Lakes & Reservoirs: Research and Management 1999 **4**: 55–64

The environmental state of Argentinean lakes: An overview

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Abstract

Due to the great climatic variety and the peculiar north–south orographic distribution, Argentinean lake systems include a wide diversity of aquatic environments. The deepest lakes are situated in the Andean Patagonia and Tierra del Fuego, and range from ultraoligotrophic to oligotrophic. Patagonian Plateau lakes are shallower than Andean lakes and usually range from mesotrophic to eutrophic. All lakes in the Chaco-Pampa Plain are very shallow and range from eutrophic to hypertrophic or salt lakes. Most of the lakes situated in the central–western and northwestern arid regions are reservoirs or salt lakes, and range from mesotrophic to eutrophic. More than half of the northwestern reservoirs have very low dissolved oxygen concentrations in the hypolimnion during mid-summer. Argentina has more than 400 lakes with surface area >5 km^2, but for some of them not even major ion data are available. In order to synthesize and to extract general characteristics and patterns, issues have been selected which adequately reflect the character of the lake environment in Argentina. We divided Argentina according to geographical regions into six major divisions: Puna, Chaco-Pampa Plain, Peri-Pampean Sierras, Andean Patagonia, Patagonian Plateau, and Misiones Plateu and Brazilian Shield-related systems. Most of the lakes situated in Patagonia are undisturbed lakes. However, the Chaco-Pampa Plain lakes are usually lightly impacted by agricultural operations. Moreover, most of the reservoirs located in the Argentinean arid 'corridor' are highly impacted by agriculture. Other lakes in both north and south Argentina range from salt lakes, through dark humic-stained lakes and large river floodplain lakes, to dilute high altitude glacial lakes. Argentina still has a larger proportion of its lake waters in natural conditions. However, expected developments for natural resources indicates that Argentinean goals for lake water management should include the preservation of some proportion of pre-European natural lake environment, and the evolution of a stable, managed lake environment in the more developed regions.

Key words

aquatic ecosystem health, Argentina, Argentinean lakes, lakes, regional limnology.

INTRODUCTION

Three first-order geomorphological regions can be defined for Argentina: the Andes Cordillera and associated mountains, the Great Plains, and Patagonia (Iriondo 1989). In the Andes the principal processes of significance to lacustrine development were glacial and tectonic events, and mass movements. The Great Plains, which cover the central and northwestern provinces, are the site of extensive continental sedimentation. This region has very gentle slopes and significant neotectonic activity. A succession of humid and dry climates as well as its geomorphology result in an important development of wetland systems and very shallow lakes (Iriondo 1984). Patagonia is a complex landscape dominated by tablelands. The tablelands consist of tectonically uplifted basaltic plateau and coarse grain fans originated in the Andes. In the Patagonia landscape numerous closed depressions were formed by wind erosion (Iriondo 1989).

Argentina has a wide array of lake types in regard to formation, size, shape, chemistry, and natural fertility. However, the diversity of surface water in a region depends on three main factors: climate, geology and relief. In South America, the dominant climatic changes are in a west–east direction due to the Andes. Therefore, in Argentina where the bi-oceanic distances are shorter, some north–south

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Accepted for publication 27 October 1998.

changes are masked by the Andes Mountains. Thus, north to the 38°S, Argentina presents an increasing aridity from east to west. On the contrary, south of 38°S there is a decreasing aridity from east to west. Due to the great climatic variety and the peculiar north–south orographic distribution, Argentinean lake systems include a wide diversity of aquatic environments (Quirós 1988; Quirós *et al* . 1984, 1988). The above changes and the north–south climatic variation from humid tropical to cold temperate climates allow the existence of different aquatic systems, some with strong changes even within single catchment areas (Drago & Quirós 1996).

The water chemistry of Argentinean lakes has not been studied intensively although limnological research over the years has accumulated major ion data for several lakes (Drago & Quirós 1996). In the present study, because of the desire to synthesize and to extract general characteristics and patterns, issues have been selected that adequately reflect the character of the lake environment in Argentina.

METHODS

In this overview, the major ion chemistry has been used to indicate regional groups of lakes. Argentina has more than 400 lakes with surface area >5 km^2, but for some not even major ion data are available. However, among the principal factors likely to influence water chemistry, catchment lithology, lake origin, climate, and proximity to the sea are known for most lakes. This allows the lakes to be grouped into major divisions according to these factors, and to extrapolate with reasonable confidence from the water chemistry of a few representative lakes to that of the group as a whole.

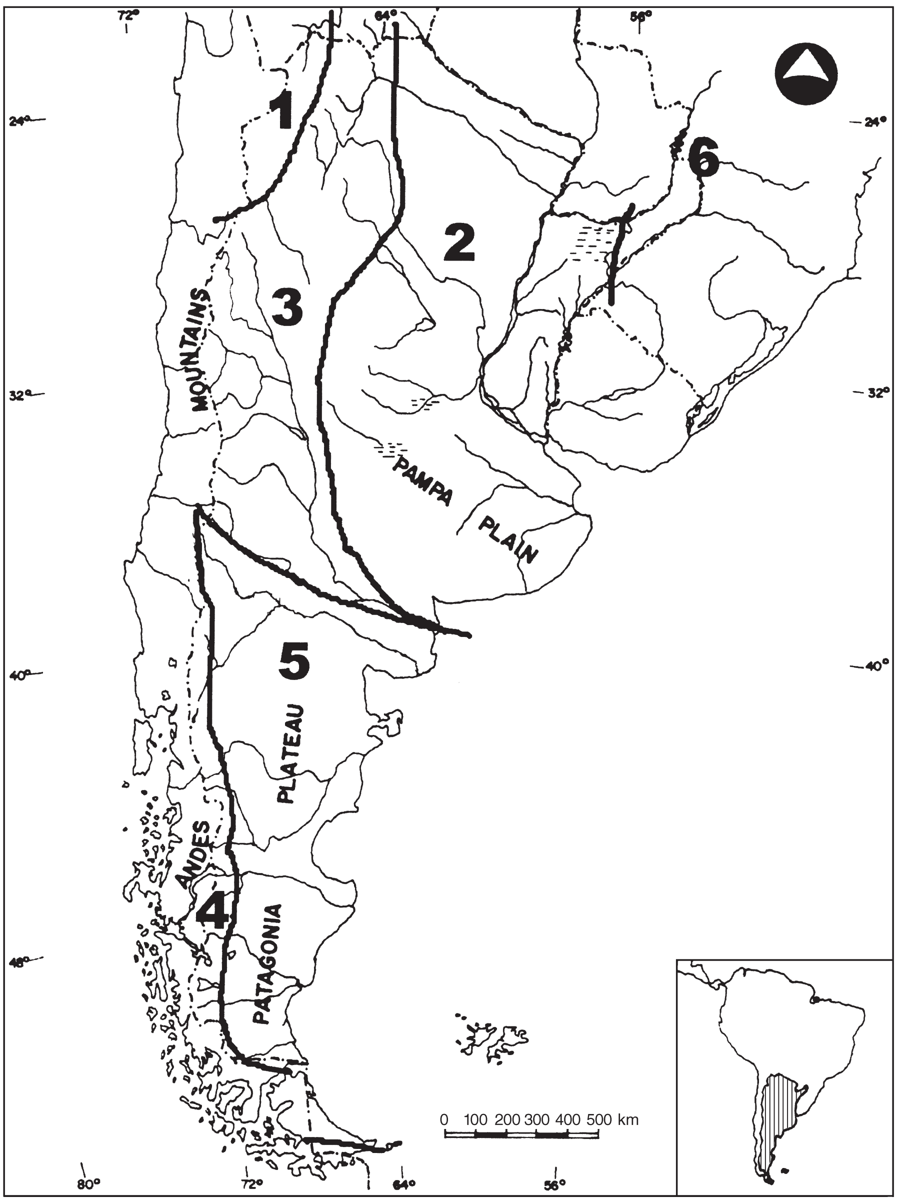

Fig. 1. Geographical lake regions for Argentina. 1, Puna; 2, Chaco-Pampa Plain; 3, Peri-Pampean Sierras; 4, Andean Patagonia; 5, Patagonia Plateau; 6, Misiones Plateau.

The origins and development of the Quaternary lakes of Argentina have been reviewed by Iriondo (1989), and an overview of the hydrochemistry of the Argentinean inland waters was presented in Drago and Quirós (1996). Argentinean lake and reservoir database (ARLARE data, Quirós *et al*. 1988) and Argentinean database for the surface waters of Argentina (ASALT data, Drago & Quirós 1996) were used to classify Argentinean lakes.

We divided Argentina according to regions into six major divisions: (i) Puna, (ii) Chaco-Pampa Plain, (iii) Peri-Pampean Sierras and associated valleys and 'bolsones', (iv) Andean Patagonia, (v) Patagonian Plateau, and (vi) Misiones Plateau and Brazilian Shield influenced Region (Fig. 1).

Factor analysis was applied to environmental data for Argentinean lakes (ARLARE data). In this analysis all factors that had have eigenvalues greater than one were retained. This approach was useful because only a few factors have contained most of the variance in the ARLARE data set. With the exception of fish biomass when biological standing stocks were used for analyses, communalities had usually been high.

Regional features

The Argentinean geographical regions used are quite diverse (Drago & Quirós 1996). Therefore, a more appropriate secondary lake division was also considered (Table 1). The mean values (Table 2) and the wide range of variation of total dissolved solids and ionic ratios for lakes within each region and among regions reflect that variability (ASALT data).

Table 1. Geographical Lake Regions of Argentina

Region	Description
1	Puna
2	Chaco-Pampa Plains
2.1	Chaco shallow lakes
2.2	Hilly-swampy belts on Uruguay river
2.3	Ibera System and related swamps
2.4	Parana River related lakes
2.5	Pampa shallow lakes, river related
2.6	Pampa shallow lakes, endorheic basins
3	Peri-Pampean Sierras
3.1	Valleys (exorheic)
3.2	*Bolsones* (endorheic)
4	Andes Mountains
4.1	Andean Patagonia, glacial lakes
4.2	Andean Patagonia, volcanic influenced
5	Patagonian Plateau
5.1	Exorheic rivers related
5.2	Patagonia endorheic basins: tectonic influenced
5.3	SE Tierra del Fuego humic-stained lakes
6	Brazilian Shield-related

In the Puna Region (Fig. 1), the present salt lakes are Holocene in age (Iriondo 1989) and most of the salt comes from Tertiary evaporites. Salt lakes (*salares* and *salinas*) contain waters ranging from medium to high salinity.

The Chaco-Pampa Plain Region (Fig. 1) embraces the central, northern and some eastern portions of Argentina. The north–south distribution of the tropical, subtropical and temperate climates and the concurrent lowering of temperatures from north to south and southwestern, the decrease of rain from east to west and to southwest, and the neotectonic patterns, indicate the ecological complexity of lakes in this region (Tables 2,3). Thus, their positions within this grouping are dependent on the relief, climate, geological substrate, soils and land use within each catchment area. For this region, the lakes show a large heterogeneity on edaphic influences, from the very dilute waters of the aeolian shallow lakes located in the central and northwestern portions of the Corrientes province (Ibera Swamps), through the very shallow lakes situated in the central Pampa, to the highly saline waters in the provinces of Buenos Aires, La Pampa and Cordoba (Table 2). Floodplain lakes for Argentinean large rivers have been described by Bonetto *et al.* (1969) for the Salado River; and by Drago and Vasallo (1980) for the lower Middle Parana, by Pedrozo *et al.* (1992) and Carignan and Neiff (1992) for the upper Middle Parana, and by Bonetto *et al.* (1994) for the deltaic floodplain of the lower Parana.

In the Peri-Pampean Sierras Region (Fig. 1), we have included (Drago & Quirós 1996) the whole Argentinean 'arid corridor', except the Puna. The western border is the Andes Cordillera, and the irregular eastern border is the Chaco-Pampa Plain, including high and low mountain ranges, valleys and *bolsones*. In the semi-arid valleys and *bolsones* large salt lakes and playas are widespread, but the reservoirs feeding by rivers flowing from the mountains usually have lower total dissolved solids (Tables 2,3).

The Andean Patagonia Region (Fig. 1) is from 39° to 55° south, and contains the largest and deepest glacial lakes in South America (Table 3). In the lacustrine area (9500 km^2) more than 300 large and small lakes occur widely, from them usually originate the largest Patagonian rivers that feed large reservoirs located in the Patagonian Plateau.

The Patagonian Plateau Region (Fig. 1) is a complex landscape mainly characterized by a basaltic plateau and tectonically uplifted pebble fans (Iriondo 1989). The allochthonous–exorheic rivers originated in the Andes can cross this arid region and feed large arificial lakes. Moreover, some large depressions of Patagonia contain permanent natural and artificial lakes (Table 3), while others have temporary waters (*bajos*) with evaporite deposits in the central areas.

The Brazilian Shield Influenced Region (Fig. 1) comprises a small part of the Misiones Plateau, but most of the flood-plain lakes and the large reservoirs in the lower Rio de la Plata basin depends usually more on climate, geology and land use practices in the Brazilian Parana and Uruguay catchment areas than in other sources (Table 2, region 2.4).

RESULTS

Classification of lakes

Water chemistry

The Argentinean studies show a wide range of dissolved salts values (Table 2; Drago and Quirós (1996), for a review). Argentinean lakes cannot be grouped on the basis of water chemistry in any more detail than that shown in Fig. 2 (Table 2). Local deviations in catchment geology can cause major changes in water chemistry, and although these may be relevant to individual lake descriptions, such detail is mostly outside this discussion in which the main objective is to identify general features distinguishing Argentinean lakes.

The geology and hydrology of the arid regions of Argentina are complex, possibly more than for any other lake group in Argentina. This is likely to be reflected in a wide diversity of lake water chemistry. Saline and hypersaline lakes form the largest group in northwestern and central Argentina and in the Patagonian Plateau (Fig. 2). However, some striking differences are evident between the regions. For most of the saline and salt lakes situated in the Argentinean central and northwestern arid regions (Table 2, regions 1.0, 2.6, and 3.2) old sea salt dominate the major ions giving NaCl waters (Table 2). In contrast, Patagonian Plateu lakes situated in endorheic catchments (Table 2, region 5.2) also have NaCl dominated waters, but some small lakes situated near the Andes lie in catchments containing sedimentary rocks and in their waters carbonate and Ca are predominant (note the differences between anionic ratios in Fig. 3 and Table 3).

Numerous other lakes, mostly artificial reservoirs, are scattered over the northwestern and western arid regions and the Patagonian Plateau (Table 2, regions 3.1 and 5.1, respectively). Most are fed by rivers originated in the Andes Cordillera and related mountains. The riverine influence is reflected in their water chemistry through higher carbonate

Table 2. Water chemistry characteristics for Argentinean lakes

Lake Region	No.	TDS (mg m^{-3})	EC (uS)	TA (meq L^{-1})	CL (meq L^{-1})	SO_4 (meq L^{-1})	Ca (meq L^{-1})	Mg (meq L^{-1})	Na (meq L^{-1})	K (meq L^{-1})
1 Puna	3	110 863		1.01	1834	50	25	4.9	1841	10
2 Chaco-Pampa Plains										
2.1 Chaco Plain	10	111	145	0.75	0.44	0.39	0.5	0.38	0.61	0.07
2.3 Ibera System and related	35	52	34	0.64	0.38	0.29	0.38	0.15	0.56	0.08
2.4 Parana River related	8	68	83	0.59	0.28	0.11	0.34	0.24	0.39	0.06
2.5 Pampa Lakes (river related)	16	943	1213	7.5	4.7	1.7	0.9	1.7	11.1	0.29
2.6 Pampa Lakes (endorheic basins)	36	31 169	25 126	20.3	420	102	15	51	473	1.2
3 Peri-Pampean Sierras										
3.1 Valleys (exorheic)	24	307	420	1.52	0.69	2.1	2.16	0.75	1.31	0.09
3.2 'Bolsones' (endorheic)	5	26 042	5445	14	336	60	2.8	16.8	433	0.8
4 Andean Patagonia										
4.1 Glacial Lakes	55	59	64	0.62	0.07	0.12	0.42	0.23	0.17	0.01
4.2 Geothermal influence	1	479	1950	0	1.99	5.83	0.52	0.72	0.33	0.08
5 Patagonian Plateau										
5.1 Exorheic basins	13	243	265	2	0.54	0.73	1.1	0.61	1.66	0.06
5.2 Endorheic basins	32	12 865	18 573	8.8	189	49	4.05	30.3	214	0.19
5.3 Southeastern TF humic-stained	4	104	118	0.84	0.43	0.1	0.64	0.16	0.52	0.02

Modified from Drago and Quiros 1996. ASALT data.

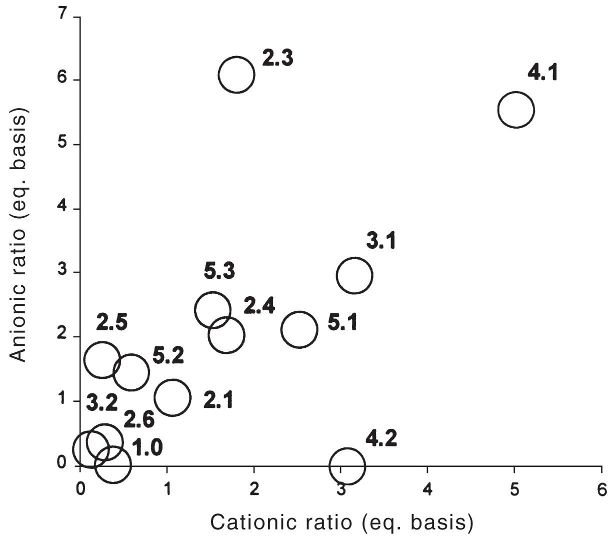

Fig. 2. Relationship between cationic ((Ca + Mg)/(Na + K)) and anionic (($CO_3 + HCO_3$)/(Cl + SO_4)) ratios for ASALT data (Drago & Quiros 1996).

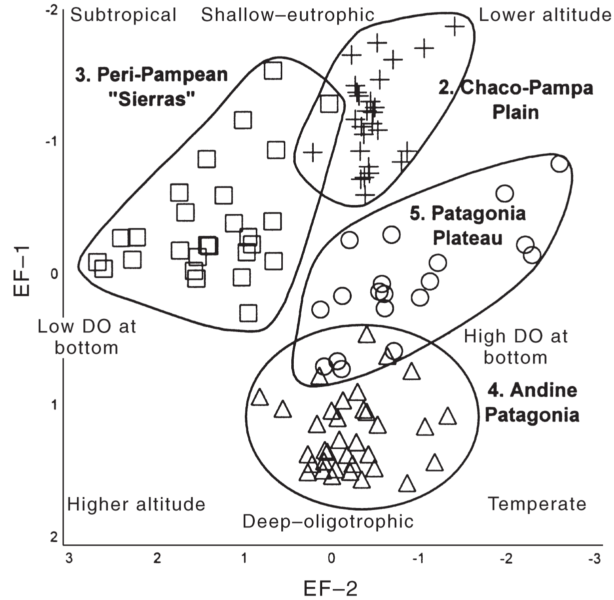

Fig. 3. Environmental factor analysis ordination of Argentinean lakes. Factor loadings for each axis are given in Table 4. DO, dissolved oxygen.

Table 3. Some environmental characteristics for Argentinean lakes

Geographical Region	Chaco-Pampa Plain lakes	Peri-Pampean Sierras reservoirs	Andean Patagonia lakes	Patagonia Plateau lakes
Number of lakes	27	27	35	19
Surface area (km^2)	92.6	30.6	98.3	174.8
Mean depth (m)	2.2	15	63.1	17
Volume (hm^3)	585.2	361.9	12 122.2	5121.5
Latitude	36.2	29.9	43.6	43.2
Altitude (m)	79.4	880.7	663.5	550.2
Rainfall (mm year^{-1})	800	524	1218	283
Air temperature (°C)	15.3	16.9	6.9	9.3
Frost-free period (days)	233	274	25	69
% Stratified lakes	0	41	71	0
Total dissolved solids (mg m^{-3})	3575	686	55	725
Total alkalinity (meq L^{-1})	10.46	2.02	0.51	5.72
Anionic ratio (equivalent basis)	1.15	2.68	7.44	6.45
Cationic ratio (equivalent basis)	0.25	2.83	4.28	1.67
Total phosphorus (mg m^{-3})	572	68	7	183
Total nitrogen (mg m^{-3})	8563	2008	702	3022
TN : TP (molar basis)	33.2	65.4	228.6	36.6
% Cyanobacteria	62.5	26.8	8.1	3.6
True colour (Hazen)	69	14	6	13
Secchi disk lecture (m)	0.84	1.84	10.25	2.51
Chlorophyll (mg m^{-3})	59.9	20.3	2.2	13.2
% Oxygen saturation at bottom	87.9	35.5	82.6	79.8

Modified from Quiros *et al.*, 1988, ARLARE data.

and Ca contents when compared with their endorheic counterparts for the same region (Fig. 2).

The shallow lakes of the Chaco-Pampa Plain situated in exorheic river basins have also lower salt content than their endorheic counterparts (Table 2, region 2.5), and Na and carbonates dominate their waters. Their mean ionic composition is similar to the mean values for the Patagonian Plateu lakes (Fig. 2). However, these lakes lie in catchments containing sedimentary rocks and in their waters Ca is increased in concentration relative to Na and Mg compared with those ratios in sea salts.

The lakes situated in northeastern Argentina fall conveniently into several groups as shown in Fig. 2, but even among these groups the differences in water chemistry are not great (Table 2, regions 2.1, 2.3, and 2.4). However, the diluted waters of the Ibera Swamp lake system are relatively richer in carbonates (Fig. 2).

The distinctive characteristic of the Andean Patagonia landscape results from glacial action and later strong fluvial erosion. The above features, together with the hard rock composition, produce dilute and very dilute waters to this region (Table 2, region 4.1). Patagonian Andean lakes form the largest group in Argentina. As expected, their waters are very diluted, with total dissolved solids (TDS) ranging from 23 mg L^{-1} for large subalpine lakes to 230 mg L^{-1} for small lake basins draining metamorphic rocks. A dominance of Ca and carbonate waters is apparent for this region. However, a few lakes in this region have volcanic and geothermal influence (Table 2, region 4.2).

Other lakes in both north and south Argentina, while not unusual in terms of water chemistry, cover a wide range of environments, from dark humic-stained lakes (Table 1, region 5.3), through large river floodplain lakes, to dilute high altitude small glacial lakes.

Environmental classification

Due to the great climatic variety and the peculiar north–south orographic distribution, Argentinean lake systems include a wide diversity of aquatic environments. Therefore, a more detailed lake classification was obtained for a group of 108 Argentinean lakes and reservoirs located between 25° and 55° south throughout the central–western and northwestern arid regions, the Chaco-Pampa Plain, the Patagonian Plateau, the Patagonian Andes, and Tierra del Fuego (ARLARE database, Quirós *et al.* 1988). Limnological characteristics of studied lakes are shown in Table 3.

The deepest lakes are situated in the Patagonian Andes and Tierra del Fuego, and ranged from ultraoligotrophic to oligotrophic. All the lakes in the Pampa Plain are very shallow and range from eutrophic to hypertrophic or salt lakes. Most of the central–western and northwestern reservoirs and Patagonian Plateau lakes range from mesotrophic to eutrophic, and more of than half of the northwestern reservoirs have very low dissolved oxygen concentrations in the hypolimnion during mid-summer (Table 3).

Water residence time (T_w) ranges from several years for Andean lakes to a few days for reservoirs situated in large rivers (Calcagno *et al.* 1995). Moreover, for Patagonian Plateu lakes T_w ranges from 0.9 year to more than 5 years for lakes and reservoirs located in exorheic river basins, respectively. Water residence times are usually lower than 2–3 months for Pampa lakes, and range between 0.1 and 3 years for reservoirs located in the Peri-Pampean region.

Factor analysis ordination of Argentinean lakes using climatic, morphometric, chemical, and nutrient variables, have discriminated four main lake groups (Fig. 3). The two first eigenvalues explained 65% of total variance (Table 4). The first factor (EF-1, Table 4) weights shallow, warm, eutrophic, nitrogen limited lakes situated at lower latitudes as opposed to southern, cold-temperate, oligotrophic, more diluted, phosphorus limited mountain lakes. The second factor (EF-2, Table 4) weights bottom oxygen limited, bottom warm lakes as opposed to cold well-oxygenated southern lakes. Therefore, for Argentinean lakes, climatic,

Table 4. Environmental factor analysis ordination for 108 Argentinean lakes at mid-summer. Percentage of total variance explained and factor loadings (> 0.30)

Variable	EF-1 (51.3%)	EF-2 (14.0%)
Surface area		–0.31
Volume	0.55	
Mean depth	0.83	
Colour (true)	–0.58	
Air temperature	–0.82	0.46
Frost-free period	–0.79	0.51
Latitude	0.53	–0.78
Altitude	0.37	0.54
Water temperature (at surface)	–0.75	0.51
Water temperature (at bottom)	–0.90	
Dissolved oxygen (at bottom)	0.38	–0.75
Total dissolved solids	–0.88	
Total alkalinity	–0.89	
Hardness	–0.76	
Anionic ratio	0.45	
Cationic ratio	0.60	0.37
Total phosphorus	–0.88	
Total organic nitrogen	–0.87	
Total organic carbon	–0.89	
TN : TP	0.62	

morphometric, and edaphic characteristics are usually closely related (Table 3; Quirós, 1991b).

The result of ordination was the arrangement of lakes in a low-dimensional space such that similar systems are close by and dissimilar lakes further apart. The northern warm-temperate and subtropical lakes and the Chaco-Pampa lakes (regions 3 and 2, respectively) were clearly separated from cold-temperate southern lakes (regions 4 and 5). However, some overlapping between Andean and Patagonian Plateu lakes is apparent, as well as between Pampa lakes and reservoirs situated in the Peri-Pampean Sierras region (Fig. 3). Two small subsets are clearly separated from the rest of lakes. The first includes four large and shallow lakes situated in the Patagonian Plateau region where cationic ratios are well below one. The second comprises five lakes located at higher altitudes in the Peri-Pampean region and with low dissolved oxygen concentrations at mid-summer.

A second factor analysis ordination was achieved using biological standing stocks and water transparency as lake variables. The first eigenvalue explained almost 70% of total variance and weights lakes according their biological standing stocks and water transparency (BF-1, Table 5). As expected, more transparent lakes have also lower phytoplankton, zooplankton, and fish biomass. However, for crustacean zooplankton and fish factor communalities are lower than for phytoplankton, microzooplankton and water transparency. Trophic interactions may explain those differences (Quirós 1990). Moreover, trophic cascade effects for Argentinean lakes have been addressed before (Quirós 1995; 1997a).

As expected, biological standing stocks are highly linked to environmental characteristics. The first environmental factor (EF-1, Table 4) explains a high percentage of the variation for the first biological factor (BF-1, Table 5; $R^2 = 0.75$). A high overlapping is apparent between Chaco-Pampa lakes and some small and shallow lakes and reservoirs situated in the Peri-Pampean Sierras region, and between more extended reservoirs located in the latter region and lakes and reservoirs located in the Patagonian Plateau (Fig. 4). However, higher differences for natural productivity might be expected for shallow lakes between southern lakes of the Patagonian Plateau and the Chaco-Pampa Plain and northern lakes, due to differences in growing season length.

Table 5. Factor analysis ordination for 108 Argentinean lakes at mid-summer, biological standing crop variables and water transparency. Percentage of total variance explained and factor loadings

Variable	BF-1 (69.5%)
Chlorophyll concentration	–0.92
Macrozooplankton biomass	–0.82
Microzooplankton biomass	–0.92
Fish biomass	–0.58
Secchi disk lecture	0.88

State of the environment health of the Argentinean lakes

The diverse water quality issues confronting Argentinean lakes include major types of pollution that are unregulated or uncontrolled. Most of these lake water quality problems are concentrated pollutants from untreated point source discharges resulting from industry and urban areas, and diffuse pollutants from unregulated non-point source discharges resulting from various activities that take place in a watershed such as agriculture, deforestation, logging, animal production, mining activities, urban runoff, wastewater treatment and on-site septic systems. During the last few decades, growth in population, urban and industrial expansion, and increase in recreational interests, have led to a greater demand for control of lake water pollution. However, point sources are still substantial in Argentina. A high percentage of the urban population of Argentina still discharge untreated effluents to inland waters, perhaps because of the relative abundance of river and lake waters available for dilution of effluents.

For Argentina, human population density is low as well as human population per lake surface area (Quirós 1997b).

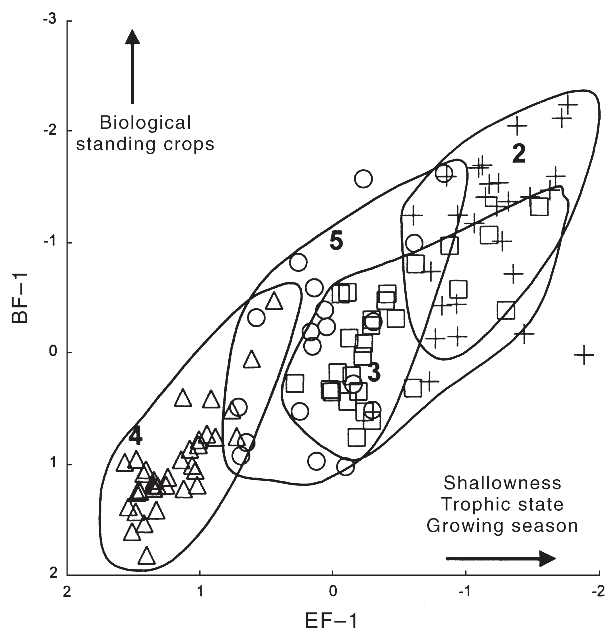

Fig. 4. Relationship between the first axis for environmental variables ordination (EF-1) and the first axis for biological standing stocks ordination (BF-1). See Tables 4 and 5 for factor loading weights.

Moreover, for some regions of Argentina (e.g. Patagonia region) large animal population density is higher for sheep and cattle than for it is humans (Di Pace 1992). Therefore, it is to be expected that the environmental state of the Argentinean lakes will usually be good. However, some lake water quality problems have often been reported for Argentina.

Most of the lakes situated in Patagonia are seldom disturbed. However, some distinct water quality problems have been reported for lakes situated near medium-sized urban concentrations (e.g., Lacar and Nahuel Huapi lakes) and for reservoirs located in rivers used for semi-intensive crop-land irrigation or fish farming. Erosion has increased rates of sedimentation in lakes and reservoirs, and has caused some deterioration in lowland lakes.

In the Chaco-Pampa Plain the lakes are naturally eutrophic or hypertrophic. Furthermore, these lakes are highly exposed to human uses of land and water resources (Quirós 1993) and are usually lightly impacted by agricultural operations, dairy, and other food processing industries. However, some impairment in their environmental state is actually apparent (Quirós, pers. obs. 1998). Moreover, an irrigation boom is expected for the Argentinean corn belt during the next few years.

Most of the reservoirs located in the central–western and northwestern arid regions of Argentina are highly impacted by irrigation agriculture, high slope cattle husbandry, soil erosion, mining, untreated sewage discharges, sugar cane mills, and other food industries (Gavilan 1981; Chambouleyron *et al*. 1993). Organic matter loads to reservoirs are usually high and very often reservoirs have their hypolimnion devoid of dissolved oxygen at mid-summer (Quirós 1988). For some of those reservoirs (e.g., San Roque Reservoir), heavy cyanobacterial blooms have been reported (L. Pizzolon pers. comm. 1997).

Argentinean freshwaters have experienced a number of introductions of and invasions by exotic invading plant and animal species during the last two centuries. Baigun and Quirós (1985) have reviewed introductions of freshwater fish species to Argentinean inland waters. Fish management in Argentina has usually been directed towards sport fisheries. Many of the exotics are now widespread and there are relatively few lakes that do not carry stocks of some non-native species, primarily rainbow trout (*Oncorhynchus mykiss*) or Argentinean silverside (*Odontesthes bonariensis*) native to the Pampa Plain. The latter species, a visual planktivorous fish, was spread in most of the reservoirs located in the Peri-Pampean Sierras. A heavy 'top-down' effect on algal biomass may be suspected there (Quirós 1990, 1998).

Most of the glacial lakes in Patagonia and Tierra del Fuego had been successfully colonized by introduced salmonids (Quirós 1991b). Rainbow trout stocks rapidly become established in Argentina and it is likely to occur, as a result of widespread and intensive efforts at stocking. However, salmonid introductions were unsuccessful for central–western and northwestern reservoirs (Quirós 1987). Other exotic fish, like common carp (*Cyprinus carpio*) is common to most northwestern reservoirs and in the last few years it has colonized most of the very shallow lakes in the Salado river basin (Pampa Plain).

DISCUSSION

Issues and constraints for Argentinean lake management

In Argentina, lake management is not a widely recognized profession. As in other developing countries, the immediate goals of water development are to support increasing levels of economic growth, and sometimes to conceive ways of increasing the availability of fresh water to meet anticipated demands. Only a few programs directed to control or eliminate lake pollution have been implemented. Among them, many programs have failed to eliminate lake pollution because of: (i) little or no funding provided to federal and local governments, (ii) a lack of adequate water legislation, (iii) fragmented authority and responsibility, (iv) a lack of accountability, (v) an overlapping of boundaries and jurisdictional disputes, (vi) inadequate technical expertise and poor problem solving skills, and (vii) a lack of public participation in lake water quality planning process.

Moreover, their approach has failed to recognize the interrelated processes and important linkages in the ecological systems of watersheds. Occasionally short-term solutions to lake water quality problems have been implemented based on the political jurisdictions of provinces and municipalities, instead of being based on ecological timeframes and watershed boundaries. In Argentina, many lake water quality programs have usually been started, and ended, in 'in-lake' 1-year studies for the variability of some lake characteristics.

Clean lake water is an essential resource for many ecosystem services and human activities. Water management at the watershed level was, to present, rarely used in Argentina. When it was recommended, it was never implemented. Best management practices for agriculture have usually been considered not necessary due to the low intensity of agriculture for most of the agricultural land in Argentina (Di Pace 1992). Furthermore, a sustainable use of marginal land in arid and semi-arid zones for a sustainable agriculture has not usually been exercised or even considered. However, actual agricultural intensification and diversification will produce large changes in water use and huge modifications for lake environmental state. An increase in conflicts of interests between abstractive users and instream users may be also expected over the next few years. Therefore, both approaches, the traditional end-of-the-pipe treatment and the more holistic watershed and integrated landscape management (Naiman 1992; Carpenter *et al*. 1998) should be implemented without delay for management of the Argentinean lakes.

For Argentina, little explicit information is available about the impact of introduced fishes on the native fauna. Avoiding ill-considered and frivolous releases of non-native fishes into lakes that do not already carry stocks of such species should be one of Argentina's lake management goals. However, it remains important to ensure that any further moves to widen the range of the non-native species are made only after careful consideration of the ecological risks and potential gains.

These results were obtained mainly from lake comparisons. However, each lake is unique, and a study and a good understanding of the unique features are essential for good lake management. Yet, there are also characteristics of watershed and lake behaviour that are, if not general, certainly shared by many individual lakes within each lake system. Lake managers can exploit this commonality in management studies, providing they are aware of where the commonality ends and the uniqueness begins. In fact, to the degree that management studies must surely depend upon the efficient use of resources, all such management is probably a compromise between unique and common features.

The classification we obtained for the Argentinean lakes is based on the premise of similar behaviour among lakes. As was stressed before (Reckhow *et al*. 1980), this is both a strength and a weakness. Its strength lies in the fact that the classification necessarily is not lake-specific, so that models and data are transferable to other individual lakes within each lake subset, keeping analysis costs low. Its weakness is that the ease of use of the results of the classification and related statistics can foster inappropriate use of the classification described herein and give an incomplete study of the unique features of a lake. This will lower management costs but will increase risks associated with poor management decisions. However, expectations not only dictate the model and theories we derive, they also determine the patterns in data we see and remark (Holling 1992). Again the lesson is to know the limitations of the general classification (Reckhow *et al*. 1980) for Argentinean lakes.

Argentina still has a larger proportion of its lake waters in natural conditions. However, expected developments for natural resources indicate that Argentina's goals for lake water management should include the preservation of some proportion of pre-European natural lake environment, and the evolution of a stable, managed lake environment in the more developed regions.

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