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A study of the geographic distribution of swamp forest in the coastal zone of the Araucanía Region, Chile

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A B S T R A C T

A study was made of the geographic distribution of swamp forest in the coastal territory of the Araucanía Region, Chile. An analysis of maps, aerial photographs, and satellite images was carried out, together with field work, to determine the location, degree of fragmentation, shape of fragments and habitat use of the forest. The results showed a total area of 7675 ha of forest (in a region of 165,168 ha) divided into 427 fragments of highly irregular shapes, set in a farming matrix. This forest type was located principally on alluvial (37%) and fluvial-marine (33%) plains associated with the Toltén and Queule river basins. Land unsuitable for agriculture accounted for 50% of the area of forest (CIREN Classes VII and VIII), while land with a superficial phreatic water table (0–20 cm depth) and poorly drained soils concentrated 47% and 66% of the forest respectively. The majority of the forested area stands on soils with poor drainage (available habitat), as a response to the greater biophysical restrictions which such areas represent for agriculture. Of the forested area, 59% was located on 859 properties belonging to small-holders with up to 200 ha, while 39% was located on 58 medium to large properties (over 200 ha and over 1000 ha respectively). Forty percent of the forest is within 300 m of a road and only 8% is more than 1000 m away. It is concluded that the forest is under severe pressure from human activity (by clearing for agricultural land, grazing and firewood extraction) and that there is an urgent need for a plan giving priority to conservation.

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Introduction

Swamp forest dominated by species in the family Myrtaceae is widely distributed in Chile between 30°S (Coquimbo) and 41° 28′S (Puerto Montt), forming a transition from the semi-arid to the wet temperate climate, and representing one of the ecosystems with the widest geographic and climatic distribution in Chile (Armesto, Arroyo, & Hinojosa, 2007; Maldonado & Villagrán, 2001; Ramírez, Ferriere, & Figueroa, 1983; San Martín, 2005). In the north it is limited to the coastal regions, while in the centre and south of the country the patches are distributed both along the coast and in the central valley, and less frequently on the Andean precordillera. The location of the patches is determined by the presence of springs or areas where there is a superficial phreatic water table, and the type of soil therefore does not appear to be a determining factor in its development. For this reason these forests are described as azonal hygrophilous formations, i.e., their presence is not determined by the regional climate but by an excess of humidity in the soil (e.g., Amigo & Ramírez, 1998; Maldonado & Villagrán, 2001; Ramírez et al., 1983; Ramírez, San Martín, & San Martín, 1996).

In the extreme north of their range these ecosystems are dominated by *Luma chequen*, *Drimys winteri* and *Escallonia revoluta* (Maldonado & Villagrán, 2001, 2002). Further south, in the Coastal Range of central Chile, the forests are composed principally of *Drimys winteri*, *Blepharocalix cruckshanksii* and *Myrceugenia exsucca*, which differ from the typical formations of *Nothofagus glauca* (San Martín, Troncoso, Ramírez, 1988). In the southern part of its range the forest is characterized by the presence of *Myrceugenia exsucca* and *Blepharocalix cruckshanksii*, with *Drimys winteri* as an accompanying species; in this zone the swamp forest is inserted in the

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distribution range of the ancient roble-laurel and lingue forest (*Nothofagus oblicua* - *Laurelia sempervirens* and *Persea lingue*) (Ramírez et al., 1983, San Martín, Ramírez, Figueroa, & Ojeda, 1991).

Swamp forest is a particular type of wetland, classified by the Ramsar Convention as "freshwater, tree-dominated wetlands" in category (Xf) (Ramsar Convention Secretariat, 2006). These ecosystems maintain a rich diversity of species and also contribute to regulate river flows, thus helping to slow erosion processes and control floods (Hauenstein, González, Peña-Cortés, & Muñoz-Pedreros, 2002, 2005; Ramírez et al., 1983; Richardson, 1994). Wetland areas have been recognised internationally for their high biological and environmental value, and as providers of ecosystem services. In Chile there is a Wetlands Protection Policy expressed in the National Wetlands Strategy and the National Biodiversity Strategy (CONAMA, 2003, 2005). At the same time there are financial incentives through Decree Law 701 (on forestry development, 1974) and Law 18.450 (to encourage private investment in irrigation and drainage works, 1985) which permit the execution of drainage projects to increase the area suitable for agriculture or forestation, representing a serious threat to these ecosystems (Ojeda, 1998; Ramírez et al., 1996; Peña-Cortés, Gutiérrez et al., 2006).

Swamp forests have often been threatened by the destruction of their habitat by clearing for agricultural land, grazing and firewood extraction. These, leave remnant patches following human land conversion activities due to the fact that swamp forests occupy land of lower agricultural value (Ramírez et al., 1983, 1996; San Martín et al., 1988; Squeo, Arancio, & Cavieres, 2001). In their central and southern range, the expansion of forestry plantations, tree-felling and the introduction of alien species are practices which alter these ecosystems, modifying the natural succession process and preventing regeneration (Ramírez et al., 1983, 1996; Hauenstein et al., 2002, 2005).

One of the geographic zones with the greatest diversity of wetlands in Chile is the coast of the Araucanía Region. It is a territory which is essentially agricultural, where farm and forest owners co-exist with numerous Mapuche indian communities in an area characterized by a high level of property division and high indices of poverty and rural habitation. Historically, this territory has experienced high levels of anthropogenic activity, resulting in soil erosion, the deterioration of natural resources and the alteration of the ecological landscape (Peña-Cortés et al., 2008; Peña-Cortés, Escalona-Ulloa, Rebolledo, Pincheira-Ulbrich, Torres-Álvarez, 2009; Peña-Cortés, Gutiérrez et al., 2006; Peña-Cortés, Rebolledo et al., 2006). Under these circumstances, the original evergreen forest proper to the coastal zone has been significantly modified by human action, initially by the early colonists who cleared land for crop and livestock farming by burning and subsequently by the forestry industry (sawmills) (Bengoa, 1990, 1991; Torrejón & Cisternas, 2002; Peña-Cortés et al., 2009). Today the evergreen forest is being altered and replaced by agroforestry use, leading to their distribution in small fragments of secondary forest and a few remnants of the original forest (Peña-Cortés et al., 2009; Peña-Cortés, Rebolledo et al., 2006). The local name for swamp forest in the Mapuche language is "Menoko" and this type of wetland is highly valued by the Mapuche people since it is an important source of medicinal plants and a protection for springs and watercourses (Catriquir & Durán, 2005; Durán, Quidel, & Hauenstein, 1997; Peña-Cortés et al., 2004).

Given the cultural and environmental importance of these swamp forests, the object of this study is to analyse their geographic distribution and relation to environmental and anthropogenic factors in the coastal zone of the Araucanía Region. To do this the study will address four questions: (1) What are the size and shape of the fragments of forest? (2) Are forest fragments concentrated in particular environmental units? (3) Is the distribution of the forest proportional to the habitat available? And (4) What is the degree of anthropogenic pressure on the forest? The answers to these questions will serve as a guide for the conservation of these ecosystems.

Materials and methods

Study area

The study area forms part of the coastal zone of the Araucanía Region in Chile located between 38° 30′ and 39° 30′ South and 72° 45′ and 73° 30′ West. The climate is oceanic with mediterranean influence (Di Castri & Hajek, 1976), with average annual precipitation between 1200 mm and 1600 mm. The territory consists of a landscape transformed both human activity and natural processes (i.e., The 1960 Valdivia earthquake). The geomorphology varies from mountain ranges to marine abrasion platforms and extensive fluvial-marine plains, where various types of wetlands can be found (Peña-Cortés, Gutiérrez et al., 2006; Peña-Cortés, Rebolledo et al., 2006).

Basic information and map processing

The basic cartographic reference information was obtained from the Geographic Military Institute of Chile (Instituto Geográfico Militar de Chile – IGM, 1968) updated to 2000. This material was complemented by the digital cartographic base of the Territorial Planning Laboratory of the Catholic University of Temuco (LPT-UCT) and the register of vegetation resources of Chile (CONAF-CONAMA-BIRF, 2007). The swamp forest cover and the geomorphology were identified and quantified by interpretation of aerial photographs and satellite images (Table 1).

The aerial photographs were geo-referenced with the PCI Geomatics v8.2 Orthoengine module. A Thin Plate Spline technique was used to perform an image to image rectification with the Landsat image as the base image. The same software was used to construct the ortho-photomosaics for digitization of the subject layers. The identified swamp forest fragments were verified in field from 2007 to 2009.

The processing and spatial analysis of the fragments of forest were carried out using ArcGis 9.3 software (Esri, 2008) with its Image Analyst, Spatial Analyst and Patch Analyst extensions, as well as the Hawth's Tools extension (Beyer, 2004). The sizes of the fragments were measured using the Xtool Pro extension (DeLaune, 2000).

The land use capacity, drainage and depth of the phreatic water table were obtained from digitized information provided in the CIREN (2002) agro-ecological study. Information on property divisions was prepared based on the CIREN Ortho-photomosaics, maps provided by the National Corporation of Indigenous Development (Corporación Nacional de Desarrollo Indígena – CONADI) and information from the National Tax Service (Servicio de Impuestos Internos – SII). The road network was updated with GPS mapping equipment, based on the digital maps of IGM and the Ministry of Public Works (Ministerio de Obras Publicas – MOP) updated to 2009.

Size and shape of forest fragments

The shapes of the fragments of swamp forest were quantified using Patton's diversity index (1975), which varies between one (a perfect circle) and infinity (non Euclidean shapes). This index was classified into five shape range classes following Henao (1988): round (<1.25), round oval (1.25–1.5), oblong oval (1.5–1.7), oblong rectangular (1.7–2) and amorphous (>2) (e.g., Rau & Gantz, 2001, Pincheira-Ulbrich, Rau, & Peña-Cortés, 2009). Subsequently, the

Table 1
Cartographic material consulted.

Type of data	Resolution/scale	Source of data	Purpose
Topographical maps	1:25,000 and 1:50,000	Military Geographical Institute (Chile), date 1968.	Cartographic reference information.
Digital cartographic base	1:20,000	Territorial Planning Laboratory of the Catholic University of Temuco (LPT-UCT), date 2006–2009.	Cartographic reference information and road network.
Vegetation resources of Chile	1:20,000	CONAF-CONAMA-BIRF (2007)	Land use cover.
Aerial photographs	1:20,000	Project 1030861 (FONDECYT), date 2004.	Swamp forest cover and geomorphology.
Orthorectified LANDSAT7 ETM + image	Pixel: 30 × 30m	Ministry of Housing and Urbanization (Chile), date 2003.	Geo-referencing and spatial adjustment.
ASTER image, 3 scenes level 1B	Pixel: 15 × 15m	Acquired from the National Aeronautics and Space Administration (Nasa), date 2004.	Swamp forest cover.
Digital cartographic layer	1:20,000	Agro-ecological study (CIREN 2002).	Land use capacity class, drainage and depth of the phreatic water table.
Digital cartographic layer	1:50,000	National Corporation of Indigenous Development (Chile), date 2003 and National Tax Service (Chile), date 2003.	Property divisions.
Digital cartographic layer	1:50,000	Ministry of Public Works (Chile), date 2009.	Road network.

degree of association between the shape and the size of the fragment was evaluated by calculating Pearson product-moment correlation coefficient (r) between the area of the fragment (ha) and Patton's diversity index (1975) with a statistical significance of 5%. Both variables were transformed by logarithm (log 10) to produce a dataset close to normal distribution. Finally, to determine the differences in the distribution of fragment sizes (ha) among the five classes defined by Henao (1988), the Kruskal–Wallis non-parametric test was applied with 5% statistical significance (Siegel & Castellan, 1988). If Kruskal–Wallis test produced significant differences, Dunn's multiple comparison test was applied *a posteriori* to determine where the difference occurs with 5% statistical significance. The statistical analyses were performed using the software SigmaPlot 9.01™ with the SigmaStat™ module.

Location and fragmentation of swamp forest

The distribution of the swamp forest was characterized on the basis of four spatial location attributes: geomorphology, land use capacity, drainage, and depth of phreatic water table. The geomorphology was ordered in erosion and accumulation relief by hierarchy (mountain ranges, platforms, terraces and plains) (Peña-Cortés & Mardones, 1999). Those geomorphologic units which presented swamp forest on less than 1% of their area were grouped as unclassified areas. Land use capacity in the coastal zone consists of six classes, according to the nomenclature used by CIREN (2002): class II, class III, class IV, class VI, class VII and class VIII. This classification orders land from suitable for crops (class II) to land of no agricultural value (class VIII). Land drainage was classified into three groups by CIREN (2002): land with poor drainage (drainage class 1 and 2), land with moderate drainage (drainage class 3 and 4) and well-drained or over-drained land (drainage class 5 and 6). Finally, the depth of the phreatic water table was classified in three categories by CIREN (2002): land with a superficial phreatic water table (<20 cm), land with the phreatic water table at a depth of 20–50 cm, and land with the phreatic water table at a depth greater than 50 cm.

To determine which geographic units contain forest with the greatest fragmentation (i.e., number of patches as a result of natural and human causes), the size of the fragments (ha) was compared within the four spatial location attributes. To do this, the individual fragments located in a single unit of analysis (e.g., alluvial plain) were selected. When the fragment overlapped more than one unit of analysis (e.g., platforms and terraces), it was included only if more than 60% of its area fell into one of the units, in which case its whole area was attributed to that unit.

To test for significant differences between the distribution of fragments sizes (ha) among the units contained within the four categories (geomorphology, land use capacity, drainage, and depth of phreatic water table), the Kruskal–Wallis non-parametric test with 5% statistical significance was calculated (Siegel & Castellan, 1988). If Kruskal–Wallis test produced significant differences, Dunn's multiple comparison test was applied *a posteriori* to determine where the difference occurs with 5% statistical significance. The statistical analyses were performed using the software SigmaPlot 9.01™ with the SigmaStat™ module.

Habitat use

Swamp forest is distributed mainly on land with excess humidity, which is the principal factor determining its distribution (e.g., Maldonado & Villagrán 2001; Ramírez et al. 1983; San Martín et al. 1988). However, other wetlands may occur in these same sites (i.e. marshes), but this depends on the state of ecological succession, the natural processes (i.e. The 1960 Valdivia earthquake), and the effect of human activity which transforms the swamp forest into marshes or anthropogenic prairie for crops and animal grazing (Ramírez et al., 1996). According to this, it is of interest to evaluate whether the forest is distributed proportionally to the habitat available or if there is evidence which demonstrates a differential proportion (positive or negative selectivity for a type of substrate). To do this, the available habitat was taken to be the land with poor drainage in the geomorphologic units identified. Then, to determine the difference between the proportion of habitat available and the proportion of habitat actually "used" by the forest, a chi-square goodness of fit test (X^2) was done (Siegel & Castellan, 1988). If this produces significant differences, Bonferroni's test was applied *a posteriori* to determine in which geomorphologic units these differences arose. Thus the results may indicate: positive selectivity (proportion of forest statistically greater than habitat available), negative selectivity (proportion of forest statistically less than habitat available) and no significant selectivity (proportion of forest not statistically different from habitat available) (e.g., Neu, Byers, & Peek, 1974). These tests were done using the Habuse software (Byers, Steinhorst, & Krausman, 1984) with 5% statistical significance.

Anthropogenic pressure on the forest

Anthropogenic pressure on the forest was characterized by the construction of maps considering two factors: distance of the forest from the road network, and property division (size of property). Assuming that the pressure of use on the forest diminishes with the distance from the nearest road (Altamirano & Lara, 2010; Pauchard & Alaback, 2004), the first analysis consisted of a quantification of the area of forest (ha) located in five distance classes from the road network: 0–50 m, 50–100 m, 100–300 m, 300–700 m, 700–1000 m and >1000 m. Then assuming that the pressure of use on the forest diminishes as the size of the property in which it is located increases, a second analysis was done to quantify the area of swamp forest in eight ranges of property size: 0–10 ha, 10–30 ha, 30–70 ha, 70–100 ha, 100–200 ha, 200–500 ha, 500–1000 ha and >1000 ha. Both analyses were done using the Spatial Analyst module of ArcGis 9.3.1 software. To complement this analysis, the continuous area of swamp forest and anthropogenic pressure factors was related.

Results

Size and shape of forest fragments

In the coastal zone of the Araucanía Region 427 fragments of swamp forest were identified, with sizes varying between 0.25 ha and 936 ha. Together the fragments represented an area of 7675 ha, equivalent to approximately 4.6% of the territory evaluated (in a region of 165,168 ha). Seventy-five percent of the fragments were smaller than 10.7 ha, while just 43 fragments accounted for 66.8% of the total area of swamp forest (Fig. 2a).

The Pearson product-moment correlation coefficient (r) between the area and shape of forest patches showed a positive association (Fig. 1b, $r = 0.65$, $p < 0.01$). This implies a tendency for the complexity of the shape to increase with the size of the fragment. Findings also showed that small fragments (<20 ha) had a greater variability of shape, from almost circular to very irregular, while larger fragments did not present Euclidean shapes but tended towards shapes which were clearly more irregular or amorphous (Fig. 2b–d).

According to Henao's shape classification (1988), the general shape of the fragments was very irregular, with 54.1% of the fragments ordered in the highest range of this classification (amorphous = 5), while only 10% were classified as round (class 1) (Fig. 1c). This last group of fragments, with a tendency to circular shape, amounted in total to only some 2% of the total area of swamp forest (Fig. 1a and d). The analysis of the distribution of the fragment sizes in the five ranges defined by Henao (1975) showed a clear difference (Kruskal–Wallis, $p < 0.01$). Dunn's multiple comparison produced significant differences between the fragment sizes grouped in the most irregular shape class (amorphous = 5) and the other six combinations of less irregular shapes ($p < 0.05$; Table 2). This allows us to state that the amorphous fragments are larger than the fragments tending towards Euclidean shapes, implying that the former present more irregular edges and are therefore highly susceptible to degradation by physical and biological agents.

Location and fragmentation of swamp forest

The swamp forest was located for the most part on alluvial (37%) and fluvial-marine (33%) plains, associated principally with the Toltén and Queule river basins, in a farming matrix. It was also

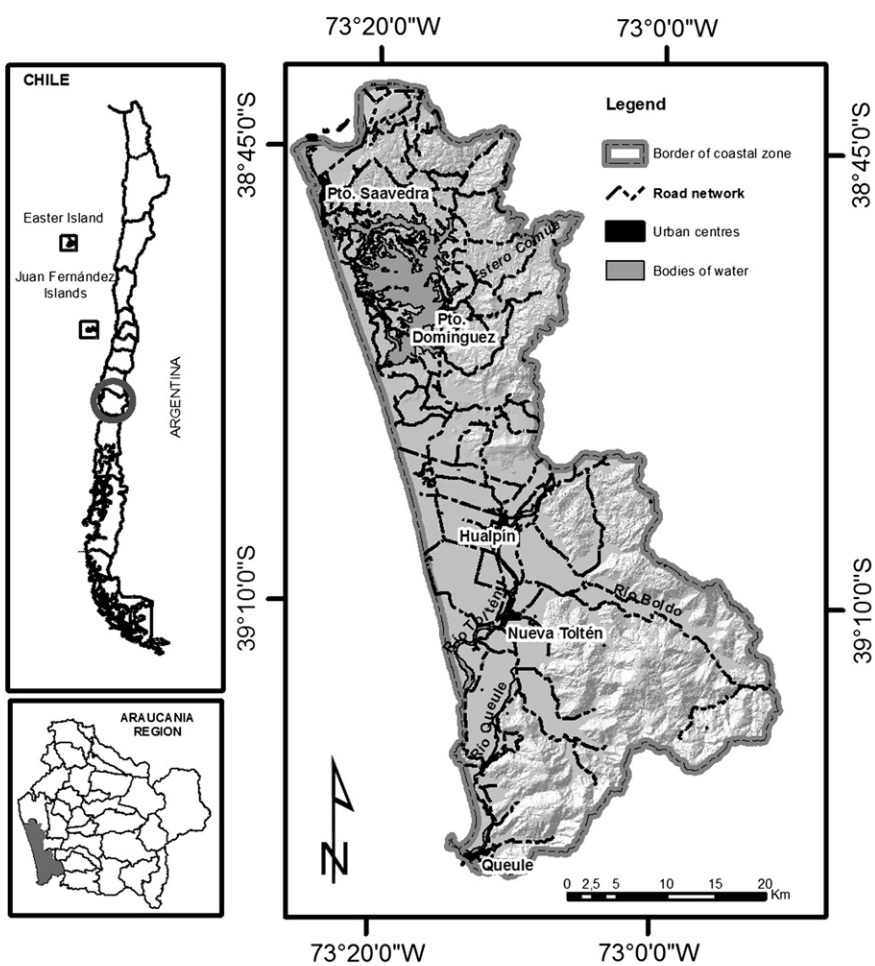

Fig. 1. Map of the location of the study area in the coastal zone of the Araucanía Region.

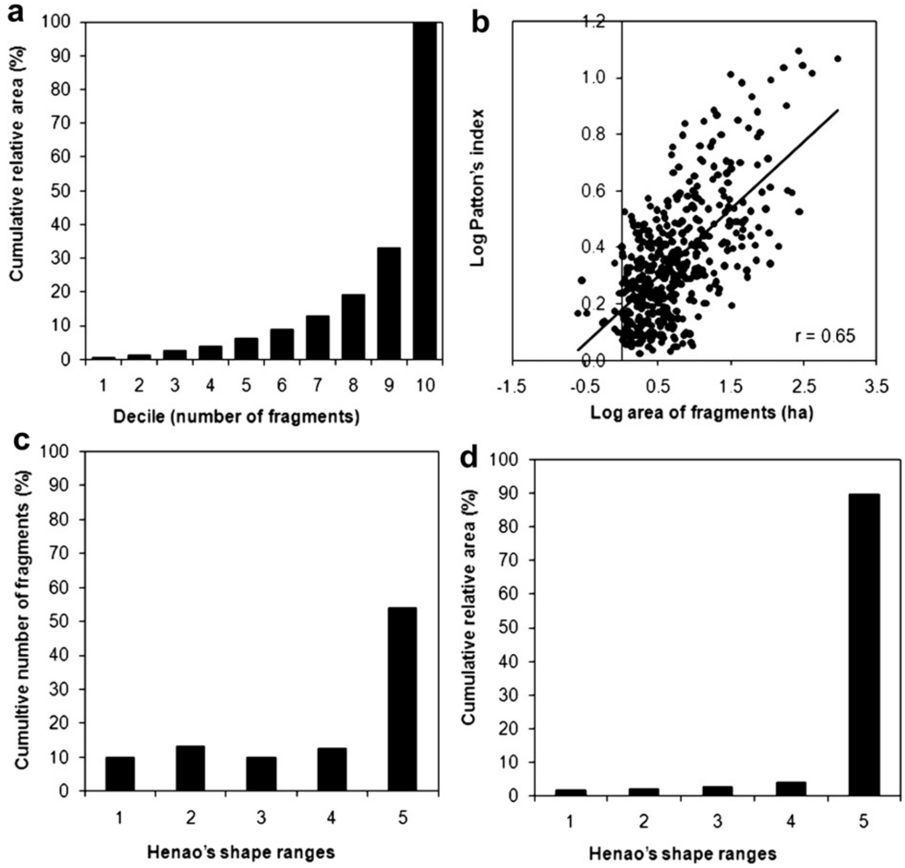

Fig. 2. General parameters of size and shape for fragments in the coastal zone of the Araucanía Region. a. cumulative distribution of number of fragments v/s relative cumulative area, b. Pearson product-moment correlation coefficient (r) between the size and shape of the fragments ($p < 0.01$), c. distribution of the number of fragments according to Henao's shape classes (1988), d. area of fragments according to Henao's shape classes. 1 = round, 2 = round oval, 3 = oblong oval, 4 = oblong rectangular and 5 = amorphous.

found to a lesser extent in the centre-north of the study area (Budi Lake) in interfluvial or low-lying areas in metamorphic rock platforms (12%) and marine abrasion platforms (8%) in a farming matrix but with less intervention and the presence of secondary forest; the remaining area of swamp forest (12%) was found in other geographic units, such as terraces (5%) and flood plains (1%). According to the land use capacity, 50% of the swamp forest occurs in classes VII and VIII, representing severe restrictions for agriculture, in territory located in the area of influence of Budi Lake and along the courses and mouths of the Toltén and Queule rivers. The other 50% of the forest was distributed in land with use capacity classes II, III, IV and VI in proportions varying between 11 and 14%,

Table 2
Results of the multiple comparison test between the distribution of fragment sizes by shape class (Henao, 1988).

Multiple comparisons			
Henao	Dunn (p)	Henao	Dunn (p)
1–2	n.s.	2–4	n.s.
1–3	n.s.	2–5	<0.05
1–4	n.s.	3–4	n.s.
1–5	<0.05	3–5	<0.05
2–3	n.s.	4–5	<0.05

Dunn = *a posteriori* test (Kruskal–Wallis).
1 = round, 2 = round oval, 3 = oblong oval, 4 = oblong rectangular and 5 = amorphous.

mainly in the area located between the southern limit of Budi Lake and the Toltén river basin.

According to depth of the phreatic water table, 47% of the forest was on land with a surface table (0–20 cm), while 7% and 20% was found on land with water table at depths of 20–50 cm and greater than 50 cm respectively. The intermediate class of 20–50 cm water table depth appears to be scarce; however, it must be considered that exact information is available for only 2000 ha (26% of the forest). In this respect, the information available indicates that the sites where the water table lies deepest, are located in areas associated with the Toltén and Queule rivers, while the parts with poor drainage are associated with the Queule river basin. Finally, the classification criterion which concentrated the greatest area of swamp forest was land drainage, with 66% of the forest being found on poorly drained land, while 15% and 19% were found on land with moderate and good drainage respectively. Land with poor and moderate drainage is found principally associated with the Toltén and Queule river basins and includes part of Mahuidanche (the eastern slope of the Coastal Range), which is a priority conservation site (Muñoz, Núñez, & Yáñez, 1996). The well-drained land is found principally in the area of influence of Budi Lake and the northern part of the coastal zone. The forest on this land represents edge habitats associated with superficial phreatic water table land and watercourses (Table 3; Fig. 3).

The distribution of fragment sizes between the geomorphologic units showed no significant differences (Kruskal–Wallis, $p = 0.881$). Likewise no significant differences were found between the sizes of fragments located in the six categories of land use capacity (II, III, IV, VI, VII and VIII) (Kruskal–Wallis, $p = 0.085$), nor between the three classes of phreatic water table depth (<20 cm, between 20 and 50 cm, >50 cm) (Kruskal–Wallis, $p = 0.115$). However, significant differences were found in land with different drainage categories (Kruskal–Wallis, $p < 0.01$). Thus forest located on poorly drained land presented a size distribution which differed from that in areas with moderate and good drainage (Dunn; $p < 0.05$). These results would indicate that swamp forests located on land with poor drainage are less fragmented (larger average patch size) than those located on land with better drainage (smaller average patch size) (Table 3, Fig. 3).

Habitat use

The analysis of habitat use only considered forest on poorly drained land (5046 ha) in relation to the overall of poorly drained land in geomorphologic units identified for the coastal zone (24,422 ha). This testing showed that the distribution of swamp forest was not proportional to the availability of this type of land or habitat ($X^2 < 0.01$). Thus, swamp forest was found in a greater than expected proportion (positive selectivity, $P < 0.05$) on alluvial plains and low-lying and interfluvial areas in marine abrasion platforms. This may be explained by the fact that the marine abrasion platform makes up the valley floors where less anthropogenic pressure has been exercised on the forest (e.g., Mahuidanche), while the forest on alluvial plains occurs on class VIII land with less demand for agricultural use.

On the other hand, there are units where the distribution of forests is less than expected (negative selectivity; $P < 0.05$), for example in fluvial-marine plains, flood plains, dunes, mountain range and metamorphic rock platform. In the case of the extensive fluvial-marine plain, this may be attributed to the pressure of use for firewood extraction and land clearance for agricultural use. The same has occurred on the flood plain; however, this latter unit is scarce, being found only in a few parts of the Toltén river system. Meanwhile dunes would not appear to be the most suitable substrate for swamp forest to grow, possibly due to changes in the drainage and the influence of the ocean. Likewise the metamorphic rock platform does not often form part of the watercourses where swamp forest is more frequently found, although it may be that forest was rather more extensive on this unit in the past. Finally, a lower proportion of forest was found in zones bordering the mountain range due to the topography, which does not favour its development (Table 4).

Anthropogenic pressure on the forest

Fifty nine percent of the swamp forest was located on 859 properties belonging to small-holders with up to 200 ha, while 39% was located on 58 medium and large properties (from 200 ha and over 1000 ha respectively), and only the remaining 2% was classified as government-owned land or watercourses (Table 5, Figs. 4 and 5). With respect to the road network, the results showed that only 8% of the forest was more than 1000 m away from the nearest road, 51% was within 100–700 m and the other 40% was less than 300 m from a road (Table 5, Figs. 4 and 5). Fig. 4a and b show that a large part of the forest is distributed over areas with a high degree of property division and very close to roads, especially in the northern part of the coastal zone. As a prime example, to the east of Budi Lake (Puerto Domínguez) there is a large swamp forest (421 ha) along the course of the Comúe stream on properties not larger than 10 ha and surrounded by a dense road network. The larger, more continuous areas occur towards the south, particularly in areas forming part of the sector known as Mahuidanche, on the eastern slope of the Coastal Range (Fig. 4). Part of this forest is located in large properties, far from the road network, and has been recognised by the environmental institutions as a priority site for conservation (Muñoz et al., 1996).

Discussion

In the coastal zone of the Araucanía Region, swamp forests composed of *Blepharocalix cruckshanksii* and *Myrceugenia exsucca* form an important part of the landscape mosaic, and their distribution depends on the presence of humid areas subjected to periodic or permanent flooding (Maldonado & Villagrán, 2002; Ramírez et al., 1983, 1996; Ramírez & San Martín, 2005). The existing extent of these ecosystems occurs principally on alluvial and fluvial-marine plains associated with the Toltén and Queule river basins; however, it is possible that in earlier times they extended to a larger area, since the forest does not now use all the available habitat (poorly drained land) proportionally in several geomorphologic units. In fact, swamp forest was found in a greater than expected proportion on alluvial plains and low-lying and

Table 3
Distribution of swamp forest by geomorphologic units (GU), land use capacity class (LUCC), depth of phreatic water table (DPW) and drainage (D).

GU *	Swamp forest cover			LUCC*	Swamp forest cover			DPW*	Swamp forest cover			D**	Swamp forest cover		
	ha	%	n		ha	%	n	cm	ha	%	n		ha	%	n
Flood plain	77	1	5	II	843	11	57	0–20	3572	47	117	p***	5046	66	195
Dunes	90	1	9	III	1080	14	107	20–50	529	7	23	m	1145	15	123
Mountain range	210	3	11	IV	983	13	46	>50	1557	20	121	a	1423	19	76
Terraces	350	5	25	VI	859	11	29	nc	2017	26	134	nc	61	1	6
Marine abrasion platform	582	8	22	VII	2262	29	66								
Metamorphic rock platform	912	12	50	VIII	1586	21	69								
Fluvial-marine plain	2501	33	182	nc	61	1	6								
Alluvial plain	2836	37	93												
nc	116	2	7												
Total	7675	100	404		7675	100	380		7675	100	395		7675	100	400

n = number of fragments on a single unit of analysis.
p = land with poor drainage, m = land with moderate drainage, a = land with good drainage.
*No significant differences in the distribution of fragments sizes between units of analysis (Kruskal–Wallis, $p > 0.05$).
**Significant differences in the distribution of fragments sizes between units of analysis (Kruskal–Wallis, $p < 0.01$).
***Significant larger-size fragments within the category (Dunn, $p < 0.05$).
nc = non-classified areas.

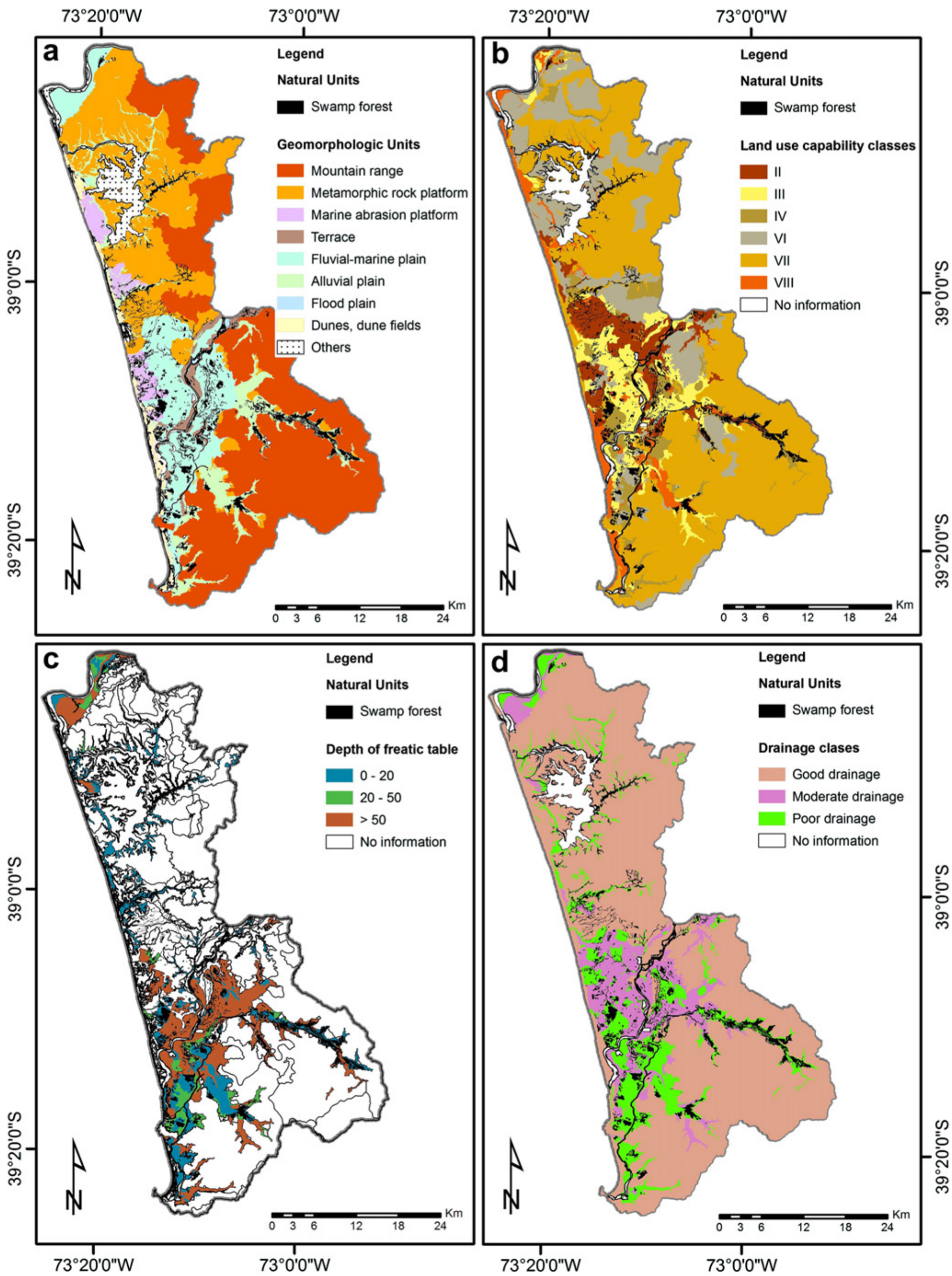

Fig. 3. Geomorphologic units (a), land use capacity classes (b), depth of phreatic water table classes (c) and drainage classes (d).

interfluvial areas in marine abrasion platforms. This is a response to the lesser demand for these types of land for agricultural use (Bengoa, 1990; CIREN, 2002). By contrast there was a lesser proportional distribution of forest on the metamorphic rock platform, which may be attributed to the high pressure of use for firewood extraction and land clearance for agricultural use which transforms the swamp forest into anthropogenic prairie (Bengoa, 1990; Ramírez et al., 1996).

The distribution of this forest has historic foundations in that the relationship of man with this territory goes back to the pre-Colombian Mapuche inhabitants, who used certain clearings and marshes for crops and animal grazing (Torrejón & Cisternas, 2002), while other areas were respected as essential spaces within their cosmovision (Catriquir & Durán, 2005; Durán et al., 1997; Peña-Cortés et al., 2004). As population required more land from the colonial period up until the beginning of the 20th century, the clearance of areas of native forest began to occur, and this situation was aggravated by the purchase of the land between the Toltén and Imperial Rivers (in 1912) where the forest was subjected to intense exploitation, generating major changes in the landscape and serious environmental deterioration (Bengoa, 1990).

The areas presently covered by swamp forest are being drained to obtain land suitable for agriculture and forestry plantations (Hauenstein et al., 2002; Peña-Cortés et al., 2009), and there are even regional policies offering a state subsidy to achieve this end (Ramírez et al., 1996; Ojeda, 1998; Peña-Cortés, Rebolledo et al., 2006). Draining of wetlands was confirmed in the field work, principally in the Toltén river basin, where firewood extraction by

Table 4
Distribution of swamp forest (SF) and analysis of habitat use on land with poor drainage by geomorphologic unit.

Geomorphologic unit	Land with poor drainage		SF expected area (ha)	Habitat proportion*		Confidence intervals**		Habitat selectivity
	Total coastal area (ha)	SF area (ha)		Available	Used	Lower limit	Upper limit	
Flood plain	34	1	7	0.001	0.000	0.000	0.001	−
Dunes	280	30	59	0.012	0.006	0.003	0.009	−
Mountain range	836	38	176	0.035	0.008	0.004	0.011	−
Terraces	823	148	174	0.035	0.030	0.023	0.036	n.s.
Marine abrasion platform	1042	368	220	0.044	0.074	0.064	0.084	+
Metamorphic rock platform	2059	319	434	0.087	0.064	0.054	0.073	−
Fluvial-marine plain	9649	1651	2035	0.408	0.331	0.313	0.349	−
Alluvial plain	8944	2439	1886	0.378	0.489	0.469	0.508	+
nc	756	56						
Total	24,422	5046	4991	1	1			

*Significant differences between proportion of habitat available and habitat used by swamp forest (chi-square goodness of fit test, $P < 0.01$).
**Bonferroni confidence intervals ($P < 0.05$).
Habitat selectivity = positive (+), negative (−) and not significant (n.s).
nc = non-classified areas.

local communities was also found. In these areas the surface drainage has been modified and the flow of water has been interrupted by road construction. The degradation of these ecosystems is not only occurring in the coastal zone of the Araucanía Region, but throughout the distribution of swamp forest in Chile, as has been observed by Ramírez et al. (1983) and San Martín et al. (1988). These authors show evidence of anthropogenic pressure as a result of the advance of forestry plantations, firewood extraction and invasion of exotic species (see also Squeo et al., 2001). Many of these ecosystems world wide are located outside protected areas (Schmitt et al., 2009) and are suffering alteration, as is occurring on the Atlantic coast of Brazil (Zamith & Scarano, 2010) and in Indonesia (Yule, 2010).

This study showed that a large number of the remaining fragments are small in size (<10.7 ha), have very irregular in shape, in areas with a high degree of property division (properties <200 ha), and very close to roads (between 0 and 700 m), particularly in the northern part of the study area. Unlike the small fragments, the few fragments larger than 100 ha, located mainly in the southern zone, have very irregular shapes, but are set in medium to large properties (>200 ha) and further from the nearest road (>700 m). The effect of the matrix and the size and shape of the fragments are important factors for maintaining the biological diversity of an ecosystem; for example size appears to be one of the most important variables in the design of protected areas (Geneletti, 2004; Hill & Curran, 2003; Tilman, May, Lehman, & Nowak, 1994; Wiersma & Urban, 2005) and in particular it has been shown that the size of a habitat has a positive correlation with the richness of tree and shrub species (e.g., Echeverría, Newton, Lara, Rey Benayas, & Coomes, 2007; Pincheira-Ulbrich, Rau, & Hauenstein, 2008; Pincheira-Ulbrich et al., 2009; Rau et al., 2006). Meanwhile the shape of the fragments determines their edge properties ("edge effect"), as well as their interaction with adjacent habitats or the surrounding matrix, meaning that in fragments with complex shapes biological invasions from the anthropogenic matrix are facilitated, leading to the degradation of the forest (Altamirano & Lara, 2010; Gascon, Williamson, & Fonseca, 2000; Laurence & Yensen, 1991; Murcia, 1995; López-Barrera, Armesto, William-Linera, Smith-Ramírez, & Manson, 2007; Pauchard & Alaback, 2004). It must be considered that wetlands are sensitive to interventions in their river basins and surrounding landscape, so that any alteration in the territory may affect both physical-biological interactions with the wetland and the quality and flow of water (Furukawa, Inubushi, Ali, Itang, & Tsuruta, 2005; Osumba, Okeyo-Owuor, & Raburu, 2010; Yule, 2010).

Table 5
Area of swamp forest (SF) divided into eight classes of property size (ha) and six classes of distance from the nearest road.

Property size classes (ha)	No of properties	SF (ha)	%	Distance from road classes (m)	SF (ha)	%
0–10	331	423	5	0–50	390	5
10–30	243	890	11	50–100	462	6
30–70	194	1292	16	100–300	2244	29
70–100	45	519	7	300–700	3008	39
100–200	77	1501	19	700–1000	938	12
200–500	31	1286	16	>1000	632	8
500–1000	17	976	12			
>1000	10	787	10			
Other areas	ni	160	2			
Total	948	7675	100		7675	100

ni = no information.

This study identifies the fragmented nature of Chilean swamp forest wetlands and anthropogenic pressure on them. These kind of ecosystems are in need of protection because of the many functions which they fulfil, including for example water flow regulation, retention of sediment and minimization of river bank erosion, water filtration and purification, provision of food source and habitat for a wide range of species especially migratory birds (Amezaga, Santamaría, & Green, 2002; Postel & Thompson, 2005; Ramsar Convention Secretariat 2006; Richardson, 1994; Yule, 2010). Some wetlands even have a function on a regional or global scale, helping to moderate climate change by acting as sinks for CO_2 (the principal greenhouse gas) (Furukawa et al., 2005; Lähteenoja, Ruokolainen, Schulmanw, & Oinonen, 2009; Limpens et al., 2008).

The swamp forests of the Araucanía Region are subject of extractive pressure (e.g., Hauenstein et al., 2002, 2005; Peña-Cortés, Gutiérrez et al., 2006; Peña-Cortés, Rebolledo et al., 2006; Peña-Cortés et al. 2009), which may have the effect of accentuating the degradation of these ecosystems, mainly due firewood extraction and land clearance for agricultural use. This situation has been recognised by the State which has declared the wetlands of the Mahuidanche sector a priority conservation site (Muñoz et al., 1996). However, the entire area of swamp forest today lies outside the Chilean National System of Protected Areas.

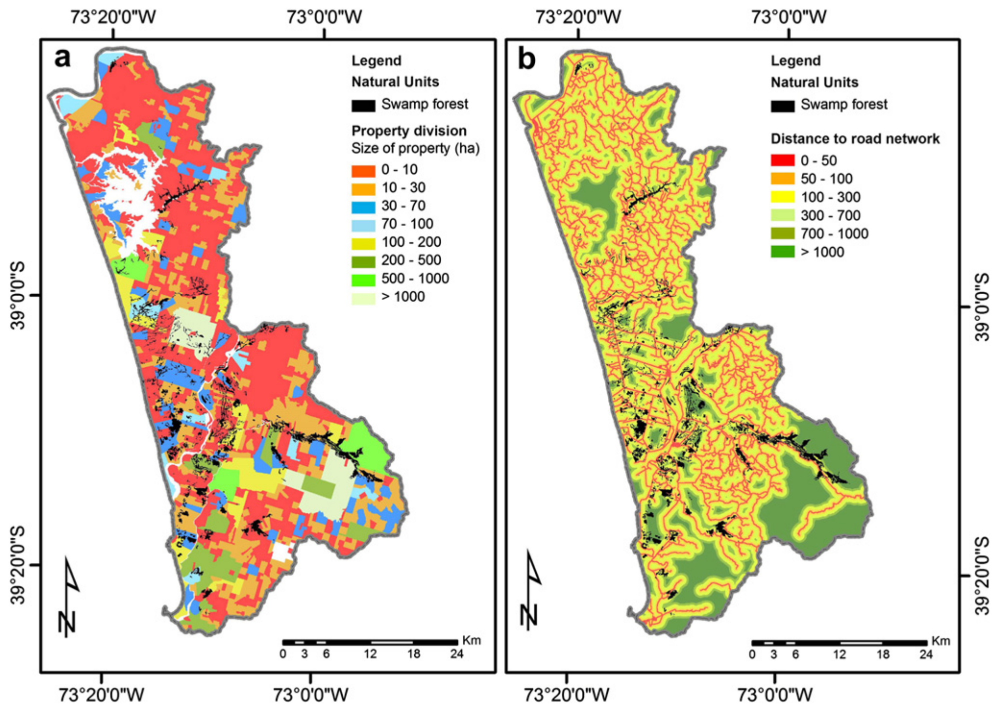

Fig. 4. Geographic distribution of swamp forest by eight classes of property size (a) and six classes of distance to the nearest road (b).

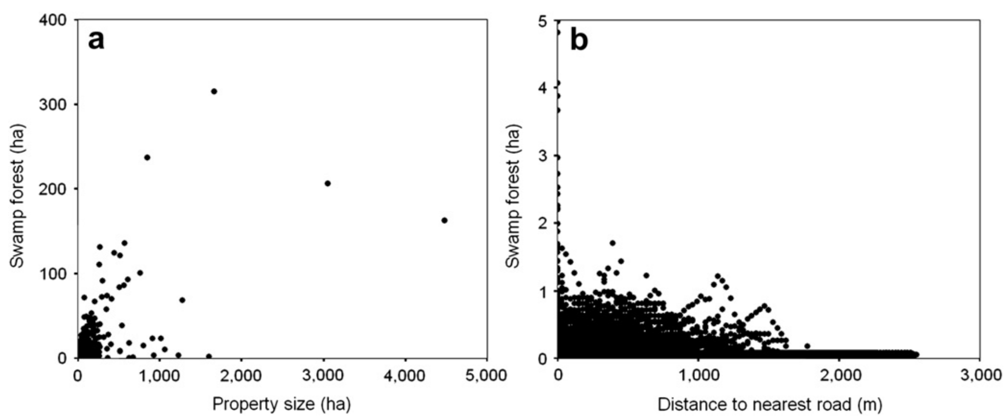

Fig. 5. Area of swamp forest by property size (a) and distance to the nearest road (b).

Conclusions

The distribution of swamp forest in the Araucanía Region responds to the presence of humid areas located principally on alluvial and fluvial-marine plains associated with the Toltén and Queule river basins. In most of its distribution the forest is subject to a high pressure of use as is shown by the farming matrix which surrounds it and the small size and very irregular shape of fragments. This situation is aggravated by modifications to the drainage of wetlands. These ecosystems do not use the entire available habitat (poorly drained land) proportionally in the several geomorphologic units. This is a response to the greater restrictions for agriculture of the land located in alluvial plains and low-lying and interfluvial areas in marine abrasion platforms, which result in a higher proportion of swamp forest. By contrast there is a lesser proportional distribution of forest on the metamorphic rock platform, which may be attributed to the high pressure of use for firewood extraction and land clearance for agricultural use.

The challenge is to maintain and conserve the networks of wetlands across a range of different boundaries and types of property and to recognize the high cultural and ecological value which these areas represent. To do this, mechanisms must be created to minimize the pressure of use on these ecosystems (e.g., by the environmental education, financial incentives for the management of swamp forest, and the generation of dendro-energy plantations), connecting and restoring degraded areas, broadening studies on ecosystem services (e.g., carbon capture), recognition of Mapuche cultural spaces and determining conservation priorities.

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coastal landscape of the Araucanía Region: geo-ecology applied to territorial planning and management in hydrographic basins).

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