45	0.01	25	30
Nothofagus nitida			X		450	0.05	20	30
Nothofagus obliqua			X		450	0.05	15	25
Nothofagus pumilio	X		X		90	0.05	20	30
Pellaea myrtillifolia			X		900	0.1	2	5
Pellaea ternifolia			X		900	0.1	2	5
Persea lingue	X	X			450	0.2	10	20
Philesia magellanica		X			45	0.1	10	15
Pilgerodendron uviferum			X		450	0.1	25	45
Pleopeltis macrocarpa			X		450	0.05	2	5
Pleurosorus papaverifolius			X		900	0.1	2	5
Podocarpus nubigenus	X	X			45	0.01	20	40
Podocarpus salignus	X	X			45	0.01	10	20
Polypodium feuillei			X		900	0.1	2	5
Polystichum andinum			X		900	0.1	3	5
Polystichum chilense			X		900	0.1	3	5
Polystichum multifidum			X		900	0.1	3	5
Polystichum plicatum			X		900	0.1	3	5
Polystichum subintegerrimum			X		900	0.1	3	5
Pteris chilensis			X		900	0.1	2	5
Pteris semiadnata			X		900	0.05	5	8
Rhaphithamnus spinosus	X	X			45	0.2	5	15
Rumohra adiantiformis			X		900	0.05	5	8
Schizaea fistulosa			X		900	0.1	2	5
Serpyllopsis caespitosa			X	X	450	0.05	2	4
Tepualia stipularis			X		225	0.05	15	20
Thelypteris argentina			X	X	900	0.05	5	8
Trichomanes exsectum			X	X	225	0.05	2	4
Weinmannia trichosperma			X		900	0.1	20	30

[a] MIGCLIM parameters were set following the available information on the studied species (Tryon, 1970; Tryon , 1986; Armesto & Rozzi, 1989; Donoso & Lara, 1998; Cuevas, 2000; Loehle, 2000; Armesto *et al*., 2001; Figueroa, 2003; Hechenleitner *et al*., 2005; Donoso, 2006; Smith-Ramírez *et al*., 2007; Rodríguez *et al*., 2009; De Groot *et al*., 2012; Gillespie *et al*., 2012; Núñez-Ávila *et al*., 2013). A dispersal kernel for propagules considered the short-distance dispersal (SDD) and the period reaching optimal maturity. The kernel of propagule production was assumed according to the period of years between the initial propagule production and the optimal maturity age, as predicted by a standard growth sigmoid function as follows; For 2 years: 0.4. For 3 years: 0.25, 0.7. For 5 years: 0.0659, 0.4974, 0.8357, 0.9549. For 10 years: 0.0046, 0.0659, 0.2521, 0.4974, 0.7019, 0.8357, 0.9130, 0.9549, 0.9769. For 15 years: 0.0007, 0.0118, 0.0659, 0.1889, 0.3600, 0.5345, 0.6811, 0.7902, 0.8656, 0.9153, 0.9472, 0.9672, 0.9798, 0.9875. For 20 years: 0.00009, 0.0021, 0.0167, 0.0659, 0.1639, 0.3004, 0.4493, 0.5873, 0.7019, 0.7902, 0.8550, 0.9010, 0.9330, 0.9549, 0.9698, 0.9798, 0.9865, 0.9910, 0.9940.

[b] The short-distance dispersal (SDD) considered the distances according to the propagule dispersion syndrome: i) long-distance travelling propagule species, assumed to reach up to 900-1000 m; ii) medium-distance travelling propagule species, assumed to reach up to 400-500 m; iii) short-distance travelling propagule ground ferns, assumed to reach up to 200-250 m; iv) short-distance travelling propagule trees or

shrubs, assumed to reach up to 80-100 m; and v) very short-distance travelling propagule species, assumed to reach up to 40-50 m (Tryon, 1970; Tryon , 1986; Armesto & Rozzi, 1989; Donoso & Lara, 1998; Cuevas, 2000; Loehle, 2000; Armesto *et al*., 2001; Figueroa, 2003; Hechenleitner *et al*., 2005; Donoso, 2006; Smith-Ramírez *et al*., 2007; Rodríguez *et al*., 2009; De Groot *et al*., 2012; Gillespie *et al*., 2012; Núñez-Ávila *et al*., 2013).

[b] The probability of long-distance dispersal (LDD) was assumed considering the abundance of natural populations and propagule dispersion syndromes: i) 0.2 or 20% for abundant ground fern species with anemochorous long-distance travelling spores and also for successfully zoochorous tree species which are very frequent; ii) 0.1 or 10% for medium-abundant fern species with anemochorous long-distance travelling spores, also for zoochorous medium-frequent tree and shrub species, and also for successfully anemochorous tree species; iii) 0.05 or 5% for scarce ground fern species, also for epiphytic fern species and also for anemochorous tree species which propagules are less able to reach long distances; iv) 0.01 or 1% for infrequent tree species with propagules with very low ability to reach long distances and v) 0 or 0% for species documented as very difficult or not able to establish away from their parent trees (Tryon, 1970; Tryon, 1986; Armesto & Rozzi, 1989; Donoso & Lara, 1998; Cuevas, 2000; Loehle, 2000; Armesto *et al*., 2001; Figueroa, 2003; Hechenleitner *et al*., 2005; Donoso, 2006; Smith-Ramírez *et al*., 2007; Rodríguez *et al*., 2009; De Groot *et al*., 2012; Gillespie *et al*., 2012; Núñez-Ávila *et al*., 2013).

Table 2.S4. Sensitivity analysis of MIGCLIM parameters SDD (short distance dispersal) and LDD (probability for long distance dispersal) and their effects on the habitat area size for all the studied species: a) by species group, and b) by each species. A full migration scenario is also included as comparison for unconstrained future habitat sizes, without using MIGCLIM. Source: own elaboration.

a)

Change in MIGCLIM parameters	Effects on habitat size by species group (mean ± standard deviation)				
	Nothofagus	Co-dominant	Ground ferns	Epiphytic ferns	Total species
SDD x 25%	-0.6% ± 0.8%	-1.8% ± 2.2%	-5.9% ± 9.2%	-7.5% ± 8.8%	-4.9% ± 8%
SDD x 50%	-0.3% ± 0.6%	-0.8% ± 1%	-2.5% ± 3.6%	-3.2% ± 4.1%	-2.1% ± 3.3%
SDD x 200%	0.1% ± 0.1%	0.6% ± 0.7%	0.6% ± 2.1%	1.5% ± 2.1%	0.8% ± 1.8%
LDD x 10%	0% ± 0.1%	-0.3% ± 0.5%	-0.4% ± 0.6%	-0.1% ± 0.9%	-0.3% ± 0.7%
LDD x 25%	-0.1% ± 0.2%	-0.5% ± 0.5%	-0.6% ± 0.7%	-0.6% ± 0.8%	-0.5% ± 0.7%
LDD x 50%	0% ± 0%	-0.3% ± 0.4%	-0.4% ± 0.4%	-0.4% ± 0.6%	-0.4% ± 0.5%
LDD x 200%	0% ± 0.2%	1.1% ± 1.1%	1.6% ± 1.8%	2.1% ± 3%	1.5% ± 2%
LDD x 400%	0.1% ± 0.1%	1.1% ± 1%	1.7% ± 1.8%	2% ± 2.9%	1.5% ± 2%
LDD x 1000%	0.2% ± 0.1%	1.9% ± 1.8%	3.3% ± 3.7%	4.2% ± 5.4%	2.9% ± 3.9%
Full migration	6.3% ± 12%	12.2% ± 12%	24.5% ± 30%	34.1% ± 49.3%	22.5% ± 32.8%

b)

Species	Effect of different MIGCLIM parameters on habitat size									
	SDD x 25%	SDD x 50%	SDD x 200%	LDD x 10%	LDD x 25%	LDD x 50%	LDD x 200%	LDD x 400%	LDD x 1000%	Full migration
Adiantum chilense	-4.8%	-2.4%	0.0%	-0.8%	-0.7%	-0.4%	1.8%	1.9%	2.3%	13.8%
Adiantum excisum	-2.7%	-1.4%	-0.1%	-0.5%	-0.5%	-0.3%	1.1%	1.2%	2.5%	12.3%
Adiantum gertrudis	-0.2%	-0.1%	0.0%	0.0%	0.0%	0.0%	0.1%	0.1%	0.2%	2.5%
Adiantum scabrum	-0.8%	-0.2%	0.0%	-0.1%	-0.1%	-0.1%	0.5%	0.5%	1.0%	3.1%
Adiantum sulphureum	-3.0%	-1.3%	0.0%	-0.7%	-0.6%	-0.4%	1.2%	1.3%	1.5%	8.6%
Aextoxicon punctatum	-1.5%	-0.8%	0.4%	-0.3%	-0.3%	-0.2%	1.0%	1.0%	1.9%	10.7%
Araucaria araucana	-0.4%	-0.2%	0.1%	-0.2%	-0.2%	-0.1%	0.4%	0.4%	0.7%	8.5%
Asplenium dareoides	-2.4%	-1.0%	0.0%	-0.4%	-0.3%	-0.2%	0.9%	0.9%	1.6%	8.5%
Asplenium monanthes	-12.2%	-4.5%	2.3%	-0.5%	-0.3%	-0.2%	1.8%	1.8%	4.9%	27.5%
Asplenium obtusatum var sphenoides	-2.6%	-1.0%	0.1%	-0.3%	-0.2%	-0.2%	0.8%	0.8%	1.5%	13.6%
Asplenium trilobum	-38.8%	-18.2%	-0.2%	-3.5%	-3.0%	-2.3%	9.4%	8.9%	22.4%	116.7%
Austrocedrus chilensis	-1.1%	-0.7%	1.0%	-0.7%	-0.6%	-0.4%	1.3%	1.2%	2.3%	14.0%
Azara petiolaris	-2.2%	-1.2%	1.1%	-0.8%	-0.7%	-0.5%	1.8%	1.7%	3.0%	9.5%
Blechnum arcuatum	-1.6%	-0.6%	0.0%	-0.1%	-0.1%	-0.1%	0.6%	0.6%	1.2%	11.3%
Blechnum asperum	-19.2%	-8.3%	0.1%	-1.2%	-1.2%	-0.8%	3.3%	3.3%	6.3%	46.7%
Blechnum blechnoides	-5.4%	-2.8%	0.0%	-0.5%	-0.2%	-0.4%	2.7%	2.5%	4.8%	53.5%
Blechnum chilense	-1.2%	-0.5%	0.0%	-0.5%	-0.4%	-0.3%	0.8%	0.7%	0.9%	11.4%
Blechnum corralense	-22.2%	-9.1%	4.4%	-1.6%	-1.0%	-1.5%	5.8%	7.1%	12.8%	33.8%
Blechnum hastatum	-2.3%	-0.9%	0.0%	-0.4%	-0.3%	-0.2%	0.6%	0.6%	0.7%	4.4%
Blechnum magellanicum	-3.4%	-1.4%	0.0%	-0.8%	-0.7%	-0.6%	2.3%	2.3%	4.4%	28.8%
Blechnum microphyllum	-1.3%	-0.5%	-0.2%	-0.4%	-0.4%	-0.3%	0.7%	0.7%	1.4%	3.7%
Blechnum mochaenum	-4.9%	-1.9%	0.1%	-0.8%	-0.6%	-0.4%	1.9%	1.9%	3.5%	33.5%
Blechnum penna marina	-3.1%	-1.2%	-0.1%	-0.4%	-0.4%	-0.3%	0.9%	0.9%	1.8%	7.4%
Blepharocalyx cruckshanksii	-3.7%	-1.7%	1.3%	-1.6%	-1.2%	-0.8%	3.2%	3.3%	6.0%	22.3%
Botrychium dusenii	0.0%	0.0%	0.0%	-0.2%	-0.2%	-0.2%	0.6%	0.5%	0.9%	6.2%
Cheilanthes glauca	-1.6%	-0.7%	-0.1%	-0.3%	-0.3%	-0.3%	0.6%	0.6%	1.1%	6.0%
Cheilanthes hypoleuca	-2.8%	-1.2%	-0.1%	-0.5%	-0.5%	-0.4%	1.2%	1.1%	2.4%	15.1%
Cheilanthes mollis	-8.5%	-3.9%	0.0%	-0.7%	-0.6%	-0.5%	1.6%	1.6%	3.8%	16.8%
Cryptocarya alba	-0.4%	-0.2%	0.1%	-0.2%	-0.2%	-0.1%	0.5%	0.4%	0.5%	8.6%
Cryptogramma fumariifolia	-0.8%	-0.1%	0.2%	-0.1%	-0.1%	-0.1%	0.7%	0.6%	1.1%	4.4%
Cystopteris fragilis var apiiformis	-1.1%	-0.5%	0.0%	-0.3%	-0.2%	-0.2%	0.5%	0.5%	0.9%	2.6%
Dennstaedtia glauca	-3.8%	-1.8%	-0.1%	-0.4%	-0.4%	-0.3%	1.7%	1.6%	3.0%	25.9%
Drimys andina	-3.0%	-1.5%	1.0%	-1.8%	-1.5%	-1.0%	2.6%	2.6%	3.4%	7.4%
Drimys winteri	-1.0%	-0.5%	0.5%	-0.9%	-0.7%	-0.4%	1.3%	1.3%	1.5%	8.9%
Elaphoglossum gayanum	-59.9%	-21.3%	11.1%	-2.6%	-2.2%	-1.6%	11.2%	10.6%	23.1%	82.9%
Elaphoglossum mathewsii	-25.9%	-13.7%	10.5%	-3.2%	-4.6%	-2.3%	4.7%	6.2%	11.1%	22.5%
Elaphoglossum porteri	-10.1%	-3.1%	1.9%	-0.2%	-0.7%	-0.7%	1.1%	0.8%	3.5%	21.1%
Equisetum bogotense	-4.4%	-1.9%	0.0%	-0.8%	-0.7%	-0.4%	1.3%	1.2%	1.5%	8.9%

Equisetum giganteum	-2.4%	-0.9%	0.0%	-0.2%	-0.2%	-0.1%	1.1%	1.0%	2.1%	46.4%
Eucryphia cordifolia	-0.5%	-0.3%	0.4%	-0.2%	-0.2%	-0.1%	0.3%	0.3%	0.7%	11.4%
Fitzroya cupressoides	-0.2%	0.0%	0.0%	-0.1%	-0.1%	-0.1%	0.5%	0.5%	0.9%	8.4%
Gevuina avellana	-1.3%	-0.6%	0.4%	-0.5%	-0.4%	-0.2%	0.9%	1.0%	1.7%	7.2%
Gleichenia cryptocarpa	-0.4%	-0.2%	0.0%	-0.3%	-0.3%	-0.1%	0.5%	0.5%	0.8%	4.4%
Gleichenia litoralis	-3.3%	-1.6%	-0.6%	-1.3%	-1.3%	-1.2%	2.1%	1.8%	2.7%	27.3%
Gleichenia quadripartita	-5.6%	-2.5%	0.2%	-0.1%	-0.6%	-0.5%	2.1%	1.9%	3.8%	23.1%
Gleichenia squamulosa	-5.2%	-2.2%	-0.1%	-0.2%	-0.7%	-0.5%	1.4%	1.3%	3.0%	18.1%
Gomortega keule	-3.4%	-1.3%	1.1%	0.0%	-0.4%	0.1%	-0.1%	-0.1%	0.0%	18.0%
Grammitis magellanica	-1.3%	-0.4%	0.0%	0.0%	-0.2%	-0.2%	0.7%	0.7%	1.1%	5.1%
Grammitis patagonica	-1.8%	-0.6%	0.0%	0.0%	-0.2%	-0.1%	0.6%	0.6%	1.1%	9.6%
Grammitis poeppigiana	-0.1%	0.0%	0.0%	0.0%	-0.1%	0.0%	0.1%	0.1%	0.2%	0.9%
Hymenoglossum cruentum	-3.2%	-1.5%	1.0%	0.0%	-0.2%	-0.2%	0.7%	0.7%	1.8%	20.1%
Hymenophyllum caudiculatum var productum	-8.3%	-4.3%	1.9%	-1.0%	-1.2%	-1.2%	0.9%	0.7%	2.5%	9.8%
Hymenophyllum cuneatum	-15.4%	-6.0%	3.2%	-0.1%	-0.7%	-0.5%	2.6%	2.7%	5.1%	45.0%
Hymenophyllum darwinii	-2.9%	-1.5%	1.3%	0.1%	-0.1%	-0.1%	1.2%	1.3%	2.3%	9.2%
Hymenophyllum dentatum	-2.5%	-1.0%	0.6%	0.1%	0.0%	0.0%	0.6%	0.6%	1.1%	9.0%
Hymenophyllum dicranotrichum	-2.6%	-0.9%	0.6%	0.0%	-0.1%	-0.1%	0.5%	0.5%	1.0%	9.5%
Hymenophyllum falklandicum	-6.2%	-2.7%	1.9%	0.0%	-0.3%	-0.3%	1.7%	1.8%	3.6%	25.3%
Hymenophyllum ferrugineum	-2.9%	-1.1%	0.7%	0.0%	-0.1%	-0.1%	1.2%	1.1%	2.3%	13.4%
Hymenophyllum fuciforme	-26.1%	-10.1%	5.5%	-0.2%	-1.0%	-0.7%	2.7%	3.1%	7.0%	94.0%
Hymenophyllum krauseanum	-6.6%	-2.4%	1.5%	0.0%	-0.2%	-0.1%	1.1%	1.0%	2.5%	18.7%
Hymenophyllum nahuelhuapiense	-9.6%	-3.6%	2.6%	0.1%	0.0%	0.0%	1.0%	1.1%	2.5%	26.7%
Hymenophyllum pectinatum	-4.2%	-1.7%	1.2%	0.0%	-0.2%	-0.1%	1.1%	1.2%	2.2%	13.7%
Hymenophyllum peltatum	-6.2%	-2.3%	1.0%	0.0%	-0.5%	-0.3%	1.3%	1.3%	2.7%	23.0%
Hymenophyllum plicatum	-3.8%	-1.5%	0.8%	0.0%	-0.1%	-0.1%	0.8%	0.7%	1.5%	14.6%
Hymenophyllum secundum	-5.1%	-2.1%	1.6%	0.0%	-0.3%	-0.2%	1.1%	0.9%	2.3%	20.6%
Hymenophyllum seselifolium	-2.9%	-1.2%	0.9%	0.1%	-0.1%	-0.1%	0.8%	0.8%	1.7%	10.8%
Hymenophyllum tortuosum	-4.9%	-1.8%	0.7%	0.0%	-0.2%	-0.2%	0.8%	0.8%	1.5%	5.4%
Hymenophyllum tunbridgense	-9.4%	-4.7%	2.2%	2.9%	-3.1%	-2.2%	14.2%	13.8%	20.0%	226.8%
Hymenophyllum umbratile	-1.8%	-1.2%	1.2%	0.6%	-0.6%	-0.6%	2.4%	2.2%	5.7%	37.7%
Hypolepis poeppigii	-1.9%	-0.7%	-0.1%	0.0%	-0.3%	-0.3%	1.0%	1.0%	2.1%	10.9%
Laurelia sempervirens	-0.6%	-0.1%	0.0%	0.0%	-0.2%	-0.2%	1.1%	1.1%	2.0%	9.4%
Laureliopsis philippiana	-0.3%	-0.1%	0.0%	0.0%	0.0%	0.0%	0.2%	0.2%	0.4%	5.2%
Lomatia hirsuta	-1.4%	-0.6%	0.4%	0.0%	-0.1%	0.0%	0.3%	0.3%	0.8%	6.5%
Lophosoria quadripinnata	-0.3%	-0.1%	0.0%	0.0%	-0.1%	-0.1%	0.2%	0.2%	0.3%	3.7%
Luma apiculata	-0.7%	-0.4%	0.3%	0.0%	-0.2%	-0.1%	0.5%	0.5%	0.9%	4.6%
Lycopodium alboffii	-4.2%	-1.5%	-0.1%	-0.1%	-0.8%	-0.6%	2.2%	2.1%	4.3%	36.8%
Lycopodium confertum	-1.0%	-0.4%	0.0%	0.0%	-0.2%	-0.2%	0.4%	0.5%	0.8%	4.1%
Lycopodium gayanum	-13.1%	-4.6%	0.1%	0.2%	-0.6%	-0.3%	2.2%	2.3%	4.4%	60.7%
Lycopodium magellanicum	-3.7%	-1.7%	0.0%	0.0%	-0.3%	-0.2%	0.9%	0.9%	1.9%	7.6%
Lycopodium paniculatum	-6.5%	-2.8%	-0.2%	-0.2%	-0.7%	-0.6%	1.7%	1.8%	3.7%	18.2%
Maytenus disticha	-2.5%	-1.0%	0.8%	0.0%	-0.3%	-0.2%	0.9%	1.0%	2.0%	22.4%
Megalastrum spectabile	-3.4%	-1.4%	0.0%	0.0%	-0.6%	-0.4%	1.9%	1.9%	3.7%	19.4%
Myrceugenia exsucca	-3.3%	-1.6%	1.3%	0.0%	-1.5%	-0.9%	2.9%	2.8%	4.7%	13.5%
Myrceugenia planipes	-4.1%	-2.0%	1.6%	0.0%	-1.8%	-1.2%	3.6%	3.5%	6.1%	18.5%
Nothofagus alessandrii	-2.2%	-1.7%	0.0%	-0.2%	-0.5%	0.0%	-0.3%	-0.2%	0.0%	37.9%
Nothofagus alpina	-0.4%	-0.2%	0.1%	0.0%	0.0%	0.0%	0.1%	0.1%	0.2%	4.0%
Nothofagus antarctica	-0.4%	-0.2%	0.1%	0.0%	0.0%	0.0%	0.1%	0.1%	0.2%	3.1%
Nothofagus betuloides	-0.1%	-0.1%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.1%	0.4%
Nothofagus dombeyi	-0.2%	0.0%	0.0%	0.0%	0.0%	0.0%	0.2%	0.2%	0.3%	2.0%
Nothofagus glauca	-1.5%	-0.5%	0.3%	0.0%	0.0%	-0.1%	0.1%	0.1%	0.3%	5.7%

Nothofagus nitida	-0.1%	-0.1%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.1%	0.6%
Nothofagus obliqua	-0.1%	0.0%	0.0%	0.0%	0.0%	0.0%	0.1%	0.1%	0.2%	1.9%
Nothofagus pumilio	-0.2%	-0.1%	0.1%	0.0%	0.0%	0.0%	0.1%	0.1%	0.2%	0.7%
Pellaea myrtillifolia	-1.1%	-0.5%	0.0%	-0.1%	-0.5%	-0.3%	0.6%	0.6%	1.1%	6.0%
Pellaea ternifolia	-1.9%	-0.8%	0.0%	0.0%	-0.2%	-0.2%	0.8%	0.9%	1.5%	11.9%
Persea lingue	-0.6%	-0.3%	0.2%	0.0%	-0.4%	-0.2%	0.7%	0.7%	0.8%	5.0%
Philesia magellanica	-4.0%	-1.9%	1.5%	0.1%	-1.5%	-0.9%	3.0%	3.0%	5.1%	30.0%
Pilgerodendron uviferum	-0.1%	0.0%	0.0%	0.0%	-0.1%	-0.1%	0.4%	0.4%	0.6%	4.7%
Pleopeltis macrocarpa	-23.9%	-11.7%	10.1%	-0.3%	-1.7%	-1.3%	4.8%	4.9%	11.1%	111.0%
Pleurosorus papaverifolius	-2.4%	-1.1%	0.0%	0.1%	-0.2%	-0.1%	0.9%	0.9%	1.9%	9.1%
Podocarpus nubigenus	-0.9%	-0.4%	0.3%	0.0%	0.0%	0.0%	0.1%	0.1%	0.3%	2.3%
Podocarpus salignus	-11.0%	-4.6%	2.9%	-0.1%	-0.4%	-0.4%	1.0%	0.8%	2.4%	61.2%
Polypodium feuillei	-5.3%	-2.2%	0.0%	0.0%	-0.5%	-0.4%	1.5%	1.7%	3.2%	18.3%
Polystichum andinum	-0.1%	-0.1%	0.0%	-0.1%	-0.3%	-0.2%	0.5%	0.5%	0.8%	2.6%
Polystichum chilense	-4.2%	-1.8%	0.1%	0.0%	-0.5%	-0.3%	1.7%	1.7%	3.5%	29.3%
Polystichum multifidum	-3.9%	-1.7%	-0.2%	-0.1%	-0.8%	-0.6%	1.5%	1.5%	3.2%	20.9%
Polystichum plicatum	-0.3%	-0.1%	0.0%	0.0%	-0.1%	-0.1%	0.3%	0.4%	0.6%	2.2%
Polystichum subintegerrimum	-3.8%	-1.6%	0.0%	-0.1%	-0.4%	-0.3%	1.2%	1.2%	2.5%	16.8%
Pteris chilensis	-13.1%	-5.9%	0.1%	0.1%	-1.4%	-1.0%	4.6%	4.2%	8.7%	64.5%
Pteris semiadnata	-12.5%	-5.6%	-0.2%	-0.1%	-1.1%	-0.8%	3.9%	4.0%	8.4%	132.5%
Rhaphithamnus spinosus	-0.9%	-0.4%	0.4%	0.0%	-0.9%	-0.5%	1.2%	1.2%	1.3%	7.2%
Rumohra adiantiformis	-2.7%	-1.1%	0.0%	0.0%	-0.2%	-0.1%	0.9%	0.8%	2.0%	29.7%
Schizaea fistulosa	-0.5%	-0.2%	0.0%	0.0%	-0.1%	-0.1%	0.4%	0.4%	0.7%	2.9%
Serpyllopsis caespitosa	-4.5%	-1.5%	0.9%	0.0%	-0.2%	-0.1%	1.2%	1.1%	2.1%	17.2%
Tepualia stipularis	-0.3%	-0.1%	0.1%	0.0%	0.0%	0.0%	0.2%	0.2%	0.4%	1.7%
Thelypteris argentina	-6.6%	-2.7%	0.0%	0.0%	-0.4%	-0.2%	1.9%	1.9%	4.2%	47.6%
Trichomanes exsectum	-11.3%	-5.4%	1.7%	0.1%	0.0%	0.1%	1.3%	1.2%	3.6%	162.0%
Weinmannia trichosperma	-0.1%	0.0%	0.0%	0.0%	0.0%	0.0%	0.1%	0.1%	0.2%	1.2%

Table 2.S5. Modeled habitat area size (km^2) under assessed scenarios: present and future (year 2050) with modeled dispersal constraints for each species and their representation under different conservation schemes in Chile. Source: own elaboration.

	Modeled Area (km^2) under scenario:												
	Present						Future under dispersal constraints						Future without dispersal constraints
Species	NPA[a]	PPA[b]	Without protection			Total	NPA	PPA	Without protection			Total	
			SBN[c]	SBR[d]	Other[e]				SBN	SBR	Other		
Adiantum chilense	2,679.1	579.4	5,313.0	8,081.1	57,341.8	73,994.3	4,565.2	1,364.7	7,505.0	9,456.1	76,338.6	99,229.6	109,451.6
Adiantum excisum	332.0	49.2	2,977.0	3,096.4	18,030.8	24,485.5	463.7	62.7	3,559.8	4,108.1	22,418.7	30,612.9	33,627.9
Adiantum gertrudis	89.4	25.3	2,775.7	1,286.3	5,107.0	9,283.6	96.7	23.1	2,374.0	1,266.0	4,983.5	8,743.4	8,978.8
Adiantum scabrum	994.2	95.6	4,632.0	7,360.3	21,855.3	34,937.4	1,913.7	164.9	5,723.3	9,199.8	29,118.9	46,120.6	47,211.2
Adiantum sulphureum	1,042.1	491.3	8,409.3	9,321.6	39,124.6	58,388.8	2,316.4	790.5	9,885.6	11,811.4	52,346.2	77,150.1	82,151.3
Aextoxicon punctatum	3,489.2	3,976.7	6,490.6	5,099.4	47,988.3	67,044.3	6,090.1	4,559.6	6,404.8	5,106.8	50,517.8	72,679.1	79,879.2
Araucaria araucana	2,829.1	112.7	286.2	2,279.7	11,437.0	16,944.7	2,291.1	205.0	304.2	913.0	5,773.8	9,487.1	10,923.6
Asplenium dareoides	9,082.6	3,636.9	3,954.4	4,735.4	41,818.2	63,227.6	11,539.2	5,361.3	4,981.1	5,550.7	57,528.7	84,961.0	90,362.0
Asplenium monanthes	396.1	177.7	60.4	505.1	3,334.0	4,473.3	863.4	623.4	9.3	654.6	4,366.7	6,517.5	7,745.9
Asplenium obtusatum	807.6	1,382.2	2,908.1	854.2	16,570.8	22,523.0	1,142.6	1,551.8	4,687.4	1,047.9	24,756.4	33,186.1	36,250.9
Asplenium trilobum	609.5	876.1	1,284.9	994.2	7,503.1	11,267.8	1,903.6	2,286.9	3,745.9	2,052.0	25,913.4	35,901.9	49,052.9
Austrocedrus chilensis	1,414.5	436.7	1,810.7	4,842.2	13,191.6	21,695.7	1,560.9	558.5	2,020.8	4,843.3	13,365.1	22,348.5	25,396.7
Azara petiolaris	250.2	80.5	2,238.8	3,071.6	4,341.5	9,982.7	344.9	88.9	2,188.6	2,993.6	4,369.3	9,985.3	10,934.6
Blechnum arcuatum	8,719.8	3,314.8	2,615.5	3,655.1	36,021.8	54,326.9	13,325.7	3,952.7	4,056.1	4,433.8	44,576.1	70,344.5	76,481.6
Blechnum asperum	1,172.9	709.5	660.1	1,384.4	11,238.6	15,165.5	3,382.8	1,800.2	1,827.2	2,280.6	28,498.1	37,788.9	44,878.5
Blechnum blechnoides	111.5	429.4	160.2	326.6	1,361.2	2,388.8	316.4	462.5	224.0	376.8	1,590.3	2,970.0	4,248.2
Blechnum chilense	6,981.7	2,894.0	7,391.7	9,051.2	70,529.9	96,848.5	10,081.4	4,097.7	9,242.7	10,352.0	88,490.1	122,263.8	133,277.1
Blechnum corralense	212.0	392.2	251.3	165.7	1,156.8	2,178.1	273.9	355.6	361.5	272.3	1,893.9	3,157.2	3,892.8
Blechnum hastatum	2,298.0	578.7	6,191.6	9,034.5	50,472.8	68,575.7	4,429.6	1,384.1	8,826.6	10,176.7	65,692.4	90,509.5	93,531.7
Blechnum magellanicum	8,065.1	593.0	2,505.8	4,117.9	23,973.2	39,255.0	8,933.6	1,083.5	3,126.6	4,697.8	28,630.9	46,472.4	57,770.2
Blechnum microphyllum	5,210.3	1,227.1	3,142.7	6,406.5	27,083.4	43,070.0	5,550.0	1,607.2	3,585.2	7,486.3	32,654.6	50,883.4	52,472.4
Blechnum mochaenum	1,050.5	448.2	728.7	1,572.4	8,151.1	11,951.0	2,156.3	327.0	1,196.7	2,196.1	12,038.8	17,914.9	21,922.9
Blechnum penna-marina	6,385.0	2,782.9	2,425.7	3,645.7	33,398.8	48,637.9	8,134.9	5,271.9	3,137.6	3,936.3	48,833.9	69,314.5	72,900.3
Blepharocalyx cruckshanksii	59.3	87.3	770.2	626.1	13,944.5	15,487.4	86.5	55.0	535.4	621.0	10,777.5	12,075.4	15,525.0
Botrychium dusenii	1,045.3	181.1	58.7	140.0	1,272.4	2,697.5	713.7	88.7	48.4	6.9	328.1	1,185.9	1,352.7
Cheilanthes glauca	2,850.7	194.3	6,195.0	8,978.1	25,975.8	44,193.9	3,653.9	276.9	6,780.5	9,616.6	31,032.6	51,360.5	54,028.4

Cheilanthes hypoleuca	466.5	163.0	4,247.3	5,409.5	14,344.8	24,631.1	431.4	126.5	5,207.2	4,694.9	18,690.4	29,150.3	32,857.8
Cheilanthes mollis	725.1	23.1	2,460.7	1,857.5	27,962.2	33,028.5	1,068.9	22.4	4,518.2	2,637.5	43,548.5	51,795.4	57,333.6
Cryptocarya alba	809.7	178.8	6,524.3	8,049.0	32,712.9	48,274.7	1,064.1	217.3	6,444.0	8,093.3	28,327.5	44,146.2	48,294.7
Cryptogramma fumariifolia	1,040.6	130.9	1,755.4	4,204.2	8,643.3	15,774.3	1,680.1	183.4	1,799.4	5,195.2	14,511.3	23,369.5	24,061.7
Cystopteris fragilis	8,662.4	2,987.7	10,212.2	10,867.8	69,396.2	102,126.2	7,997.3	4,361.8	11,309.9	12,358.6	78,729.6	114,757.3	117,430.9
Dennstaedtia glauca	437.5	141.1	3,580.2	3,555.2	6,614.4	14,328.2	577.6	158.0	4,845.4	4,596.4	11,002.7	21,180.1	24,892.5
Drimys andina	2,079.9	162.5	185.7	1,019.3	4,520.8	7,968.2	1,546.9	90.8	120.5	529.4	3,177.8	5,465.4	6,057.6
Drimys winteri	27,035.3	6,205.7	8,853.6	8,050.4	96,209.1	146,354.1	30,477.2	6,832.5	9,953.3	8,810.4	102,802.2	158,875.6	171,927.5
Elaphoglossum gayanum	490.9	372.7	502.8	201.6	2,742.8	4,310.8	733.0	936.9	993.9	914.6	12,003.1	15,581.4	19,153.4
Elaphoglossum mathewsii	182.5	1.3	9.7	2.0	228.8	424.3	308.4	0.0	0.0	5.1	313.4	626.9	722.5
Elaphoglossum porteri	422.5	0.0	0.0	0.0	143.5	566.0	620.0	0.0	0.0	0.0	294.9	914.8	1,034.4
Equisetum bogotense	4,027.1	1,417.5	6,089.5	9,618.9	46,388.0	67,541.0	6,137.0	2,273.4	8,150.6	10,904.9	70,203.5	97,669.3	103,679.4
Equisetum giganteum	215.7	38.9	2,577.9	1,716.7	7,416.9	11,966.1	494.8	39.6	2,731.0	2,279.3	9,225.2	14,769.8	20,324.1
Eucryphia cordifolia	2,527.3	2,302.8	4,965.1	2,637.5	32,407.5	44,840.3	3,939.6	3,267.4	4,645.5	2,150.6	28,404.2	42,407.4	47,512.2
Fitzroya cupressoides	4,160.7	2,611.0	2,768.4	590.0	10,077.0	20,207.2	3,027.2	1,517.5	2,020.0	109.2	6,575.0	13,249.0	14,946.5
Gevuina avellana	2,305.7	1,463.2	3,729.9	3,787.0	44,427.2	55,713.0	3,294.2	2,031.3	3,582.1	2,960.3	38,069.5	49,937.4	53,951.7
Gleichenia cryptocarpa	5,733.9	3,761.0	5,686.5	3,290.4	45,892.9	64,364.7	7,447.7	4,446.9	5,847.7	3,897.3	52,620.6	74,260.2	77,066.3
Gleichenia litoralis	192.5	629.9	312.0	128.4	1,064.8	2,327.6	42.8	231.4	138.4	76.9	567.1	1,056.6	1,693.1
Gleichenia quadripartita	6,929.1	1,615.9	1,202.0	1,496.7	17,621.2	28,864.9	9,340.5	2,489.7	1,505.1	1,333.5	24,162.0	38,830.8	45,492.3
Gleichenia squamulosa	969.9	823.8	2,605.0	1,467.1	20,409.6	26,275.4	2,121.9	2,260.8	4,859.0	1,716.4	34,922.7	45,880.9	50,646.4
Gomortega keule	37.0	7.6	140.6	81.7	1,148.9	1,415.8	28.2	7.6	84.5	57.6	815.0	992.9	1,247.3
Grammitis magellanica	33,065.3	4,601.8	5,257.5	5,152.5	72,497.8	120,574.9	40,675.5	6,260.7	7,530.4	6,552.9	93,056.6	154,076.1	160,228.2
Grammitis patagonica	8,236.9	1,490.7	594.3	695.8	37,372.8	48,390.5	9,115.6	1,500.6	1,118.7	734.1	52,971.7	65,440.7	70,072.9
Grammitis poeppigiana	8,345.5	2,072.9	1,458.1	2,039.7	16,095.2	30,011.4	4,840.5	991.7	469.5	690.2	8,484.9	15,476.8	15,761.0
Hymenoglossum cruentum	5,458.5	2,035.8	4,442.9	1,989.1	31,082.7	45,009.0	9,351.6	3,202.2	5,865.4	2,737.8	44,742.1	65,899.0	74,944.9
Hymenophyllum caudiculatum	2,346.0	1,480.1	1,804.7	1,286.3	16,746.7	23,663.7	3,930.5	3,258.6	4,332.7	2,030.9	27,725.1	41,277.8	43,591.4
Hymenophyllum cuneatum	3,255.9	815.2	890.6	771.2	11,989.3	17,722.3	5,485.2	1,790.7	2,939.6	1,422.1	25,310.9	36,948.4	44,925.5
Hymenophyllum darwinii	2,276.4	1,268.2	1,255.9	1,222.0	15,685.4	21,707.9	1,801.0	1,143.3	719.9	801.5	9,979.6	14,445.4	16,434.0
Hymenophyllum dentatum	5,853.6	3,782.7	3,971.3	3,068.7	35,539.6	52,215.9	7,872.3	4,408.6	5,541.2	3,682.7	45,865.1	67,369.9	72,062.2
Hymenophyllum dicranotrichum	6,067.3	3,295.8	4,817.3	2,229.5	36,916.6	53,326.5	9,792.5	4,100.9	5,520.4	2,701.5	46,405.1	68,520.5	73,604.8
Hymenophyllum falklandicum	4,741.8	1,026.9	986.7	1,939.0	11,653.2	20,347.5	5,014.9	1,466.5	1,158.9	1,732.1	12,860.1	22,232.5	27,371.4
Hymenophyllum ferrugineum	23,901.0	4,258.1	4,660.9	3,621.2	42,557.5	78,998.7	26,646.6	4,385.5	5,259.3	4,023.1	53,460.5	93,775.0	104,347.9
Hymenophyllum fuciforme	288.3	260.5	326.2	314.0	2,813.7	4,002.6	846.5	420.4	950.9	529.2	5,177.9	7,925.1	11,688.0
Hymenophyllum	5,956.9	1,952.2	2,841.8	2,061.0	26,887.1	39,698.9	9,544.1	3,566.7	5,673.2	3,188.3	44,777.5	66,749.7	74,161.7

krauseanum													
Hymenophyllum nahuelhuapiense	1,761.0	18.3	464.7	455.6	2,809.7	5,509.4	2,632.0	363.5	428.3	467.9	4,562.3	8,454.0	9,925.8
Hymenophyllum pectinatum	13,176.6	3,250.4	3,976.5	2,326.5	35,128.8	57,858.8	21,492.3	3,689.0	5,478.9	3,109.7	47,478.8	81,248.7	89,186.0
Hymenophyllum peltatum	3,375.1	2,328.3	2,391.3	1,485.5	15,271.5	24,851.7	2,576.2	2,539.8	4,080.1	1,579.0	18,072.4	28,847.6	34,569.1
Hymenophyllum plicatum	3,731.1	2,496.9	2,861.0	2,548.9	30,635.4	42,273.3	4,672.6	3,471.3	5,600.7	3,307.0	46,153.1	63,204.8	69,386.0
Hymenophyllum secundum	6,460.6	1,369.7	3,096.8	1,161.4	12,326.3	24,414.9	7,211.7	2,588.1	3,837.9	1,448.2	17,261.2	32,347.1	37,369.3
Hymenophyllum seselifolium	27,440.1	2,859.3	4,087.4	3,615.9	51,399.3	89,402.1	35,924.6	4,193.5	6,430.2	4,933.3	67,099.6	118,581.2	128,209.7
Hymenophyllum tortuosum	25,876.9	2,536.5	4,321.2	2,807.0	42,888.3	78,429.9	34,457.9	3,588.8	5,994.2	4,323.1	57,393.4	105,757.4	110,004.2
Hymenophyllum tunbridgense	3.4	0.0	0.7	2.7	374.7	381.6	27.5	0.0	0.0	27.1	373.2	427.9	1,293.2
Hymenophyllum umbratile	571.3	735.8	296.4	358.1	3,434.1	5,395.7	120.0	235.7	20.3	192.2	489.4	1,057.7	3,090.5
Hypolepis poeppigii	12,668.1	3,746.6	7,199.8	4,864.2	62,017.7	90,496.4	20,348.9	4,322.2	8,426.1	6,525.4	81,156.9	120,779.5	130,658.2
Laurelia sempervirens	1,378.2	474.4	2,595.8	4,543.5	31,009.2	40,001.0	2,169.7	648.3	2,907.2	5,168.7	32,679.0	43,572.9	47,341.1
Laureliopsis philippiana	11,018.7	4,696.9	5,966.0	2,605.2	48,652.0	72,938.8	11,474.2	4,799.2	5,566.7	2,004.7	42,938.5	66,783.4	70,608.3
Lomatia hirsuta	4,585.1	2,778.1	4,438.3	7,854.8	53,058.0	72,714.3	6,675.1	3,645.4	5,806.1	7,968.9	57,390.7	81,486.2	86,203.3
Lophosoria quadripinnata	17,013.8	5,170.1	6,959.3	5,482.3	82,903.6	117,529.2	19,883.6	5,351.6	7,180.1	5,882.5	87,829.5	126,127.2	130,442.9
Luma apiculata	11,558.0	5,236.0	7,905.1	8,516.3	79,894.4	113,109.7	13,116.7	5,422.4	8,595.4	8,646.1	82,924.6	118,705.2	123,890.9
Lycopodium alboffii	4,737.0	2,461.9	1,209.3	1,273.8	16,129.9	25,811.9	5,658.7	2,888.5	1,636.8	984.1	18,524.7	29,692.7	39,200.4
Lycopodium confertum	14,515.1	1,960.3	1,043.4	644.6	26,755.6	44,919.1	17,850.3	1,706.6	678.6	352.5	31,162.4	51,750.4	53,604.9
Lycopodium gayanum	822.4	507.5	764.5	303.9	3,299.5	5,697.7	837.4	663.1	1,090.9	588.3	7,031.6	10,211.3	13,668.9
Lycopodium magellanicum	17,951.9	5,144.2	2,504.2	5,673.8	45,607.6	76,881.8	22,577.5	6,330.8	3,771.2	6,354.3	62,283.0	101,316.9	107,167.0
Lycopodium paniculatum	3,304.0	1,874.3	2,662.2	1,135.9	15,099.5	24,075.9	4,362.4	2,434.9	2,691.3	2,293.9	25,951.8	37,734.3	42,120.7
Maytenus disticha	2,876.6	154.7	1,159.6	2,783.4	13,701.7	20,676.1	2,670.8	386.4	910.0	2,030.7	12,058.4	18,056.2	22,691.0
Megalastrum spectabile	4,273.0	2,000.5	2,663.7	3,250.7	32,211.3	44,399.2	6,056.4	3,423.1	5,239.6	4,283.0	47,677.1	66,679.2	75,299.0
Myrceugenia exsucca	861.6	1,434.5	5,292.5	3,213.9	42,866.3	53,668.9	1,706.3	2,373.5	6,431.7	3,965.2	45,241.3	59,718.0	66,965.9
Myrceugenia planipes	1,074.1	961.6	2,126.0	1,495.2	27,081.4	32,738.3	2,241.6	1,473.6	3,124.9	1,851.6	30,476.8	39,168.5	45,237.8
Nothofagus alessandrii	0.7	0.0	8.4	18.2	377.0	404.4	0.7	0.0	0.0	6.3	229.0	236.0	389.3
Nothofagus alpina	3,023.7	1,043.8	2,408.3	3,827.6	19,676.1	29,979.5	2,844.6	978.6	1,754.2	2,937.7	11,993.0	20,508.2	21,710.1
Nothofagus antarctica	44,886.1	7,413.6	7,711.5	8,159.8	134,355.8	202,526.7	44,978.9	7,383.5	7,770.4	6,816.0	123,225.9	190,174.7	196,451.3
Nothofagus betuloides	82,512.2	6,693.5	6,418.3	7,014.1	100,927.0	203,565.1	80,655.2	5,547.1	4,246.7	5,533.9	88,001.8	183,984.7	184,881.4
Nothofagus dombeyi	9,530.1	3,068.4	6,969.1	6,975.7	61,630.6	88,174.0	9,398.1	3,231.9	4,826.8	4,980.8	48,686.4	71,123.9	72,928.1
Nothofagus glauca	329.8	85.3	2,212.9	3,306.2	8,691.9	14,626.1	269.2	86.0	1,802.4	2,074.2	5,356.2	9,587.9	10,423.2
Nothofagus nitida	48,703.4	4,301.0	5,722.1	2,630.7	64,260.4	125,617.6	47,671.9	3,870.7	5,635.1	1,879.7	62,768.8	121,826.2	122,532.2
Nothofagus obliqua	3,779.1	1,745.2	5,348.5	7,462.3	48,852.9	67,188.0	4,228.8	1,923.3	5,222.1	6,755.4	43,971.7	62,101.3	63,388.0
Nothofagus pumilio	29,997.6	6,912.6	7,272.9	8,178.9	102,529.8	154,891.7	27,930.1	6,178.4	4,885.9	6,154.4	83,900.0	129,048.7	130,169.9

Pellaea myrtillifolia	21.2	23.7	1,176.4	1,227.0	11,584.2	14,032.5	71.5	20.9	1,460.2	1,606.7	12,572.9	15,732.1	16,570.6
Pellaea ternifolia	4,912.4	95.1	1,021.5	3,441.8	51,835.7	61,306.5	5,560.5	219.2	1,296.9	5,427.8	67,458.3	79,962.6	87,232.8
Persea lingue	1,378.2	888.7	1,888.0	3,613.5	36,604.1	44,372.5	2,175.7	1,468.9	2,543.6	3,498.0	33,530.1	43,216.3	45,436.5
Philesia magellanica	16,361.8	3,138.4	5,194.8	1,515.8	37,404.3	63,615.1	26,874.0	3718.5	5,494.7	1,599.2	47,790.0	85,476.5	104,584.1
Pilgerodendron uviferum	62,975.6	2,823.5	5,589.8	2,822.2	66,851.6	141,062.7	64,992.4	2766.2	4,891.7	2,233.3	66,416.6	141,300.1	147,910.2
Pleopeltis macrocarpa	874.8	610.4	1,261.5	1,957.6	15,913.6	20,617.8	2,244.1	685.9	1,610.8	4,100.6	33,480.0	42,121.4	65,009.5
Pleurosorus papaverifolius	528.0	143.3	4,560.0	5,088.9	12,868.6	23,188.9	724.1	215.5	5,263.2	5,765.1	15,828.1	27,796.0	29,912.0
Podocarpus nubigenus	63,971.4	4,353.6	6,107.6	3,569.5	72,795.7	150,797.7	64,767.1	3,813.9	5,628.3	2,577.2	67,753.8	144,540.3	147,939.0
Podocarpus salignus	594.6	377.9	1,201.5	1,405.3	11,171.7	14,751.0	1,037.4	523.6	1,612.8	2,393.4	11,148.7	16,715.9	25,737.6
Polypodium feuillei	1530.6	1,873.0	3,875.2	2,462.1	30,288.4	40,029.3	3,555.7	2,993.5	5,571.8	3,665.1	51,174.8	66,960.9	74,291.9
Polystichum andinum	6,127.2	1,171.5	2,278.0	3,653.1	10,050.5	23,280.3	3,379.0	498.5	1,566.3	1,963.0	5,016.9	12,423.7	13,018.5
Polystichum chilense	3,088.2	1,867.8	3,502.6	4,930.1	36,188.1	49,576.8	4,548.3	2,814.6	5,214.8	5,703.7	53,923.2	72,204.6	86,711.1
Polystichum multifidum	3,417.0	491.0	79.0	1,044.6	4,553.5	9,585.0	4,043.5	913.8	28.0	895.4	6,512.0	12,392.7	14,396.4
Polystichum plicatum	7,823.1	2,580.5	5,099.1	8,721.8	37,667.7	61,892.2	9,026.1	2,462.9	5,086.6	8,392.4	41,350.1	66,318.2	67,674.9
Polystichum subintegerrimum	1,879.9	1,141.9	1,726.0	2,817.8	30,418.6	37,984.2	4,475.8	2,277.2	3,275.5	3,282.4	43,069.7	56,380.7	62,778.0
Pteris chilensis	81.5	76.7	209.3	863.2	5,688.3	6,919.0	115.2	143.7	433.1	1,033.4	9,672.7	11,398.1	15,857.8
Pteris semiadnata	1,294.2	601.5	712.1	781.0	6,163.6	9,552.3	2,556.3	1,091.9	1,563.4	1,453.7	12,030.0	18,695.3	31,356.7
Rhaphithamnus spinosus	6,476.6	4,235.1	6,272.9	4,354.1	58,742.2	80,081.0	8,836.0	4,912.3	6,900.8	4,094.4	59,884.4	84,628.0	90,427.9
Rumohra adiantiformis	2,277.9	1,321.1	2,745.0	4,227.2	28,899.6	39,470.9	4,904.7	2,523.0	3,778.6	5,077.8	42,814.0	59,098.1	70,836.1
Schizaea fistulosa	7,520.0	1,647.1	4,755.1	670.0	22,430.4	37,022.5	11,943.6	1,684.8	4,817.1	660.6	23,302.4	42,408.5	43,472.8
Serpyllopsis caespitosa	6,209.3	1,373.8	3,928.2	1,313.9	21,770.4	34,595.5	8,840.4	2,364.3	4,813.4	1,637.8	28,908.4	46,564.2	52,503.2
Tepualia stipularis	58,386.6	3,857.7	6,050.5	1,645.1	63,980.2	133,920.0	54,307.4	3,384.3	5,988.9	897.5	59,723.1	124,301.1	126,563.4
Thelypteris argentina	933.7	41.4	5,698.0	3,706.0	34,751.9	45,130.9	1,620.1	82.2	8,614.6	6,374.5	65,701.5	82,392.9	103,872.3
Trichomanes exsectum	7.9	128.4	80.2	75.4	1,066.4	1,358.4	44.8	180.5	54.9	88.5	818.4	1,187.1	3,387.6
Weinmannia trichosperma	39,773.0	5,310.0	7,136.4	4,384.0	76,532.9	133,136.4	35,768.1	4,413.7	5,209.4	3,175.6	64,671.5	113,238.3	114,823.5

[a] NPA: Representation under the national system of protected wild areas, managed by Chilean Government.

[b] PPA: Representation under the private protected areas, managed by private owners in Chile.

[c] SBN: Representation under the prioritized sites for biodiversity conservation, at a Chilean national level.

[d] SBR: Representation under the prioritized sites for biodiversity conservation, at a scale of each Chilean administrative region.

[e] Habitat areas without any protection scheme, also outside of any prioritized sites for biodiversity conservation in Chile.

Table 2.S6. Habitat size comparisons among scenarios within species groups (obtained with paired t-tests). Source: own elaboration.

Species group	Scenario	dispersal constrained future	unconstrained future
Nothofagus	present	t = -3.87, df = 8, p-value = 0.004742	t = -3.3695, df = 8, p-value = 0.009793
	dispersal constrained future		t = -2.6222, df = 8, p-value = 0.03055
Co-dominant	present	t = -0.5985, df = 26, p-value = 0.5547	t = 2.1225, df = 26, p-value = 0.04348
	dispersal constrained future		t = -7.9683, df = 26, p-value = $1.906\text{x}10^{-8}$
Ground ferns	present	t = 8.6654, df = 54, p-value = $8.443\text{x}10^{-12}$	t = 10.2558, df = 54, p-value = $2.775\text{x}10^{-14}$
	dispersal constrained future		t = -9.9539, df = 54, p-value = $8.051\text{x}10^{-14}$
Epiphytic ferns	present	t = 6.0128, df = 26, p-value = $2.382\text{x}10^{-06}$	t = 6.9601, df = 26, p-value = $2.171\text{x}10^{-7}$
	dispersal constrained future		t = -7.1138, df = 26, p-value = $1.486\text{x}10^{-7}$

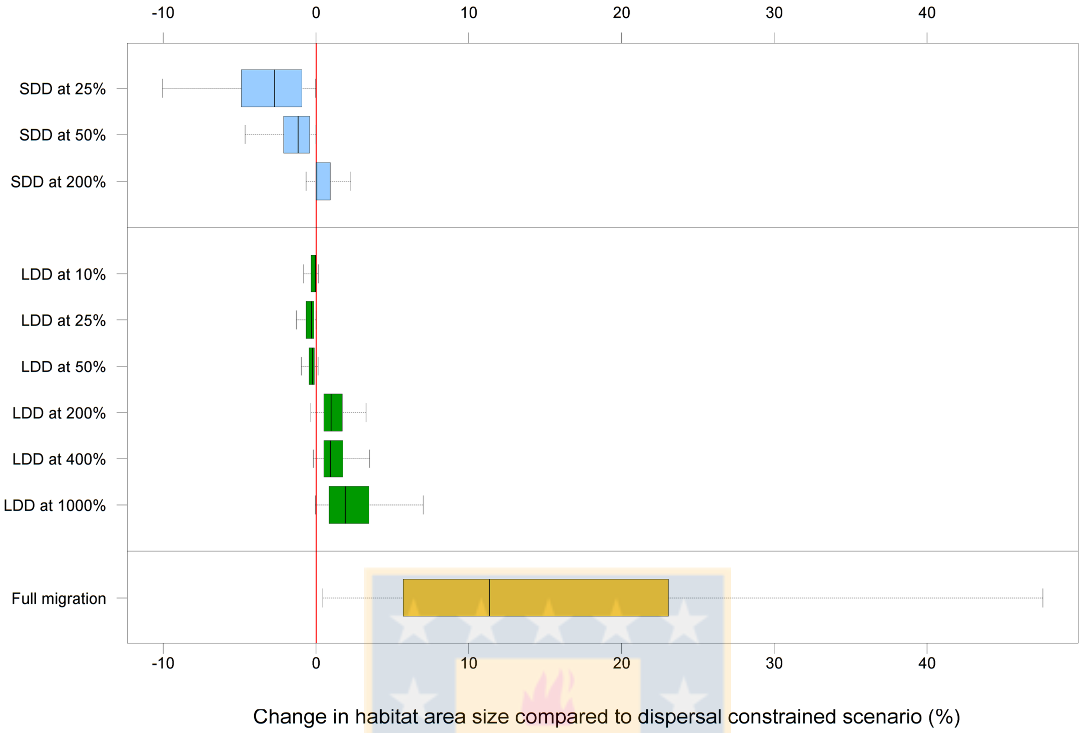

Figure 2.S1. Sensitivity analysis of changes in MIGCLIM parameters SDD (short distance dispersal) and LDD (probability for long distance dispersal) and their effects on the habitat area size for all the studied species, following 2.S4 Table. Vertical red line represents 0% change in habitat size considering the parameters set in 2.S3 Table as 100% for both SDD and LDD. A full migration scenario is also included as a comparison for habitat sizes without using MIGCLIM. Source: own elaboration.

DISCUSIÓN GENERAL

Diferencias en los nichos y rasgos según especies y tipos de especie

En esta tesis se han reconocido diferencias entre los nichos ecológicos de especies de plantas que comparten comunidades de bosques templados de Sudamérica, tanto a nivel de especies como a nivel de los grupos estudiados de diversidad estructural. Las diferencias entre los principales factores climáticos relacionados con la variabilidad de los nichos de cada grupo de plantas se pudieron interpretar o asociar a ciertas características morfológicas o fisiológicas específicas, tal como la literatura ha anticipado. Los resultados obtenidos a partir de los análisis de *Outlying Mean Index* (OMI), mostraron una diferenciación de nicho bioclimático entre las especies estudiadas, en un primer lugar relacionado al rango de temperatura media y estacionalidad de precipitación, siguiendo la transición ecológica a partir del clima mediterráneo de Chile central, a lo largo de todo el bioma templado, hasta su transición hacia el clima subantártico patagónico (eje OMI 1). En un segundo lugar, relacionado a la temperatura mínima de invierno, que se relaciona con la transición desde hábitats con temperaturas mínimas más estables bajo algún grado de influencia oceánica, hasta los hábitats de temperaturas frías invernales más extremas correspondientes a los límites altitudinales andinos de vegetación (eje OMI 2).

Se pudo corroborar que mientras importantes clasificaciones bioclimáticas que han abordado estos ecosistemas (Amigo & Ramírez, 1998; Luebert & Pliscoff, 2006) han apuntado hacia ambos tipos de factores climáticos (*i.e*. temperatura y precipitación) como igualmente importantes, en esta tesis se encontró que las variables relacionadas a la energía (temperatura) resultaron ser más relevantes que aquellas vinculadas a la disponibilidad hídrica (precipitación), en cuanto a su rol para discriminar los nichos ecológicos al considerar la totalidad de las plantas estudiadas. Esto es coincidente con lo publicado para una escala de transición local más acotada desde el bioma templado a mediterráneo para la región del Biobío (Teneb *et al*., 2004), y también en una evaluación en la que se abordaron a escala global aquellos factores que determinan la distribución de las plantas (Box, 1995).

Resultó interesante observar que cuando se analizaron los nichos mediante OMI de manera separada según grupos de plantas, las variables bioclimáticas resultaron ser diferentes, pudiéndose en ciertos casos distinguir rasgos morfológicos o fisiológicos de las plantas estudiadas. Por ejemplo, los nichos dentro del grupo de especies de árboles del género *Nothofagus*, se discriminaron principalmente por la temperatura máxima del mes más cálido. Esto es coherente con lo estudiado por Alberdi (1995), quien informó valores de temperaturas correspondientes a TL50 foliares correspondientes a meses de verano para las especies más australes incluyendo *Nothofagus* formadores de *treeline*. Estos valores siguieron el orden concordante encontrado en esta tesis respecto a la posición de nicho: *N. dombeyi*, *N. pumilio*, *N. antarctica*, *N. nitida* y *N. betuloides* siguiendo desde un menor valor de resistencia a heladas estivales concordante con nichos correlacionados con mayores temperaturas de verano, hacia un TL50 que refleja mayor resistencia a heladas junto con una posición de nicho correlacionada con menores temperaturas estivales. Aún más, estas diferencias entre nichos podrían también ser interpretadas a la luz de la capacidad potencial de las especies para sobrevivir luego de la germinación: semillas más grandes (*N. glauca*, *N. obliqua* o *N. alpina*) y por ende más capaces de alcanzar la humedad del suelo más profundo previniendo así la desecación (Donoso, 1993; Donoso, 2006), fueron encontradas en especies con nichos relacionados a temperaturas de verano más altas, mientras que se encontró lo opuesto para las semillas más pequeñas (*N. betuloides*, *N. antarctica* o *N. nitida*) que no requerirían este tipo de estrategia (Donoso, 2006). No obstante, las diferencias en nichos de las especies codominantes estuvieron principalmente dirigidas por la estacionalidad de la precipitación, siguiendo la transición climática desde condiciones de verano seco hacia una precipitación más constante durante todo el año. En relación a esta transición, la esclerofilia foliar podría interpretarse como relacionada: Especies con una mayor esclerofilia tales como *Azara petiolaris*, *Cryptocarya alba*, *Persea lingue*, *Myrceugenia exsucca* o *Podocarpus salignus* (Alberdi, 1995; Read *et al*., 2016) presentaron posiciones de nicho asociadas a sequía estival, mientras que especies con menor valor de esclerofilia como *Drimys winteri*, *Tepualia stipularis*, *Weinmannia trichosperma* o *Laureliopsis philippiana* (Alberdi, 1995) presentaron posiciones de nicho relacionadas a precipitación constante a lo largo del año.

Respecto a los nichos de los helechos terrestres, el monto de precipitación anual correspondió a la variable más importante para diferenciar sus nichos. Con ciclos de vida y patrones de distribución dirigidos mayormente por la disponibilidad de agua (Quian *et al*., 2012), las diferencias de nicho en los helechos terrestres estuvieron coherentemente relacionadas al gradiente de montos de precipitación, desde especies de helechos del tipo cheilanthoide y del género *Adiantum* adaptados a baja precipitación, hasta helechos terrestres especialmente adaptados a hábitats más húmedos (Rodríguez, 1995; Parra *et al*., 2015). Por su parte, los helechos epífitos, dentro de un espacio de nicho más pequeño comparado con otros grupos de acuerdo al análisis OMI general, presentaron a las extremas térmicas (*i.e.* máxima temperatura estival, mínima temperatura invernal) como las variables discriminantes de nicho más relevantes. Algunas especies presentan estrategias poikilohídricas (ausencia de estomas y falta de vacuolas principales en las células de las láminas) como en la mayoría de los helechos de la familia Hymenophyllaceae, generalmente asociados a hábitats costeros o australes con estabilidad térmica (Ponce *et al*., 2012), mientras que estrategias como rizomas reservantes de agua en *Polypodium feuillei* se encontraron en nichos con mayores extremas térmicas, correspondientes al bioclima templado con transición hacia el bioclima mediterráneo (Rodríguez, 1995). Estas diferencias en las variables bioclimáticas forzantes de la variabilidad de nichos según grupos de especies, apoyan la hipótesis 1 de esta tesis, en los casos de las variables forzantes para segregar los *Nothofagus* dominantes en ambas dimensiones OMI 1 y 2, en OMI 2 para las leñosas codominantes, en OMI 1 para los helechos terrestres y en OMI 2 ara los helechos epífitos.

Diversas respuestas de desplazamiento según grupo de especies

En la observación de cambios modelados como efecto de cambio climático, cabe señalar que la incorporación de restricciones específicas a la migración de las especies de plantas estudiadas en esta tesis, constituye un elemento novedoso respecto de otros estudios previos que han considerado esquemas binarios (*i.e*. futuro sin capacidad de dispersión, versus futuro con total capacidad de dispersión), incorporando de esta forma un mayor realismo en las estimaciones de distribución futura al tomar en cuenta los procesos y mecanismos de dispersión específicos. Respecto de los efectos evaluados de las distribuciones medias en los gradientes de altitud y latitud, aunque la mayoría de las especies mostró efectos proyectados de desplazamiento hacia una mayor altitud y una mayor latitud, las respuestas variaron según grupo de especies. Más de la mitad de las especies arbóreas estudiadas mostraron estas tendencias globalmente más comunes: hacia los polos y hacia mayor altitud (Jump *et al*., 2009; Parmesan, 2015). No obstante, para ambos grupos de helechos del sotobosque, las respuestas de desplazamiento en elevación y en latitud fueron más diversas en dirección y en magnitud que para los árboles dominantes. Estas respuestas diferentes han sido documentadas en plantas para otras comunidades a lo largo del mundo (Kelly & Woulden, 2008; Lenoir *et al*., 2010) pero en esta tesis se encontró una mayor diversidad de respuestas en plantas de bosques templados sudamericanos, en comparación con aquellas modeladas por VanDerWal *et al*. (2012) para especies de bosques templados australianos. La variación en respuestas ante cambio climático para helechos terrestres y epífitos en esta tesis, se muestran relacionadas a una más heterogénea ubicación de posiciones de nicho climático, en comparación con los árboles, tal como se muestra en el análisis OMI (Fig. 1.2).

De acuerdo a los modelos lineales, encontramos diferentes tendencias en desplazamiento altitudinal: árboles de *Nothofagus*, especies codominantes y helechos terrestres esperaron en general, mayores desplazamientos para sus especies localizadas en elevaciones más altas, que para aquellas de sitios de elevaciones más bajas. Sin embargo, este patrón fue inverso para helechos epífitos, tal vez relacionado a una ocupación distinta de este grupo de especies a lo largo del gradiente de elevación: la altitud media de las especies de helechos epífitos estuvo restringido a altitudes más bajas de los 600 m. s.n.m. mientras que los otros grupos de plantas excedieron los 1000 m s.n.m.

Luego de observar el gradiente latitudinal, el patrón de desplazamiento en este gradiente podría estar relacionado a la extensión de las distribuciones medias de las especies. Para helechos terrestres, se observó una presencia más amplia (latitudes medias entre los 25 y 50 grados sur) y aquellos con latitud media más baja esperaron mayores desplazamientos latitudinales. De manera inversa, *Nothofagus* y codominantes (latitudes medias entre 35 y 48 grados sur) esperaron sus mayores desplazamientos latitudinales para las especies localizadas hacia mayores latitudes. Tanto los patrones de desplazamiento proyectado en el gradiente altitudinal como en el latitudinal, no se presentan de manera homogénea en todos los grupos de plantas, y estas diferencias están en alguna medida relacionadas con los diferentes forzantes climáticos de sus nichos, de forma que al dividir el total de especies según magnitud de cambio en elevación, un 58% de los árboles correspondió a especies con mayores cambios, versus sólo un 46% de los helechos, sugiriendo que se proyecta mayores cambios para los árboles en comparación a los helechos, en la misma dirección que lo resultante de las medias de los índices de cambio altitudinal, con 8.1 para los árboles y 7.3 para los helechos. Al considerar los cambios en latitud, 47% de los árboles se encontraron en la mitad con mayores cambios versus 51% de los helechos, sugiriendo un mayor cambio proyectado para los helechos que para los árboles en el gradiente latitudinal indicado por los valores medios de índice de cambio latitudinal de 0.49 para árboles y 0.56 para helechos, todo lo cual apoya la hipótesis 1 de esta tesis.

Desplazamientos altitudinales y latitudinales en relación a la posición de nicho y a la amplitud de nicho

La relación encontrada entre los cambios modelados en elevación y posición de nicho de las especies, reveló una proyección de mayor desplazamiento altitudinal para aquellas plantas asociadas a la transición bioclimática de templado a mediterráneo, en contraste con aquellas relativas a la transición desde templado a subantártico. Esto es opuesto al gradiente bioclimático análogo europeo analizado por Pauli *et al.* (2012), con un mayor cambio altitudinal para plantas templado-boreales que para las plantas cuya distribución es más cercana al bioma mediterráneo. El patrón aquí encontrado incluyó la segregación de nicho en un escenario de cambio climático con precipitación decreciente en casi todo el gradiente templado, mientras que en Europa la precipitación se espera aumente en el bioma homólogo (IPCC, 2013). Además, en los bosques templados de Sudamérica, el gradiente altitudinal mismo se mostró más amplio en la transición bioclimática de templado a mediterráneo que respecto a la transición de templado a subantártico, haciendo posible un mayor potencial para expresar los cambios altitudinales debido a cambio climático.

Los cambios esperados en elevación y latitud estuvieron directamente relacionados con la posición de las especies en la dimensión de nicho correspondiente al gradiente térmico desde temperatura invernal moderada, hasta la temperatura invernal más fría. Una posible explicación podría ser que el cambio climático se espera que aumente la temperatura a través de toda la extensión de los bosques templados de Sudamérica, el cual puede elevar el umbral térmico mínimo a lo largo del ecosistema completo, de manera que los mayores cambios podrían estar intensificados hacia el *treeline* andino y hacia el límite patagónico de estos bosques (inviernos más fríos), comparados con la porción templada moderada con influencia oceánica.

La literatura ha establecido la existencia de una relación inversa entre la amplitud de nicho y los efectos proyectados de cambio climático (Thuiller *et al*., 2005). Los resultados de esta tesis sugirieron esta tendencia correspondiente a los impactos en el gradiente altitudinal: plantas con amplitud de nicho más estrecho estuvieron vinculadas a mayores desplazamientos altitudinales, al menos para la principal dimensión de nicho OMI, en línea con lo evaluado en Sudáfrica para plantas (Broennimann *et al*., 2006), y anfibios (Botts *et al*., 2013). En este estudio mostramos que en Sudamérica, las especies con nicho restringido a lo largo del gradiente bioclimático templado desde mediterráneo hasta subantártico correspondieron a las plantas con mayores desplazamientos en términos de elevación debido a cambio climático, lo cual brinda apoyo a aceptar la parte referente al gradiente de altitud de la hipótesis 2 de esta tesis (hipótesis 2a).

Los desplazamientos proyectados para las plantas dentro del gradiente latitudinal no mostraron el patrón inverso anteriormente señalado al contrastarlos con la amplitud de nicho, apoyando de esta forma al rechazo de la parte relacionada al gradiente latitudinal de la hipótesis 2 de esta tesis (hipótesis 2b). En vez, los desplazamientos latitudinales estuvieron relacionados de forma directa a la amplitud de nicho para ambas dimensiones OMI analizadas, en especial en el eje 1, el cual está correlacionado con el gradiente bioclimático de bosques templados, orientado latitudinalmente desde la transición a mediterráneo hasta la transición a subantártico. Hasta donde esta tesis ha explorado, este corresponde al primer estudio que muestra este patrón. Este resultado podría estar explicado desde el punto de vista del amplio gradiente latitudinal en el cual se desarrollan los bosques templados de Sudamérica, y también considerando el patrón directo encontrado entre la amplitud de nicho de las plantas (en ambas dimensiones OMI) y la distribución media latitudinal de las especies, mostrando valores de amplitud de nicho más amplios hacia una latitud más alta. Los resultados de esta tesis también mostraron una relación directa entre la latitud media de las plantas y sus rangos latitudinales, patrón correspondiente al efecto

Rapoport (Stevens, 1989), el cual ya había sido descrito por Arroyo *et al*. (1996) igualmente para especies de plantas de estos mismos bosques templados sudamericanos.

La relación directa encontrada entre el desplazamiento latitudinal y la amplitud de nicho podría ser también explicado debido a que las plantas con mayor amplitud de nicho en estos bosques están relacionadas a distribuciones latitudinales más amplias, y al hecho que las principales variables que dirigen los nichos climáticos presentaron una transición en el sentido latitudinal, así como también los cambios proyectados para esas variables que presentan un gradiente por latitud y al hecho que no se esperen grandes cambios en los extremos latitudinales de acuerdo a los mecanismos de dispersión de cada especie. Esto podría ayudar por ejemplo a producir extinción local en la distribución septentrional, al mismo tiempo que aumentos de la extensión local hacia su distribución meridional, lo que no se observa con frecuencia en especies con distribuciones latitudinales restringidas.

Representación de los hábitats bajo conservación efectiva y cambios esperados producto del cambio climático

Esta tesis incluyó el análisis del grado de representación de los hábitat bajo protección formal en Chile (*i.e.* dentro de SNASPE) a escala de especie de planta. Pese a estudios anteriores que evaluaron representación a escala de ecosistemas (Pliscoff & Fuentes-Castillo, 2011) y a escala de hábitat de especies en animales (Tognelli *et al*., 2008), el trabajo de esta tesis en este ámbito corresponde al primer análisis formal de evaluación de representación de especies de plantas y al primer estudio del efecto esperado de cambio climático sobre la representación de hábitats bajo esquemas de protección para Chile. Referente a la hipótesis 3 de esta tesis, los resultados apoyan dicha hipótesis al constatarse una insuficiencia del sistema de áreas protegidas formales en el resguardo de umbrales mínimos de protección de los hábitats para las especies estudiadas. El actual nivel de representación de los hábitats dentro de las áreas SNASPE al nivel de especies de plantas puede ser considerado bajo comparado con otros estudios: sólo un 50% de las especies mínimamente representadas, comparadas con un 100% de ellas en Europa Occidental, y un 89% en la región de El Cabo en Sudáfrica (Hannah *et al*., 2007). En esto es importante observar el hecho que las áreas SNASPE presentan un fuerte sesgo hacia el sur y no es coincidente con la distribución de la mayor diversidad de plantas vasculares, que se ubica en las regiones más centrales y del centro-sur de Chile (Armesto *et al*., 1998).

Resulta interesante el que los resultados de esta tesis hayan mostrado que las áreas SNASPE mantendrán o incluso aumentarán el nivel de representación de las plantas estudiadas de los bosques templados dominados por *Nothofagus* en el escenario de cambio climático para la segunda mitad del siglo, alcanzando hasta un 52.5% de las especies en Chile. Esto contrasta con la representación proyectada de un 94% de las especies de plantas de Europa Occidental y de un 78% de las especies de la región de El Cabo en Sudáfrica, para un mismo umbral de representación mínima de 10% (Hannah *et al*., 2007) y con algunas especies de vertebrados en Europa, para los que se espera que pierdan representación en áreas protegidas bajo escenarios de cambio climático (D'Amen *et al*., 2011, Carvalho *et al*., 2011).

El escenario futuro de cambio climático indicó cambios en el tamaño de los hábitats de las especies de plantas que comparten su distribución con las especies de *Nothofagus* pertenecientes a los bosques templados sudamericanos. No obstante, se constataron diferencias según grupos de plantas respecto de cambios en los tamaños de hábitat, al mismo tiempo que se pudo ver que estos cambios no necesariamente van de la mano con los efectos en el nivel de representación de sus hábitats en áreas de protección oficial tales como las SNASPE. Por ejemplo, mientras los tamaños de hábitat para las especies de *Nothofagus* se espera que disminuyan en el futuro, sus niveles de representación se proyecta que aumenten, sugiriendo que las unidades de SNASPE se localizan en áreas útiles para estas especies en el largo plazo. Además, estas áreas de conservación formal del estado, incluyen zonas que pueden ser propensas a ser colonizadas por estas especies en un futuro corto plazo, de acuerdo a las restricciones específicas de migración consideradas. La misma observación puede hacerse con las especies co-dominantes; las especies cuyos tamaños de hábitat se proyecta que disminuyan (51.9% del número de las especies evaluadas), se espera que aumenten sus niveles de representación en SNASPE. Además, para las especies cuya distribución se prevé que tengan una expansión (48.1%), se espera de igual forma que aumenten su representación. Ejemplos de esto se pueden ver en especies como *N. alpina* y *N. dombeyi*, cuyos rangos septentrionales de distribución y hábitats de altitudes menores se espera que disminuyan producto del cambio climático. Al mismo tiempo se espera que sus hábitats futuros incluyan hábitats presentes que puedan persistir en el tiempo además de las nuevas zonas de expansión en el futuro, y en ambos casos coincidan con la actual ubicación de las áreas protegidas SNASPE a mayores altitudes. La misma situación puede ocurrir con los árboles codominantes endémicos del centro-sur de Chile, que requieren una alta disponibilidad hídrica, como *Laurelia sempervirens* y *Persea lingue*. Se espera que estas especies disminuyan su distribución septentrional y de bajas altitudes, en las cuales se proyecta que disminuya la precipitación durante la temporada de crecimiento y es coincidente con áreas donde las áreas protegidas SNASPE son escasas o no existen. Además, se espera que estas especies mantengan su distribución meridional o se expandan hacia áreas cercanas a sus extremos de distribución sur, donde proporcionalmente se localizan más áreas protegidas pertenecientes al SNASPE.

Se espera que los helechos del sotobosque presenten una respuesta diferente de los otros dos grupos anteriormente mencionados: 90.9% de las especies de helechos proyectan una expansión del tamaño de sus hábitats, pero sólo 63.6% de ellos muy probablemente aumentará su nivel de representación SNASPE. Sin embargo, la diferencia más notable se observa en los helechos epífitos; 88.9 de ellos se espera que aumenten su área de distribución, pero sólo 44.4% de ellos podrían expandir su proporción de representación en SNASPE. Esto probablemente esté relacionado al hecho que las unidades de SNASPE están geográficamente sesgadas hacia una mayor altitud, mientras que una proporción importante de las especies de helechos epífitos están propensas a expandirse hacia bosques de altitudes menores que están escasamente incluidas en SNASPE. Esto último implica que la ubicación de las reservas de SNASPE continuará siendo útil en el futuro, excepto para un tercio (29.7%) del total de las especies estudiadas, para las cuales las nuevas áreas colonizables no coincidirán con las áreas protegidas SNASPE, o bien se trata de algunos hábitats actualmente protegidos por SNASPE que en el futuro puedan no ser climáticamente apropiados para esas especies en el futuro. Entre estas especies, se puede mencionar un conjunto de helechos terrestres de distribución más asociada a transición hacia clima mediterráneo de Chile central, tales como *Cheilanthes hypoleuca*, *Dennstaedtia glauca*, *Pteris chilensis* y *Thelypteris argentina*, cuya representación futura se espera disminuya debido a que sólo las pocas unidades SNASPE existen en Chile central pueden en el futuro no ser útiles para la conservación de esas especies luego de cambio climático.

Algunas otras especies de helechos terrestres que presenten amplias distribuciones de sus hábitats tales como *Blechnum magellanicum* y *Lycopodium magellanicum* se espera que presenten una expansión de su distribución hacia zonas no incluidas en SNASPE, resultando en una disminución de sus valores de representación futura. Otros casos como *Elaphoglossum porteri* o *Elaphoglossum gayanum* que tienen áreas de distribución presentes muy pequeñas y que prevén disminución en sus niveles de representación, podrían deberse al hecho que sus distribuciones actuales se hallan mayormente dentro de unidades SNASPE, y en el futuro podrían expandir sus pocas poblaciones hacia otras zonas fuera de las áreas SNASPE. Los nichos ecológicos de ambos grupos de helechos tanto terrestres como epífitos resultaron más heterogéneos, comparados con aquellos de los árboles dominantes con los cuales comparten distribución, también con una respuesta diferencial en los cambios del tamaño de hábitat, por lo tanto también una respuesta diferente en los niveles de representación en las áreas del SNASPE.

La ubicación actual de los parques y reservas pertenecientes a SNASPE asegura suficiente protección para mantener el mismo número de especies de árboles de *Nothofagus* y helechos epífitos. De esta forma, la localización actual de las áreas protegidas de SNASPE aunque insuficiente para el total de las especies, es importante para la representatividad actual y este papel continuará siendo importante luego que las especies de estos bosques templados enfrenten los efectos del cambio climático en el futuro. Esto sugiere que cualquier alteración a las unidades de SNASPE, tales como desafectación o reducción de sus superficies para una explotación productiva o ya sea cambios en sus principales funciones, hacia objetivos que no sean la preservación de la representación de los hábitats de las especies, deberían por lo tanto desaconsejarse desde el punto de vista de las políticas de manejo de los recursos biológicos hacia sobrellevar los efectos de cambio climático. Aún más, el actual rol de SNASPE en la conservación de biodiversidad en el largo plazo, no está completamente asegurado aún ya que no se han completado todos los planes de manejo para estas unidades. En años recientes, ha habido un debate sobre la redefinición de los objetivos principales del sistema de áreas protegidas SNASPE y el gobierno ha incluido al turismo como uno de los objetivos principales, lo que ha permitido la construcción de infraestructura *ad hoc* en territorio que antes era completamente preservado. Por otro lado, la restricción del manejo de ganado de comunidades aledañas a estas unidades, el control de especies invasoras y la definición de límites en el número máximo de visitantes por unidades de áreas protegidas se encuentran entre los desafíos que deben lograrse para poder asegurar el rol de conservación de largo plazo de las áreas SNASPE.

Representación de los hábitats bajo otros esquemas propuestos de conservación y cambios esperados producto del cambio climático

Esta tesis ha abordado las opciones de áreas de protección privada (PPA), que pese a que aún formalizadas por ley, podrían constituir con su adicionalidad en superficie a mejorar y alcanzar niveles relevantes de representación al complementar el SNASPE. Los resultados de esta tesis mostraron que tendrían un efecto complementario muy positivo al sistema de áreas de SNASPE, ya que PPA añadiría hábitats bajo conservación formal para un 97.5% de las especies evaluadas, aumentando conservación adicional para un 73.7% de las especies estudiadas en el escenario futuro analizado. Cuando se consideraron umbrales de representación mínima, las unidades de PPA mostraron una ayuda efectiva para el 16.1% de las especies estudiadas en poder alcanzar niveles de representación adecuada, para ambos umbrales del presente escenario. Más aún, las unidades PPA podrían servir a la representatividad de la conservación a un 16.9% de estas especies si se considera el umbral de 17% ante el escenario de clima futuro. Los efectos positivos de incluir las áreas PPA son más importantes aún para las especies de helechos del sotobosque que para los árboles dominantes debido a la distribución de las unidades PPA es complementaria a las áreas SNASPE hacia menores altitudes, donde algunos helechos del sotobosque podrían tender a expandir su distribución en el futuro de acuerdo al escenario de clima futuro. Ya que las reservas SNASPE se ubican desigualmente a lo largo del territorio de Chile, proporcionalmente con una mayor distribución hacia las áreas más meridionales y mayores altitudes, las PPA se pueden ajustar espacialmente como un complemento importante para las áreas SNASPE, de la misma forma en la que se ha encontrado evidencia por otras evaluaciones de reservas de tipo privado (Jackson & Gaston, 2008; Gallo *et al*., 2009).

Tal como se propone como nuevas áreas protegidas bajo la estrategia nacional de biodiversidad de Chile (CONAMA, 2005), una eventual implementación de los sitios prioritarios para biodiversidad de alcance nacional (SBN) virtualmente completan las necesidades suplementarias para alcanzar una representación mínima para la mayoría de las especies estudiadas luego de considerar SNASPE y PPA, tanto para el escenario presente como futuro con un umbral de 10%, apoyando de esta manera la aceptación de la hipótesis 4 de esta tesis. El efecto de incluir los sitios prioritarios de alcance de las regiones administrativas de Chile (SBR) resultó importante para lograr niveles satisfactorios de representación de las especies al aplicar el umbral de representación más restrictivo. Esto contrasta con el hecho que la política ambiental de Chile recientemente ha considerado la mayoría de estas áreas SBR como de menor prioridad para ser implementadas como reservas, debido a que ellos son territorios de propiedad privada. Si se aplicase el umbral propuesto por la Cumbre de Nagoya (*i.e*. 17%), aún habría un grupo de especies compuesto por los árboles *Nothofagus alessandrii* y *Blepharocalyx cruckshanksii*, los helechos terrestres *Pteris chilensis*, *Cheilanthes mollis* y *Pellaea ternifolia* y el helecho epífito *Hymenophyllum tumbridgense*, que no podrían lograr una representación mínima con las áreas SNASPE, PPA, SBN y SBR combinadas; la mayoría de ellas distribuyen sus hábitats hacia zonas transicionales de clima templado hacia clima mediterráneo, con escasa representación bajo los esquemas de conservación, asociado además a una alta tasa de reemplazo debido a uso antrópico de la tierra. Si se implementasen las áreas SBN y SBR, sería prudente incluir porciones de áreas de hábitats de estas especies en las reservas propuestas de igual manera.

Aún cuando se espera que el cambio climático afecte los hábitats de las especies de plantas evaluadas de estos importantes bosques templados, la ubicación actual de las unidades de conservación determinan que no habrá cambios significativos en términos de número de especies con una representación mínima para el escenario futuro evaluado. El análisis de los efectos del cambio climático sobre el tamaño de los hábitats y su representación en áreas protegidas, que consideren sólo los árboles dominantes como una base, puede no ser aplicable a otros grupos de especies asociadas, como ha sido en este caso para las especies de plantas que incluyen el sotobosque.

CONCLUSIONES GENERALES

A través del análisis OMI se pudo discernir exitosamente los nichos ecológicos de plantas del centro y sur de Chile que comparten comunidades de bosques templados sudamericanos, distribuidas en dos dimensiones bioclimáticas: una delineada por el rango de temperatura media y estacionalidad de la precipitación que se presenta en una transición de bioclimas mediterráneo-templado-subantártico y la segunda comprendida por la temperatura mínima del mes más frío en una transición desde ambientes con influencia oceánica hacia el *treeline* andino y umbral patagónico.

Las variables bioclimáticas claves para los nichos variaron según grupo de especies: la temperatura máxima del mes más cálido para los *Nothofagus* dominantes, la estacionalidad de la precipitación para las especies codominantes, precipitación anual para los helechos terrestres y ambas extremas de temperatura máxima del mes más cálido y la temperatura mínima del mes más frío, para los helechos epífitos. Se sugiere que estas diferencias encontradas podrían deberse a rasgos específico morfológicos o fisiológicos.

Los desplazamientos altitudinales y latitudinales en respuesta al cambio climático para las especies del sotobosque no pueden asumirse que con la misma dirección o magnitud que los árboles que dominan estos bosques templados. La mayoría de los árboles dominantes y codominantes presentaron desplazamientos esperados hacia mayor altitud y latitud, mientras que los grupos de helechos se proyecta tendrán respuestas más diversas en dirección, relacionadas a diferencias en características del nicho. La magnitud de los desplazamientos difirió entre grupos de especies también, combinando la segregación del nicho en las dimensiones ambientales, de manera que los árboles mostraron mayores desplazamientos esperados en el gradiente de elevación que los helechos, mientras que los helechos mostraron mayores desplazamientos esperados que los árboles en el gradiente de latitud, siguiendo diferentes forzantes de nicho climático.

Los cambios altitudinales esperados sugirieron estar inversamente relacionados a la amplitud de nicho tal como la literatura ha planteado. La variación latitudinal de la amplitud de nicho de las especies estudiadas, siguió el efecto Rapoport, y junto con la expresión desigual de proyección de cambio climático en la distribución completa de los bosques templados sudamericanos, puede explicar el hecho que los cambios latitudinales mostraran una relación directa con la amplitud de nicho, en contra de lo esperado según literatura.

Los hábitats de especies de plantas de los bosques templados de Sudamérica se encuentran insuficientemente representados en SNASPE. No obstante, pese a que la mayoría de las especies de árboles modelados se espera que disminuyan su tamaño de hábitat por efecto de cambio climático, se espera al mismo tiempo aumenten su representación en SNASPE. Por otro lado, la mayoría de las plantas de sotobosque se espera aumenten tanto sus tamaño de hábitat como su nivel de representación en el SNASPE. A diferencia de análisis hechos en otros países en los que la eficiencia de conservación de las áreas disminuye con el cambio climático, esta tesis indicó que el SNASPE está localizado espacialmente correspondiente a áreas propensas a mantenerse o expandirse como hábitats útiles para la mayoría de las especies estudiadas, ante cambio climático, lo que destaca la necesidad de fortalecer y no afectar estas áreas.

Los hábitats de especies de plantas estudiadas pueden complementar una suficiente representación en áreas protegidas al incorporar reservas privadas PPA y sitios prioritarios SBN ayudando al SNASPE a lograr una representación mínima de la mayoría de las especies de plantas estudiadas. Esta representación complementada se mantiene o incluso aumenta ante cambio climático para muchas de las especies estudiadas tanto en el presente como en el escenario de cambio climático futuro cuando se considera el umbral mínimo de 10%. Si se tomara en cuenta un umbral de 17%, sería esencial el considerar una implementación agregada de los sitios prioritarios a escala regional SBR.

Las evaluaciones de efectos de cambio climático debieran llevarse a cabo a nivel de especies y es importante no asumir que los efectos esperados sobre las especies de árboles dominantes son necesariamente aplicables a las especies de sotobosque y el empleo de restricciones de dispersión a la migración debieran incluirse siempre para modelar distribuciones futuras más realistas.

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