The World's Largest Wetlands

Ecology and Conservation

Edited by **Lauchlan H. Fraser and Paul A. Keddy**

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Introduction

Globally, wetlands cover an estimated 7 to 8 million km^2 (Mitsch *et al.* 1994). These azonal ecosystems are widely and disjunctively spread throughout all major biomes of the Earth, following no evident pattern. Under the guise of wetlands fall a wide variety of ecosystems, ranging from open water bodies to peatlands. A comprehensive global strategy for the conservation of wetlands, thus requires recognition of the huge diversity of wetlands, and intimate knowledge of local environmental conditions and the biota of each wetland area and surrounding vegetation types. Because major wetland areas occur at many latitudes and are embedded in many different terrestrial ecosystems, it stands to reason that the sum total of wetland biodiversity could turn out to be quite high on a global scale in comparison with land area occupied by wetlands.

The southwestern border of southern South America is characterized by cool and windy summers, with recorded annual average precipitation reaching as high as 7 m on one offshore island. This area (and others further to the north) was heavily glaciated in the Pleistocene, and today consists of a highly dissected, rugged landscape interrupted by two major icefields (Southern Patagonian and North Patagonian) and numerous fjords. Corresponding closely in its distribution to this heavily glaciated land area is found a major area of cool temperate wetlands (Fig. 12.1). This peat-forming complex, widely separated geographically from other cool temperate wetland areas in the southern hemisphere, and known as the Magellanic tundra or moorland complex (Pisano 1977,

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1981, Moore 1979), contains four major subtypes (Fig. 12.2). Under present-day climatic conditions the wetland complex is distributed in a continuous fashion from the extreme southern part of the continent to around 43° S in the Region XI of Chile and from sea level to above treeline (Pisano 1983). Outlying areas of peatlands appear northward on the island of Chiloé (Ruthsatz & Villagrán 1991), and at several locations further north in the Coast Range to around 38° S (Looser 1952, Ramírez 1968) as well as inland along the Andes to around 40° S (Fig. 12.1). A few additional *Sphagnum* patches are found in the mediterranean area in central Chile as far north as 31° S where they are associated with disjunct forest islands considered to be postglacial relicts (Hauser 1996). Although the wetland zone is concentrated west of the main Andean cordillera, significant extensions of *Sphagnum* bogs can be found in Tierra del Fuego to the east of the Andean divide (Arroyo *et al.* 1996a) where they extend to the extreme southeastern tip of the island. With the exception of those peatlands occurring east of the Andes on the extreme tip of the Argentine sector of Tierra del Fuego, the vast majority of southern South American temperate peatlands are located in what is Chilean territory.

Cool temperate South American wetlands have received limited attention in the wetland literature (e.g. Moore 1979, Pisano 1983). Although mapped in Mitsch's (1994) global overview of wetlands, such peatlands were not described in the text. In an effort to ameliorate this situation, in this chapter we: (1) outline the present-day distribution of peatlands in southern South America, drawing on information deriving from a recent land survey in Chile (CCB 1999); (2) describe the various peatland subtypes; and; (3) provide a first estimate and phytogeographic analysis of native vascular plant biodiversity for the entire peatland complex. The level of wetland protection, and threats and opportunities are then discussed as elements for developing an integral strategy for peatland conservation in southern South America.

Extent of southern South American peatlands

A recent Geographic Information System survey (CCB 1999) of the major vegetation types in Chile allows the first fairly accurate estimate of the extent of southern South American peatlands. Based on information for regions VIII to XII of Chile, wetlands, without distinction as to kind, occupy 4.36 million ha, with the vast majority (4.25 million ha) located in the southernmost XI and XII political regions (44° to 55° S). Although there are no published figures with regard to different wetland types, it can safely be assumed that the great majority of wetlands at these latitudes correspond to peatlands of the typical

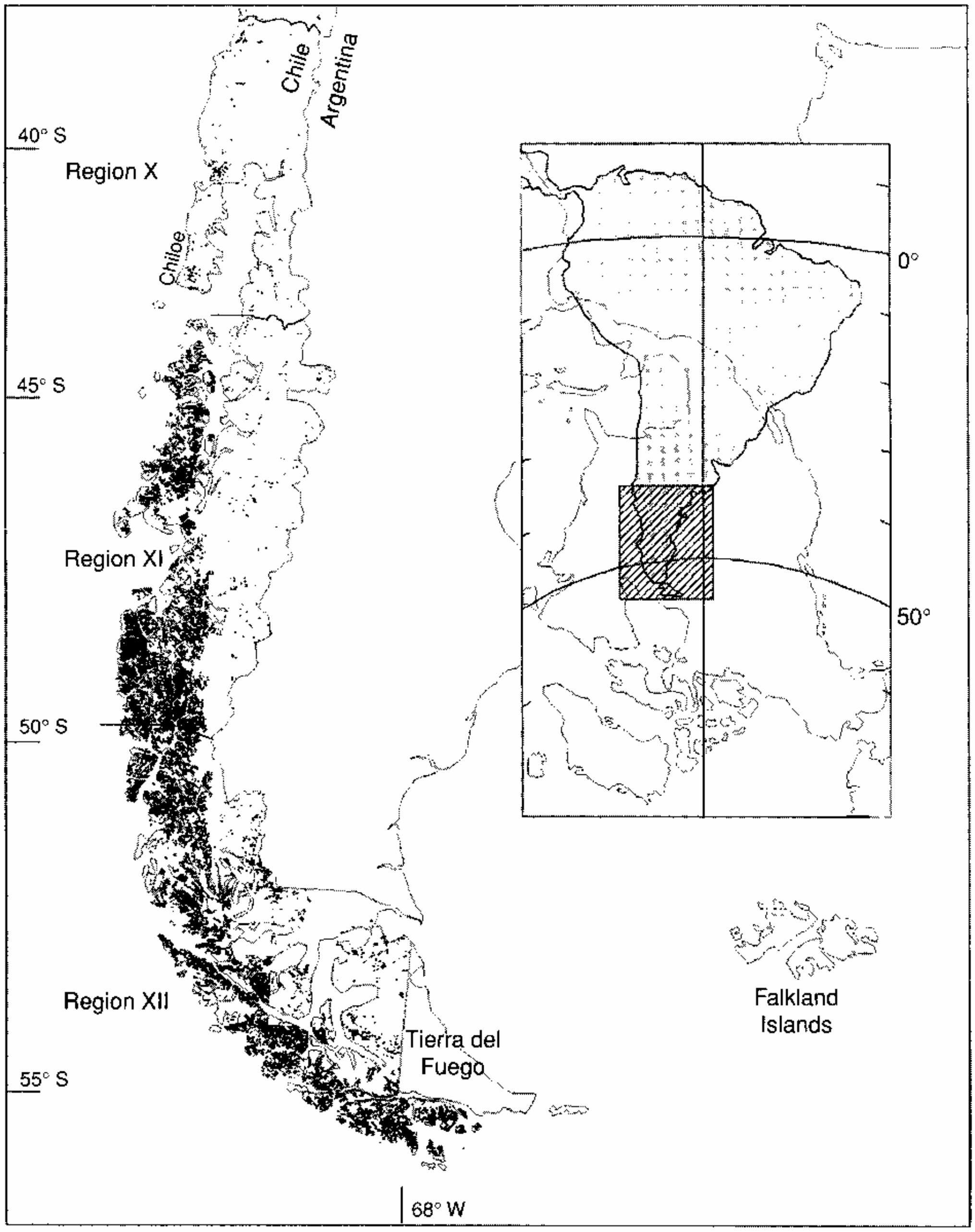

Figure 12.1 Distribution of wetlands in southwestern southern South America. The wetland category corresponds principally to peatlands (see explanation in text). Original data from CCB (1999). The map of South America superimposed on an inverted North America shows relative land areas at equivalent latitudes in the two hemispheres.

Figure 12.2 Distribution of four peatland types across the east–west rainfall gradient in South America. Modified after Pisano (1977).

Magellanic tundra (or moorland) complex. In regions IX and VIII (where wetlands are insignificant on a regional scale: a total of 34 000 ha) the broad wetland category includes some high-elevation Andean bogs of an entirely different nature as well as marshes and swamp forest (neither of which will be considered here). Taking the latter into account, and accommodating for a small area of peatlands in Argentine Tierra del Fuego, as a conservative estimate, the Magellanic tundra complex covers around 4.4 million ha, an area equivalent to 1.7% of boreal peatlands (based on a total boreal-peatlands area of 260×10^6 ha; Apps *et al.* 1993). The proportion of total land area occupied by wetlands increases markedly with increasing latitude, reaching 23.5% in the southernmost Region XII of Chile (Fig. 12.3). Although the total area is small on a global scale, southern South American peatlands make up 25.5% of the combined area of forests and peatlands, whereas boreal peatlands represent only 17% of the northern forest–peatland complex (Apps *et al.* 1993). The relative importance of peatlands versus forest, moreover, increases dramatically with increasing latitude in southern South America, to the extent that the former come to occupy a greater amount of the land area than forests south of 49° S (Region XII) (Fig. 12.3). Thus peatlands are salient ecosystems in southern South America.

Characteristics of the peatland complex

Southern South American peatlands are strongly embedded within the southern temperate forest matrix (Fig. 12.2). This being so, it should be

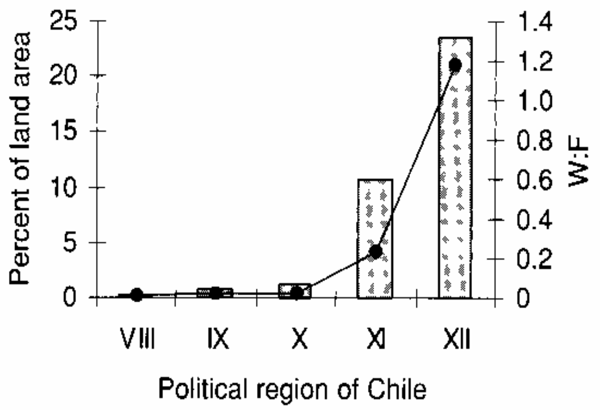

Figure 12.3 The percentage of total land area covered in wetlands in five political regions of Chile (bars), and the ratio of wetlands to native forest (W:F) for those regions (line). The wetland category corresponds principally to peatlands (see explanation in text). See Fig. 12.1 for latitudinal limits of political regions.

self-evident that peatlands and forests are intimately connected at the level of ecosystem processes. Peatlands, for example (particularly, *Sphagnum*-dominated peat bogs in the drier and windy eastern part of the wetland zone – see below), can play a vital role in maintaining the water balance in forests. Wetlands develop where local drainage conditions impede the growth of forest (mostly *Nothofagus* dominated): or in areas where temperature and frost conditions may be amenable to forest development, but exposure to wind is not. Soils are generally nutrient deficient and poor in bases (Ruthsatz & Villagrán 1991). Bog development is enhanced throughout the peatland zone by impermeable igneous rock (Andean diorite) and metamorphic schists (Precambrian and/or Paleozoic) which engender poor drainage and extensive paludification. From south to north, wetlands of the Magellanic moorland complex penetrate the "boreal" temperate rain forest and perhumid evergreen rainforest zones (Arroyo *et al.* 1996a), where they can be found interfingering with evergreen Magellanic rain forest dominated by *Nothofagus betuloides*, *N. dombeyi*, and *Fitzroya cupressoides*. To the east, peatlands penetrate into the deciduous temperate forest zone dominated by *Nothofagus pumilio* and *N. antarctica*. The peatlands find their greatest development in areas of oceanic climate where the mean temperature of the warmest month is low (7.5 to 9.0 °C; Tuhkanen *et al.* 1990) and frosts are rare – reflecting the range of forest types in which they are embedded; however, southern South American peatlands can be found over an amazingly wide precipitation range, varying from as little as 500 mm on the eastern border of the *Sphagnum*-dominated peat bog zone in Tierra del Fuego (Arroyo *et al.* 1996a), to over 4000 mm at coastal locations on the southwestern continental margin (di Castri & Hajek 1976), and as much as 7330 mm on the island of Guarello just off the mainland at 50° S. Indeed, as better knowledge has arisen of the distribution of *Sphagnum* peat bogs in Tierra del Fuego and cushion bogs in Chiloé, it has become evident that peatland development is not excluded under mildly continental climates. The extensive *Sphagnum* bogs in central Tierra del Fuego may be found under a mean summer temperature of 10 °C, a coldest-month temperature below zero, and the presence of frost – as deduced from the climatic zones defined by Tuhkanen *et al.* (1990) for Tierra del Fuego. On the island of Chiloé, upland cushion and cyperoid bogs are sporadically subjected to frost throughout the entire year (Ruthsatz & Villagrán 1991).

Pisano (1983) recognized four main peatland subtypes in the wetland complex. These subtypes develop under different rainfall, drainage, and wind regimes; and vary in their physiognomy, dominant plant species, and abundance of *Sphagnum*. The distribution of the four subtypes over an east–west gradient is illustrated in Fig. 12.2. Under a regime of 500 to 1500 mm precipitation, corresponding to the drier eastern part of the wetland zone (Pisano 1977, Arroyo *et al.* 1996a), rain-fed, ombrotrophic raised and blanket bogs are the norm. Raised and blanket bogs are found predominantly in the deciduous-forest zone and on the deciduous-forest–evergreen-rain-forest ecotone to the west. Such bogs, dominated by *Sphagnum*, are found mostly at higher latitudes and lower elevations, and stand out on the landscape because their intense brick-red colour contrasts against the surrounding green forest matrix. Their greatest development is seen in the central and southern parts of Tierra del Fuego. In strongly water-logged areas, *Sphagnum*-dominated bogs give way to juncoid bogs dominated by *Marsippospermum grandiflorum* overtopping a dense and continuous understorey of *Sphagnum*. At the drier end of the rainfall gradient, the typical *Sphagnum* and juncoid bogs are associated with increasing cover of *Empetrum rubrum*; at the wetter end, stunted individuals of the small gymnosperm, *Pilgerodendron uviferum*, are typical. Development of swampy conditions at the bog edge in both *Sphagnum*-dominated and juncoid bogs is generally associated with a band of stunted individuals of *Nothofagus antarctica*. Raised bogs tend to be sharply differentiated from the surrounding forest matrix and are associated with extensive peat development (Hauser 1996).

In areas of intermediate rainfall (1000 to 2000 mm) to the west and north of the *Sphagnum* bog zone, the typical bog is the non-raised cyperoid type (also referred to as "graminoid bog" as a result of the plant form of *Schoenus antarcticus*; Pisano 1983). Cyperoid bogs are dominated by *Schoenus antarcticus*, with the presence of typical species such as: *Carpha alpina*, *Schoenus andinus*, and *Rostkovia magellanica*; a number of grass species; and stunted individuals of a few shrubs and *Nothofagus antarctica*. Physiognomically flatter, such bogs contain variable amounts of *Sphagnum* and other mosses which form a basal stratum. This bog type varies enormously in size from hundreds of hectares to local patches of a few square meters within forests. The dominant species may penetrate the forest understorey along swampy streamsides and be found in forest hollows. Cyperoid bogs are associated with shallower peat development, in comparison with *Sphagnum* bogs, and deep soils that are rich in humified organic matter. Forest islands or isolated individuals of *Nothofagus antarctica*, *N. betuloides*, *N. nitida*, and *Pilgerodendron uviferum* are commonplace such that the ecotone of the forest tends to be more gradual.

Along the extremely exposed and wet western border of the wetland zone, cyperoid bog gives way to non-raised cushion bog (Pisano 1977, 1981), also known as "Magellanic moorland" *sensu stricto* (Godley 1960, Moore 1983). Dominant cushion species include *Donatia fascicularis*, *Bolax caespitosa*, *Astelia pumila*, *Oreobolus obtusangulus*, *Caltha dioneifolia*, and *Drapetes muscosa*. Such bogs may entirely lack *Sphagnum*, or may contain only limited amounts in an understorey position. Cushion bog also typically contains several species of sedges, dwarf-shrubs, and stunted individuals of *Nothofagus antarctica* and *N. betuloides*. Cushion bog appears again at higher elevations close to the treeline on the eastern side of the Andes in Tierra del Fuego. On account of the harsher environmental conditions, the ecotone between cushion bog and forest tends to be more abrupt than in the case of cyperoid bogs.

Biodiversity in southern South American peatlands

Biodiversity is generally measured at the ecosystem and species levels. More-sophisticated currencies of biodiversity attempt to incorporate phylogenetic content and even genes. Knowledge of the biodiversity in peatlands of southern South America is still woefully patchy even at the most-basic levels. While the main peatlands subtypes have been described, their distribution – other than in the extreme south of the continent – is poorly known. The latter is perhaps not surprising given that huge areas of the vast, highly dissected wetland zone are accessible only by way of the sea, determining that much of the zone still remains unexplored. Many basic questions remain to be answered. For example, where does the northern limit of *Sphagnum*-dominated wetlands lie? It is well known that the diversity of peatland subtypes is higher at the southern than at the northern extreme of the wetland complex. However, huge knowledge gaps remain in between. As in other poorly explored parts of the world, knowledge at the species level varies enormously among the taxonomic groups. Best known are the vascular plants and the dominant mosses, which will

Table 12.1 *Native mammals and birds found in* Sphagnum-*dominated peatlands in Tierra del Fuego, southern South America. Sources: Schlatter* et al. *(1995), Willson* et al. *(1995), Arroyo* et al. *(1996a).*

Mammals
Hippocamelus bisulcus
Lama guanicoe
Birds
Chloephaga picta
Chloephaga polycephala
Elaenia albiceps
Falco peregrinus
Falco sparverius
Gallinago paraguaiae
Geranoetus melanoleucus
Lessonia rufa
Muscisaxicola macloviana
Podiceps occipitalis
Polyborus plancus
Pygochelidon cyanoleuca
Pyrope pyrope
Rallus sanguinolentus
Rollandia rolland
Tachycineta leucopyga
Vultur gryphus

be referred to extensively here. Information on mammals and birds is limited (Table 12.1). Even for vascular plants, present knowledge is only sufficient to evaluate diversity on a broad, regional scale. Still less is known about the ecological dynamics of peatlands. For example, practically nothing is known about successional processes in southern temperate peatlands, not to mention functional biodiversity.

The four major peatland types, while physiognomically different, intergrade floristically. Based on a survey of the published literature and examination of herbarium records carried out by us, the total vascular plant flora – considering all peatland subtypes – numbers around 277 species contained in 134 genera (Table 12.2). This number can be expected to increase as more sites are studied. The dominant vascular plant species (although different in each of the peatland subtypes) tend to be invariant for each subtype throughout the entire latitudinal range of the wetlands. Many species listed as occurring in the

Table 12.2 *Genera of vascular plants in southern South American temperate peatlands.*

FE	Genus	Family	*N*	FE	Genus	Family	*N*
ST	*Abrotanella*	Asteraceae	4	C	*Isoetes*	Isoetaceae	1
ST	*Acaena*	Rosaceae	5	T	*Isolepis*	Cyperaceae	2
W	*Agrostis*	Poaceae	7	C	*Juncus*	Juncaceae	8
T	*Alopecurus*	Poaceae	1	W	*Lagenophora*	Asteraceae	1
SA	*Amomyrtus*	Myrtaceae	1	SA	*Lebetanthus*	Epacridaceae	1
W	*Anagallis*	Primulaceae	1	SA	*Lepidothamnus*	Cupressaceae	1
T	*Apium*	Apiaceae	1	ST	*Leptinella*	Asteraceae	1
T	*Armeria*	Plumbaginaceae	1	ST	*Lilaeopsis*	Apiaceae	1
C	*Asplenium*	Aspleniaceae	1	T	*Litorella*	Plantaginaceae	1
ST	*Astelia*	Liliaceae	1	ST	*Lomatia*	Proteaceae	1
T	*Aster*	Asteraceae	1	C	*Luzula*	Juncaceae	4
SA	*Asteranthera*	Gesneriaceae	1	ST	*Luzuriaga*	Philesiaceae	2
SA	*Azorella*	Apiaceae	5	W	*Lycopodium*	Lycopodiaceae	4
T	*Baccharis*	Asteraceae	2	SA	*Macrachaenium*	Asteraceae	1
W	*Berberis*	Berberidaceae	4	ST	*Marsippospermum*	Juncaceae	1
C	*Blechnum*	Blechnaceae	3	SA	*Misodendrum*	Misodendraceae	2
SA	*Bolax*	Apiaceae	2	T	*Montia*	Portulacaceae	1
W	*Botrychium*	Opioglossaceae	1	SA	*Myoschilos*	Santalaceae	1
T	*Bromus*	Poaceae	1	SA	*Myrceugenia*	Myrtaceae	1
W	*Callitriche*	Callitrichaceae	1	C	*Myriophyllum*	Haloragaceae	1
T	*Caltha*	Ranunculaceae	3	SA	*Myrteola*	Myrtaceae	1
W	*Cardamine*	Brassicaceae	1	SA	*Nanodea*	Santalaceae	1
C	*Carex*	Cyperaceae	24	W	*Nertera*	Rubiaceae	1
ST	*Carpha*	Cyperaceae	1	ST	*Nothofagus*	Fagaceae	5

W	*Cerastium*	Caryophyllaceae	1	SA	*Olsynium*	Iridaceae	1
SA	*Chiliotrichum*	Asteraceae	1	ST	*Oreobolus*	Cyperaceae	1
SA	*Chloraea*	Orchidaceae	2	SA	*Ortachne*	Poaceae	1
SA	*Chusquea*	Poaceae	2	ST	*Ourisia*	Scrophulariaceae	2
ST	*Colobanthus*	Caryophyllaceae	2	SA	*Ovidia*	Thymelaeaceae	1
ST	*Cortaderia*	Poaceae	1	C	*Oxalis*	Oxalidaceae	2
T	*Deschampsia*	Poaceae	5	SA	*Perezia*	Asteraceae	3
SA	*Desfontainia*	Desfontainiaceae	1	SA	*Philesia*	Philesiaceae	1
ST	*Deyeuxia*	Poaceae	3	ST	*Phyllachne*	Stylidiaceae	1
ST	*Donatia*	Donatiaceae	1	SA	*Pilgerodendron*	Cupressaceae	1
SA	*Drapetes*	Thymelaeaceae	1	W	*Pinguicula*	Lentibulariaceae	2
SA	*Drimys*	Winteraceae	1	C	*Plantago*	Plantaginaceae	1
C	*Drosera*	Droseraceae	1	T	*Poa*	Poaceae	8
C	*Eleocharis*	Cyperaceae	3	T	*Polypogon*	Poaceae	1
SA	*Embothrium*	Proteaceae	1	C	*Polystichum*	Dryopteridaceae	1
T	*Empetrum*	Empetraceae	1	C	*Potamogeton*	Potamogetonaceae	1
T	*Epilobium*	Onagraceae	2	W	*Pratia*	Campanulaceae	2
W	*Equisetum*	Equisetaceae	1	W	*Primula*	Primulaceae	1
C	*Erigeron*	Asteraceae	2	ST	*Pseudopanax*	Araliaceae	1
SA	*Escallonia*	Saxifragaceae	3	T	*Puccinellia*	Poaceae	1
W	*Euphrasia*	Scrophulariaceae	2	T	*Ranunculus*	Ranunculaceae	8
W	*Festuca*	Poaceae	6	ST	*Rostkovia*	Juncaceae	1
SA	*Fitzroya*	Cupressaceae	1	C	*Rubus*	Rosaceae	1
T	*Fragaria*	Rosaceae	1	T	*Rumex*	Polygonaceae	1
ST	*Gaimardia*	Centrolepidaceae	1	SA	*Saxegothaea*	Podocarpaceae	1
C	*Galium*	Rubiaceae	3	T	*Saxifraga*	Saxifragaceae	1

(cont.)

Table 12.2 (*cont.*)

FE	Genus	Family	*N*	FE	Genus	Family	*N*
SA	*Gamochaeta*	Asteraceae	1	W	*Schizaea*	Schizaeaceae	1
W	*Gaultheria*	Ericaceae	6	ST	*Schizeilema*	Apiaceae	1
T	*Gentiana*	Gentianaceae	1	C	*Schoenoplectus*	Juncaceae	2
SA	*Gentianella*	Gentianaceae	1	W	*Schoenus*	Cyperaceae	3
T	*Geum*	Rosaceae	2	C	*Senecio*	Asteraceae	5
W	*Gleichenia*	Gleicheniaceae	3	SA	*Serpyllopsis*	Hymenophyllaceae	1
SA	*Greigia*	Bromeliaceae	1	SA	*Sisyrinchium*	Iridaceae	1
W	*Gunnera*	Gunneraceae	2	SA	*Tapeinia*	Iridaceae	1
SA	*Hamadryas*	Rosaceae	1	T	*Taraxacum*	Asteraceae	1
ST	*Hebe*	Scrophulariaceae	1	SA	*Tepualia*	Myrtaceae	1
T	*Hierochloe*	Poaceae	2	SA	*Tetroncium*	Juncaginaceae	1
C	*Hippuris*	Hippuridaceae	1	T	*Thlaspi*	Brassicaceae	1
T	*Hordeum*	Poaceae	2	SA	*Tribeles*	Saxifragaceae	1
W	*Huperzia*	Fagaceae	1	C	*Triglochin*	Juncaginaceae	1
W	*Hymenophyllum*	Hymenophyllaceae	6	T	*Trisetum*	Poaceae	4
T	*Hypochaeris*	Asteraceae	2	ST	*Uncinia*	Cyperaceae	3
SA	*Iocenes*	Asteraceae	1	T	*Viola*	Violaceae	3

FE, floristic element; C, cosmopolitan; T, temperate; ST, southern temperate; SA, South American; W, widely distributed; *N*, number of species in genus in peatlands.

peatlands are found there only occasionally, being more typical of the forest and alpine habitats. A recent checklist of Chilean mosses provided by He (1998), cites 15 species and 3 varieties of *Sphagnum*; however, it is unclear as to how many of these species occur in peatlands. Included is *Sphagnum magellanicum* Brid., a widespread species in boreal peatlands, and a dominant species in *Sphagnum* bogs in southern South America. There are many other bryophytes, but taxonomic uncertainties do not allow reliable figures for these groups at this point in time. Better knowledge of bryophytes is highly desirable for assessing wetland biodiversity in southern South America. He (1998) shows that moss diversity increases with latitude in Chile. He lists 450 species of mosses for the Region XII of Chile, and similarly high numbers for the regions XI and X; with these kinds of figures, a large number of moss species can be expected for peatlands. Baseline studies at two locations in Tierra del Fuego indicate that *Sphagnum* bogs contain a very-rich lichen flora varying in composition from the edges of bogs to their centers (Arroyo *et al.* 1996a). Species of the following genera of lichens (including important nitrogen fixers) may be associated with peat bogs in Tierra del Fuego: *Caldia, Caldonia, Cladina, Clasia, Coleocaulon, Coelopogon, Endocaena, Hypogymnia, Icmadophila, Lecidea, Leptogium, Micrea, Ochrolechia, Peltigera, Polycladium, Pseudocyphellaria, Psoroma, Rhizocarpon, Siphula, Siphulastrum, Sphaerophorus, Sticta,* and *Usnea* (Galloway 1995). In order to evaluate the biodiversity of peatlands, it becomes interesting to compare species richness with that of other ecosystems. It comes as a surprise that, in terms of numbers of species, the peatland vascular flora is 63% of the size of the rain-forest flora (comprising 443 species of vascular plants, Arroyo *et al.* 1996b).

For native animals, peat bogs are the homes or feeding sites of several species of birds, including two species of wild geese. "Guanaco" (*Lama guanicoe*) and the rare *Hippocamelus bisulcus* ("huemul"), two large mammals, may be found browsing in peat bogs. The "huemul" is Chile's national symbol.

In Table 12.2 the 134 plant genera occurring in peatlands have been classified into major floristic elements. Carrying out this exercise is, of course, fraught with pitfalls as all genera do not fall neatly into the categories used. Nevertheless, this kind of analysis is useful in order to understand the origin and phylogenetic diversity contained in the peatland flora. Examination of Table 12.2 and Fig. 12.4 shows that southern South American peatlands have provided an important point of convergence for a diverse cadre of vascular plant genera. As noted by earlier workers (Godley 1960, Moore 1979, Pisano 1983), and confirmed in the more-comprehensive survey carried out here, the peatland flora contains a high proportion of southern-temperate elements (Table 12.2 and Fig. 12.4). Here are found many physiognomic dominants. Typical south-temperate elements include *Astelia* (Bromeliaceae), *Donatia* (Donatiaceae),

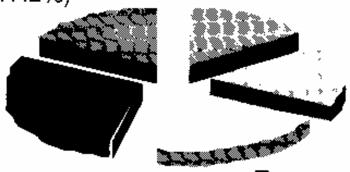

Figure 12.4 Floristic elements and their percentage contribution in the 134 genera of vascular plants found in cool temperate peatlands in southern South America.

Gaimardia (Centrolepidaceae), *Marsippospermum* (Juncaceae), *Oreobolus* (Cyperaceae), and *Phyllachne* (Stylidiaceae). Species from these genera moreover, are practically restricted to the wetland habitat. The peatlands also contain a significant contribution of species belonging to plant genera endemic to (mostly southern) South America – e.g. *Azorella*, *Bolax* (Apiaceae), *Drapetes* (Thymelaeaceae), *Lepidothamnus* (Cupressaceae), *Nanodea* (Santalaceae), *Tapeinia* (Iridaceae), and *Tetroncium* (Juncaginaceae). Although rarely dominant, a significant number of the taxa belonging here are in practice restricted to the wetland habitat (e.g. *Lepidothamnus*, *Nanodea*, *Tapeinia*, and *Tetroncium*). As occurs in boreal peatlands, the cosmopolitan and widespread element is also well represented, as are genera of wide temperate distribution in the northern and southern hemispheres (Table 12.2 and Fig. 12.4).

An exceptional number of the southern-temperate elements in the peatlands are represented by one or a few species in southern South America (Table 12.2) (e.g. *Astelia*, *Carpha*, *Donatia*, *Oreobolus*, *Phyllachne*, *Drapetes*, *Lebetanthus*, *Myrteola*, *Nanodea*, *Tetroncium* and *Tribeles*). This last feature, interestingly, is also characteristic of the southern South American rain-forest flora where, moreover, there are many monotypic endemic genera (Arroyo *et al.* 1996b). The more speciose genera in the wetland flora (reaching an extreme in *Carex* with 24 species), in contrast, tend to derive from the cosmopolitan and widespread elements; however, species belonging to these last floristic elements are rarely dominant and many have only been reported for a few localities. A comparison of the peatland subtypes reveals an interesting pattern. The southern-temperate element seems to be most-strongly represented in the cushion-bog subtype. The foregoing tendencies could indicate that the South American peatland complex is ancient, dating to the time when South America, Antarctica, New Zealand, and Australia made up a single land mass. Such a complex would have been present on Antarctica presumably in the Eocene–Miocene interval, with strong representation of the cushion-bog form. Subsequent to the break-up of the continents, the wetlands probably diversified ecologically and became enriched with additional South American elements, as well as with additional widespread and cosmopolitan elements to those perhaps already present earlier on, leading to the interesting generic mix seen today. Viewed in this light, the wetlands not only play an important role in protecting local southern South American biodiversity, but also biodiversity that is unique to southern-hemisphere lands. Needless to say, this hypothesis needs to be rigorously tested. Emerging evidence from phylogenetic (mostly molecular) studies indicates that some generic-level present-day disjunctions between southern South America and the Australasian–Pacific area can be fairly certainly ascribed to past continental connections (e.g., Mitchell & Wagstaff 2000, Renner *et al.* 2000, Swenson *et al.* 2001). However, in many cases long-distance dispersal seemed to be the more-parsimonious conclusion (Wagstaff *et al.* 2000, Winkworth *et al.* 2002). Phylogenetic information for southern South American wetland genera is still sparse. In *Phyllachne*, the New Zealand species could equally have evolved from a Tasmanian or South American lineage (Wagstaff & Wege 2002), but the timing and mode of the disjunction is not clear. For *Oreobolus*, Seberg (1988) admits that it is not easy to interpret results. In any event, the advent of molecular systematics and the molecular clock open a new and largely unexplored window for understanding wetland biodiversity. The extent to which wetland taxa have dispersed over major geographical areas versus traveling by now-separated lands is an essential question. Knowing which wetland taxa have good dispersability and are open to repeated recolonization events, and which are not, should be a factor that is taken into account when ranking the ecological vulnerability of wetlands.

Conservation

The necessarily strong focus on saving threatened temperate forests in southern South America at the present time tends to overshadow the conservation needs of other equally important ecosystems. Fortunately, by international standards, a high proportion of continental Chile is protected (19%; Arroyo & Cavieres 1997) and wetlands have fared relatively well. The recent vegetation survey (CCB 1999) shows that wetlands in general (including high-Andean wetlands and other types) enjoy a high degree of protection, with an outstanding 77% of all wetlands being contained in the State Protected Area System (comprising National Parks, National Reserves, and National Monuments). Considering southern South American wetlands separately, this figure increases to 79%. For peatlands outside Chilean territory, Parque Nacional Tierra del Fuego (63 000 ha) in southeastern Tierra del Fuego is important. The proportion of wetland area

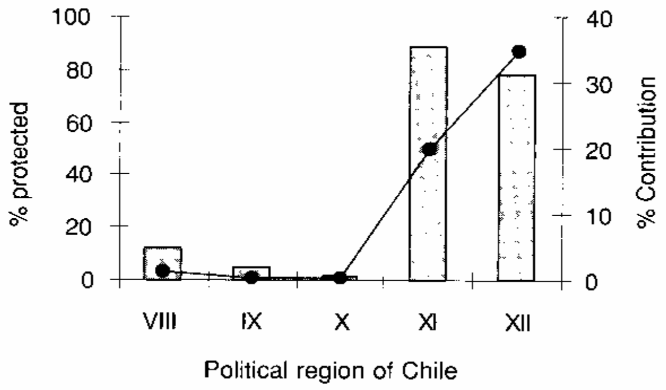

Figure 12.5 Percentage of wetlands protected in the Chilean State Protected Area System (SNASPE) for different political regions (bars) and the percentage contribution of wetlands in protected areas (line) for those regions. The wetland category corresponds principally to peatlands (see explanation in text). See Fig. 12.1 for latitudinal limits of political regions.

protected is especially high in regions XI and XII of Chile (Fig. 12.5), although the smaller outlying areas to the north (regions VIII, IX, and X) are poorly protected. Moreover, wetlands constitute a significant proportion of protected land per se in regions XI and XII (Fig. 12.5). At first sight, these figures appear to paint a positive scenario for peatland conservation in southern South America. However, this conclusion fades when the four wetland types are considered individually. As can be deduced from the location of protected areas in Muñoz-Schick *et al.* (1996), practically all of the protected areas in Chile found within the wetland zone in southern South America are located on the extreme western edge of the continent. While this location greatly favors cushion bog – and to a lesser extent cyperoid bogs – *Sphagnum* and juncoid bogs are poorly protected, perhaps as low as to the level of 10%. The largest extension of state-protected *Sphagnum*-dominated bogs in all of southern South America is probably to be found in Parque Nacional Tierra del Fuego on the southwestern tip of Argentina. Thus there is a major imbalance in the protection of different peatland subtypes. Recognition of this last situation is critical for developing future conservation strategies for southern South American peatlands. At the same time, it seems imperative to conserve more of the disjunct northern outlying areas of peatlands.

Further consideration reveals that many of the protected areas in the wetland complex fall into the category of National Reserves. In Chile, such reserves were originally set aside as frontier parks, probably more with the aim of saving land for future development schemes than for the protection of biodiversity and ecosystems per se (Armesto *et al.* 1998). Although the Chilean government does not allow extractive activities (timber harvest, etc.) in far-southern National Reserves, some reserves have recently been opened up for the development of ecotourism by the private sector, with its own inherent set of dangers when such fragile ecosystems as wetlands are concerned. The very-dynamic scene regarding development within state-protected areas in Chile makes it essential to establish clear guidelines for the conservation of peatlands and other ecosystems contained therein.

Threats and opportunities

The threats to the integrity of southern-temperate South American wetlands are: (1) timber harvesting in native forests; (2) introduced beaver; (3) exotic species; and (4) peat exploitation.

Timber harvesting in native forests

Huge tracts of native forest in the forest–wetland complex in southern South America are privately owned. Management plans exist for sustainable harvesting of one tree, *Nothofagus pumilio*, and harvesting is occurring at several locations on the island of Tierra del Fuego where *Sphagnum*-dominated bogs are most abundant. The rain forests on the Coast Range to the north, with embedded disjunct areas of peatlands, are also under threat. One major timber company in Tierra del Fuego (see Arroyo 1997), the owner of around 270 000 ha of land, has responded to the urging of Chilean scientists and has taken several measures to protect the borders of *Sphagnum* bogs, voluntarily placing around 6000 ha of peatlands under permanent protection. However, over time the removal of huge tracts of forest, no matter how careful the harvesting method, is likely to affect the delicate ecology of the fragile southern peatlands. These far-southern forested lands and their globally unique embedded wetland should be conserved.

Introduced beaver

In 1946, 26 pairs of the North American beaver (*Castor canadensis*) were released in Tierra del Fuego (Lizarralde 1993). The absence of natural predators lead to their rapid spread throughout the main and close offshore islands, leading to what could turn out to be one the greatest ecological disasters on Earth. Less than 40 years after the date of their introduction, Sielfeld and Venegas (1980) estimated 4.2 to 6.5 individuals per km^2 for Navarino Island, with peatlands being the favored habitat of beaver. Today, beaver dams and the associated effects of beavers are found from the steppe border up into the alpine region, with practically every watershed affected. Beaver damage has lead to increased paludism in existing bogs and in forested areas, with resultant invasion of

Sphagnum into previously forested areas following the death of trees. Simultaneously, the centers of existing bog are being subjected to major flooding. It is too early to predict the overall affect of beaver on wetland biodiversity and abundance. However, it is likely that the continued action of beavers will lead to local floristic impoverishment in flooded *Sphagnum* bogs. Out of defeat, local officials generally consider that the beaver problem in Tierra del Fuego is unmanageable. Fortunately, there appear to be no substantiated reports of beavers colonizing areas north of the Straits of Magellan at this stage.

Exotic species

Among the wetland subtypes, raised *Sphagnum*-dominated bogs seem to be most prone to invasion by exotic plant species. Fortunately, at this stage, the number of exotic species reported in peatlands is still relatively low (18), of which >50% are grasses. However, more introduced species are likely to arrive, especially in central Tierra del Fuego. Over the past 15 years, the island has seen an exponential increase in the number of *Lama guanicoe* ("guanaco") as a result of the latter's status as a protected animal (see Arroyo *et al.* 1996a) and lack of natural predators. Overpopulation has driven animals out of their preferred natural habitat, the Patagonia steppe (where exotic species abound; Moore 1983), into the forest habitat and other adjacent vegetation types in search of alternative resources, with the resultant establishment of exotic species along well-trampled trails in the bogs. Roads associated with timber-harvesting operations are providing additional conduits for the entrance of invasive species into peatlands. Developing a good and acceptable management plan for "guanaco" and strict specifications for road building would go a long way toward ameliorating these problem.

Peat exploitation

Under Chilean law, peat per se comes under the Mining Code, and like any mineral is considered to belong to the state, regardless of who the owner of the land may be. The right to exploit peat is granted by the court, which in turn sets the price of a patent to be paid annually to the state. Promulgation of the environmental law in Chile in the mid 1990s ushered in a potentially more-positive scenario for controlling the mining of peat. As pointed out by Hauser (1996), in that peat extraction corresponds to a mining activity, and all mining activities come under the jurisdiction of the Chilean Environmental Law, anybody wishing to exploit peat is now obliged to undertake an environmental impact study. Lappalainen (1996) estimates that 1 400 000 ha of bogs in regions XI and XII of Chile (*c.* 33% of total wetlands) are potentially expoitable for peat and/or surface *Sphagnum*. Hauser (1996) estimates the energy content of ground peat with 30% humidity at 3.24 GJ m^{-3}, for a total reserve of $15\,400 \times 10^6$ m^3. In 1996, according to Hauser (1996), peat was being exploited commercially by private companies only at two locations in the extreme south of Chile, with concessions granted for a total of 140 ha. The extracted peat is transported some 2500 km north to central Chile for use in the fruit, horticulture, and mushroom industries. Fortunately, neither at this time, nor to any extent in the past, has peat been mined commercially for use as a fuel, as has occurred in boreal peatlands. In a relative sense, it can be said that southern peatlands are in remarkably better shape than their northern-hemisphere counterparts. However, under present economic pressures in Chile and Argentina, anything could happen.

Concluding remarks

Southern South American peatlands, occupying some 4.4 million ha, constitute an island of southern-temperate and South American biodiversity distantly placed from northern peatlands and from other southern-temperate wetlands in New Zealand and Tasmania. Such peatlands can be a dominant feature of the southern South American landscape to the extent of occupying more land than forests at the extreme southern latitudes. Their interesting floristic mix of putatively ancient and more recently dispersed elements could hold many secrets regarding how wetlands are created and how they are maintained over geological time. The peatlands – thanks largely to their inaccessibility – seem not to have been exploited for fuel or peat to any extent and, except for extensive introduced-beaver activity on the island of Tierra del Fuego, are presently fairly well conserved. These wetlands definitely deserve attention from the international scientific and conservation communities.

In that southern South American peatlands and forests are intricately connected at the ecosystem level, the fate of peatlands will largely determine the future of southern South American temperate forests, and vice versa. It thus becomes imperative to develop an integral strategy to protect southern-temperate peatlands and forests. While overall protection of the wetland complex is good, and exploitation of peatlands is still moderate, major imbalances among peatland subtypes in the protected-area system make it clear that *Sphagnum*-dominated bogs, located principally in Tierra de Fuego, are at the highest risk. This risk is real, given that huge tracts of *Sphagnum*-dominated peatlands in southern South America presently lie in the hands of forestry companies. What can, and what will be done about this situation, however, is far from clear. With 50% of the land area in the Magellanic region of Chile (where most

Sphagnum-dominated peatlands lie) already contained in the State Protected Area System, it seems unlikely that the government of Chile will devote more land to conservation. It is less probable that conservationists would accept a swap of conserved forest lands for wetlands, no matter how desirable the latter. All other things being equal, in the absence of some sort of concerted international effort, it seems that conservation efforts by the private sector constitute the only real possibility for conserving the extraordinary *Sphagnum*-dominated peatlands.

Undoubtedly, carbon credit schemes, as espoused in the Kyoto Protocol, offer a potential mechanism for achieving adequate conservation of *Sphagnum*-dominated peatlands on private lands. Peat bogs represent huge stores of organic carbon, whose release through burning or draining is well known to contribute to global warming (Gorham 1991). Peat depths in southern South American bogs are variable. Palynological studies report peat depths in the range of 1 to 5.5 m (Auer 1958, Heusser 1993). However, deeper excavations in some peat bogs in the Magallanic region have revealed two separate peat layers: one composed of typical red *Sphagnum* peat of 1 to 1.8 m, and a second layer of 6 to 7 m of compact black peat with a high organic component (Hauser 1996). One detailed study suggests that the upper 50 cm of cushion-bog peat in Chiloé contains an average of around 37% carbon (dry weight) (Ruthsatz & Villagrán 1991). One large forestry company in Tierra del Fuego has already gone through the process of attaining international certification to sell carbon credits. This, and other similar initiatives, unfortunately, are on standby due to the intransient position of the United States regarding the Kyoto Protocol.

The makings of any explicit integral strategy for saving cool, southern-temperate South American wetlands should involve the participation of all stakeholders, including the private land owner. This strategy should take into account non-ecological values of peatlands as well as their biological, ecological, and landscape values. As in the northern hemisphere (French 2002), southern-temperate wetlands may in the long-run turn out to have untold archeological value due to extremely good preservation of organic evidence. The importance of such remains cannot be overemphasized: the archeological site of Monte Verde (Dillehay 1989, 1997), in Region X of southern Chile, was preserved as a result of the formation of peat over a Late Pleistocene settlement on the margin of a small creek; the water-saturated deposits afforded excellent preservation for organic remains, enabling researchers the rare chance to identify and characterize plant species used in the inhabitants' diet, as well as aspects of their wood technology. Monte Verde is the earliest archeological site in South America that is unanimously accepted by the scientific community, and has debunked long-held views about the initial peopling of the Americas (Meltzer *et al.* 1997). Palynological work suggests that outlying peatlands in the northern part of the wetland zone are remnants of a peatland area that expanded greatly during the cold–wet cycles of the Pleistocene (Villagrán 1988). In particular, the far-southern lands of South America are the home of several indigenous tribes (Selk'nam, Alacalufes, and Yamañas). These hunter–gatherers occupied different environments, including steppe, forest–wetland boundaries, and coastal zones. Preserving peatlands, should thus be a high priority for both Argentina and Chile.

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