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GLOBAL CHANGE AND RIVER ECOSYSTEMS

Global changes in pampean lowland streams (Argentina): implications for biodiversity and functioning

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Abstract The rivers and streams in the pampean plains are characterized by a low flow rate due to the low slope of the surrounding terrain, high levels of suspended solids, silty sediment in the benthos, and reduced rithron; the riparian forest of this region has been replaced by low-altitude grasslands. Many of these environments contain a wide coverage of aquatic reeds, both submerged and floating, making the pampas limologically extraordinary. These terrains have undergone a gradual transformation in response to the progress of urbanization and agricultural activity in recent years with a resulting loss of biodiversity, leaving only few sites that continue to reflect the original characteristics of the region. Because of human activities in combination with the global climate change, variations have occurred in biological communities that are reflected in the structure and function of populations and assemblages of algae, macrophytes, and invertebrate fauna or in the eutrophication of affected ecosystems. The objective of this article is to describe the principal limnologic characteristics of the streams that traverse the Buenos Aires Province and relate these features with the predicted future global changes for the area under study. Considering the future climate-change scenarios proposed for the pampean region, the projected increment in rainfall will affect the biological communities. Higher rainfall may enhance the erosion and generate floodings; increasing the transport of sediments, nutrients, and contaminants to the ocean and affecting the degree of water mineralization. Changes in discharge and turbidity may affect light penetration in the water column as well as its residence time. The modifications in the use of the soil will probably favor the input of nutrients. This latter effect will favor autotrophy, particularly by those species capable of generating strategies for surviving in more turbid and enriched environments. An accelerated eutrophication will change the composition of the consumers in preference to herbivores and detritivores. The increase in global population projected for the next years will demand more food, and this situation coupled with the new

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scenarios of climate change will lead to profound socioeconomic changes in the pampean area, implying an increase in demand for water resources and land uses.

Keywords Pampean streams · Biotic communities · Fisico-chemical · Primary and secondary producers · Landscape

Introduction

Rising human pressure on water resources and the effects of climate change will probably affect the hydrological and geomorphological state of river systems in many areas of the globe. Hydrological variations will lead to a chain of effects on the structure and functioning of river systems. Hence, these effects are expressed in the loss or malfunction of the ecosystem services that they provide (Sabater, 2008).

As a consequence, freshwater systems have been especially threatened, having suffered a higher proportion of species and habitat losses than terrestrial or marine ecosystems. Moreover, this tendency will probably continue owing to water contamination, flow reduction as a result of irrigation and reservoir construction, and overfishing among other causes (McAllister et al., 1997). Despite the relatively small areas of the earth's surface covered by freshwaters as compared to other ecosystems, these limnic bodies sustain a major biotic diversity. South America is one of the continents with the greatest proportion of freshwater and is accordingly recognized for its great variety of aquatic environments and the extent of its biodiversity (Moyle & Leidy, 1992).

The area occupied by the Argentine pampas is heterogeneous with respect to geology, climate, and extent of land-surface relief (Cabrera & Willink, 1980). The Buenos Aires Province contains the highest demographic and industrial concentration in the country, the greatest agriculture and livestock production as well as the most intense use of agrochemicals, as a result of the great expansion of agriculture within the last 150 years. Because of such intensive human activity, many pampean rivers and streams are impacted by point sources of contamination from sewer effluents and industrial wastes and by diffuse pollution associated with crop cultivation and cattle raising (Salazar et al., 1996; Sala et al., 1998; Gómez & Rodrigues Capítulo, 2001).

Most watercourses that border large cities have suffered significant modifications. For example, the rivers that pass through Buenos Aires city have been either channelized or covered over since 1870. The basins more greatly affected by industrial activity were those of the Reconquista, Matanza-Riachuelo, and Luján rivers (del Giorgio et al., 1991; Rodrigues Capitulo et al., 1997; Gómez, 1998; Rodrigues Capítulo, 1999; Salibián, 2005). With respect to crop cultivation and cattle raising, the previously diversified agriculture (e.g., wheat, corn, sunflowers, and sorghum) has been supplanted by intensive soybean monocultivation; while the earlier free-range grazing of livestock has been partially replaced by the use of feed lots.

The pampas contains ca. 21 million inhabitants, accounts for 90% of the country's soybean production, and has accordingly been the region most affected by the expansion of this crop. Since most crops cultivated in Argentina are transgenic and soybean is the leading one among them that crop also results in a pronounced increase in glyphosate application (Vera et al., 2009). The use of this herbicide in large scale can stimulate the growth of picocyanobacteria (Pérez et al., 2007) or zooplankton (Paggi & José de Paggi, 2001) and thus potentially alter the biotic structure of the bodies of water.

Other common practices that have affected pampean lotic systems have been dredging and channelization of watercourses to avoid flooding. These engineering operations have involved neither an adequate degree of planning nor any recourse to advisory consultation; this oversight has resulted in loss of habitat for a variety of invertebrate fauna, amphibians, and fish. Moreover, these interventions have involved the destruction of natural riverbanks, affecting macrophyes and riparian vegetation, and have often been accompanied by a deterioration of water quality (Bauer, 2009; Licursi & Gómez, 2009). Finally, the advance of urbanization that progressively occupied cultivatable land and caused the displacement of livestock from their traditional areas to marginal lands situated in floodplains has increased the incidence of erosion and the input of particulate material into waterways.

Current models predict temperature and rainfall increases in the pampean plains (Hulme & Sheard, 1999). Under this climatic-change scenario we can expect an increased number of lakes, changes in their runoff patterns, and a greater discharge of water in the streams and rivers. These effects, combined with changes in the land use described above, will lead to a greater input of nutrients and contaminants into streams and rivers. In addition, the increase in sea level will promote the erosion of the current coastal profile, thus adversely affecting the geometry of the mouths of watercourses.

In this article, we discuss how these global changes could affect aquatic communities of the Pampa river systems. We describe the main limnological characteristics of streams in the province of Buenos Aires and relate these characteristics to the future predicted change for the area under study. On the other hand was analyzed a simulation of the increase in nutrients in a plains fluvial system with its headwaters subjected to unhabitual hydrologic irregularities attributable to global climatic changes resulting from human activity. The long-term aim was then to examine the resulting changes in the biological structure of the trophic network and the functioning of the metabolic processes in the resident communities.

Geology and geomorphology

The pampean plains are composed of quaternary sediments originating from the erosion of the Andes mountain range and extend over an area of approx. 500,000 km^2. This flat landscape has topographic slopes that vary between 0.1 and 1 m/km but is interrupted by occasional high hills that arose during the Tertiary Period, barely exceed altitudes of 1,200 m above sea level, and occupy small areas (e.g., the Tandil and Ventana hills). Different strata of sediments reflect earlier dry and wet periods as well as the incursions of the sea. The subsurface strata are formed by slimes rich in sulfates and chlorides along with sand and clay, which compositions characterize the river and stream beds (Andrade, 1986).

The soils are composed mainly of loess, which component favors the movement of particulates and facilitates the new formation of clays that in turn generate the reducing conditions conducive to the preservation of organic material within the profile of the strata. For this reason, the soils of the area are generally fertile with a high content of nutrients and a marked capacity for cationic interchange, predominantly involving calcium (Papadakis, 1980).

Because of the plains' extensive area—both with respect to latitude and longitude—the temperatures there vary between average annual values of 18°C in the north and 12°C in the south; and the annual rainfall ranges between 600 mm in the west and 1,000 mm in the east, with maximum precipitations occurring toward the end off summer or the beginning of autumn. July, the coldest month, has an average minimum temperature below 10°C and January, the warmest, and an average of 22°C. In contrast, the most westerly region is dry and of a moderate climate, exhibits the greatest overall temperature range, and is characterized by hydrologic deficits during the warmest months.

Physiognomy of the landscape

According to Parodi (1942) the intense competition of the graminoids for water in periods of rainfall deficit would have impeded the establishment of hardwood trees within the region. For this reason, grassland is the dominant physiognomy.

In spite of this characteristic feature, large modifications of the pampean landscape have resulted from the introduction of plants and animals by the European settlers (Brailovsky & Foguelman, 1992). The changes occurred mainly in the profiles of the meadowlands as well as through the introduction of thickets of *Baccharis* spp. in elevated areas and of *Solanum glaucophyllum* in the lower regions, among others. There are vestiges of xerophilic woods within limited spaces, such as *tala* (*Celtis tala*) and *espinillo* groves (*Acacia caven*; Burgueño, 2005).

Hydrology

The predominant bodies of water in the pampean plains are shallow lakes and ponds. Moreover, in some areas, despite the slight regional topographic slope of 1 m/km, the drainage network exhibits a high density of stream and rivers 0.16 km/km^2 (Sala et al., 1998).

The pampean rivers have been grouped into four categories according to their drainage basins and geomorphology (Frenguelli, 1956; Ringuelet, 1962): (1) the Salado-River system (situated in the pampean depression with an overall basin area of 80,000 km^2); (2) the closed basins in the south and southwest vertants of the Bravar and Curamamal mountains (the endorheic system of Chasico) and the Vallimanca stream system, it being actually connected to the latter system; (3) the tributaries of the Paraná River and the Río de La Plata (the Paraná-Plata basin); (4) the watercourses of the Atlantic slope and those originating in the Sierra de la Ventana and Tandil hills. The Paraná and Uruguay rivers furthermore drain into the Río de La Plata estuary and influence the pampean hydrographic network changing the regional geomorphology (Fig. 1).

Physicochemical characteristics

In general, because of the low slope of the plains, the flow rates of the streams are low (<0.4 m s^{-1}), a value exceeded only in periods of freshets or in those streams whose sources are localized in the mountainous systems of the area (Rodrigues Capítulo et al., 2002). Giorgi et al. (2004) estimated the transport capacity and the degree of retention of particulate material and nutrients during the spring and summer months of 2003 and 2004 in some first-order streams located in the north east of Buenos Aires Province. At discharges ranging from 0.01 to 10 l s^{-1}, the fine

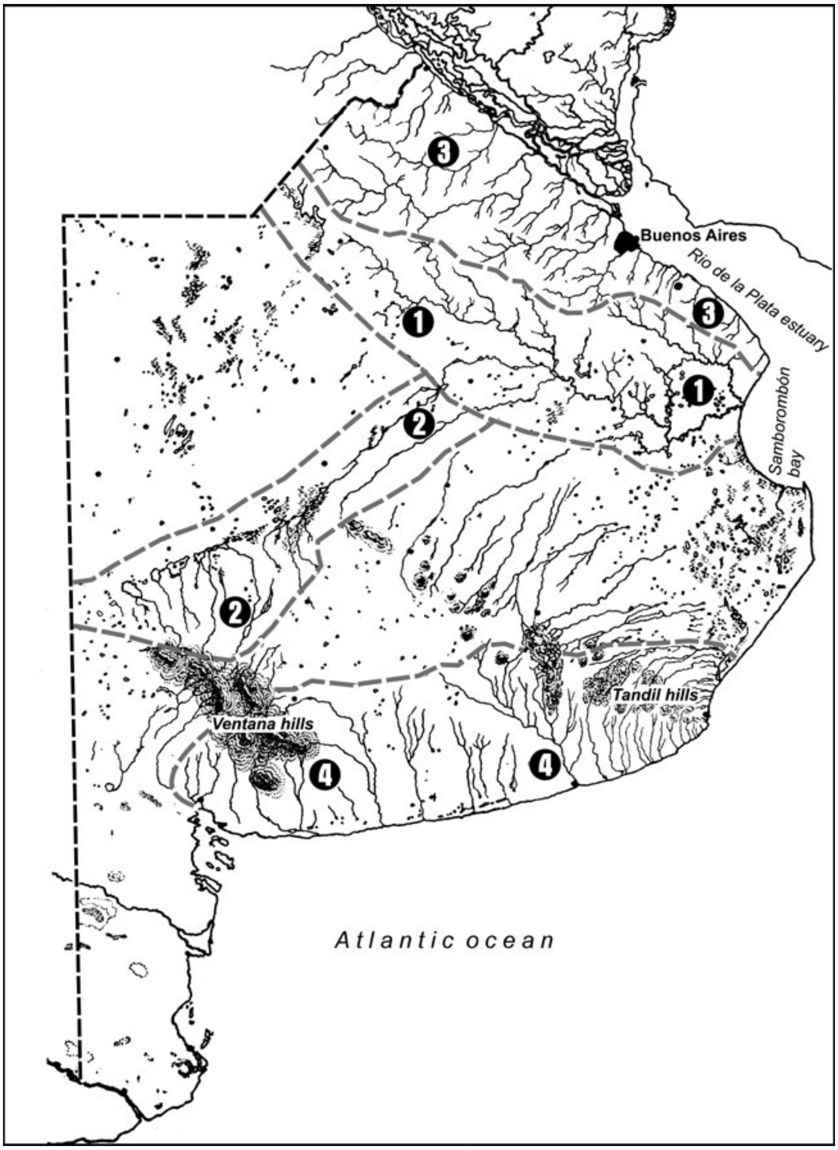

Fig. 1 Hydrographic basins of the Province of Buenos Aires (modifies of Frenguelli, 1956; Ringuelet, 1962): (*1*) Salado-River system; (*2*) basin without drainage arising from the south and southwest vertants of the Bravar and Curamamal mountains and the Vallimanca stream system; (*3*) tributaries of the Paraná River and the Río de La Plata (the Paraná-Plata basin); and (*4*) the watercourses of the Atlantic slope and those originating in the Sierra de la Ventana and Tandil hills

(between 2 mm and 50 μ) and ultrafine (<50 μ) particulate materials predominate except in the instance of the Pereyra stream where drifting methaphyton become trapped in gross particulate material (>2 mm). The streams generally have a high conductivity as result of the presence of the dissolved substances that are transported, with the total soluble solids fluctuating between 0.5 and 1.0 g l^{-1}. The low flow velocities increase the nominal travel time (NTT), the latter being considered an estimation of a stream's hydrologic-retention time (Hauer & Lamberti, 1996) and varying between 45 s^{-1} and 5 h within a reach of 100 m (Table 1).

The sinuosity of the first-order streams is low, ranging between 1 and 1.07; the relative roughness fluctuates between 1.06 and 2.60, while the Reynolds number is variable, ranging from low (12), with laminar flow, to medium-turbulent (>3,000). Moreover, the Froude number, varying from 0 to 0.59—with 1.0 corresponding to turbulence—would also indicate laminar flow.

Given their low flow rates, the streams have limited transport capacity. This parameter, however, becomes modified in accordance with increments in the order of the rivers and after a spate, with the latter usually occurring about twice a year during autumn and the late spring, as a result of higher precipitation. The low infiltration capacity of the soil owing to the high percentage of clay, which component reduces the drainage and elevates the runoff (Fidalgo, 1983), contributes to the autumn and spring spates (Table 2).

Hydrochemical characteristics

Pampean streams are characterized by alkaline waters with high conductivity and elevated dissolved-oxygen and nutrient concentrations (Feijoó et al., 1999; Bauer et al., 2002; Feijoó & Lombardo, 2007). In a study conducted on 41 streams of Buenos Aires Province, the conductivity correlated with chloride concentrations, which values exceeded by one or two

Table 1 Mean values and standard deviation (±) of transported materials in pampean streams according to (Giorgi et al., 2004) (for soluble solids the units are g l^{-1}, for the others are mg l^{-1}

	Haras	Gutierrez	Chaña	Pereyra	Nutrias
Soluble solids	0.638 ± 0.126	0.648 ± 0.090	0.583 ± 0.146	0.775 ± 0.220	0.707 ± 0.214
Ultrafine particles (DW)	0.096 ± 0.063	0.069 ± 0.055	0.048 ± 0.042	0,079 ± 0.083	0.205 ± 0.125
Fine particles (DW)	0.503 ± 0.307	0.123 ± 0.134	0.191 ± 0.318	0.329 ± 0.437	0.004 ± 0.008
Coarse particle (DW)	0.177 ± 0.251	0.103 ± 0.201	0.027 ± 0.039	3.713 ± 5.343	0.002 ± 0.003
Ultrafine particles (AFDW)	0.009 ± 0.003	0.009 ± 0.005	0.006 ± 0.004	0.010 ± 0.010	0.026 ± 0.014
Fine particles (AFDW)	0.058 ± 0.042	0.018 ± 0.021	0.031 ± 0.055	0.110 ± 0.188	0.001 ± 0.003
Coarse particles (AFDW)	0.054 ± 0.079	0.055 ± 0.107	0.013 ± 0.025	2.737 ± 4.496	0.000 ± 0.000

Table 2 Mean values and standard deviation of flow and loads of particulate and dissolved substances at two sampling stations (S1 and S2) in the Las Flores Stream at normal conditions

	Normal conditions		Flooding conditions	
	S1	S2	S1	S2
Flow (l/s)	40.6 ± 27.5	79.6 ± 46.8	491.9	240.2
TDS (mg/s)	0.7 ± 0.2	0.7 ± 0.2	0.4	0.2
SPM (mg/s)	637.3 ± 1022.0	637.0 ± 570.7	27378.0	6437.3
POM (mg/s)	63.7 ± 69.9	97.9 ± 79.3	1340.3	558.4
SRP (mg/s)	32.3 ± 25.7	48.2 ± 35.7	228.5	105.0
DIN (mg/s)	173.0 ± 154.7	345.2 ± 342.3	375.0	685.4

Values obtained during the flood of April 1993 are indicated separately. *DIN* dissolved inorganic nitrogen ($NO_3^- + NO_2^- + NH_4^+$), *TDS* total dissolved solids, *SPM* suspended particulate materials, *SRP* soluble reactive phosphorous (Giorgi et al., 2005) orders of magnitude the average concentration worldwide (e.g., 8.3 mg l^{-1}) (Berner & Berner, 1987). The chloride levels tended to increase toward the west, where the more arid conditions favor water evaporation and salinization. In general, bicarbonates tended to exceed carbonates (Feijoó & Lombardo, 2007).

The dissolved-phosphorus and nitrogen- concentrations in streamwater are relatively high compared to other lotic systems of the world (Omernik, 1977; Binkley et al., 2004). The mean nutrient values reported for Province of Buenos Aires were 0.17 mg l^{-1} of soluble reactive phosphorus and 1.50 mg l^{-1} of nitrate (Feijoó & Lombardo, 2007). According to the criteria of the Environmental Protection Agency (EPA, 2000), the pampean streams could be classified as eutrophic upon consideration of their phosphorus concentrations, but as mesoeutrophic on the basis of their nitrate levels. The nutrient levels of the pampean streams exceeded those reported for so-called pristine environments, but were not so high as would be expected for intensively cultivated basins (Amuchástegui, 2006)—at least with respect to nitrogen, the nutrient more associated with agricultural activities (Mugni et al., 2005; Feijoó & Lombardo, 2007).

Evidence suggests that eutrophic conditions in the pampean streams are not solely associated with agricultural and cattle-raising activities developed within the region. The analysis of pollen-DNA sequences at some sites within the pampas revealed the existence of bodies of water at an advanced stage of eutrophication with abundant aquatic genera typical of such enriched conditions (Prieto, 1996; Zárate et al., 2000), considerably before the introduction of cattle by the Spaniards during the Colonial period and the rise of agriculture during the nineteenth century.

Nutrient levels in streamwater vary seasonally; especially at high flows (Vilches et al., 2008) and in response to a rainfall, when increments in phosphorus and nitrogen levels are usually observed (Mugni, 2009).

Decomposers

The information on the identity and abundance of decomposers in the pampean streams is scant and fragmentary. Bacterial densities reported for the sediments and water columns are of the orders 10^6–10^8 and 10^6–10^7 l^{-1}, respectively, depending on the variations in the concentration of organic material and the season, with higher values being recorded in the warmer periods (Cochero et al., 2008; Sierra, 2009).

Many of the principal taxonomic groups involved in the mineralization of organic material are the zoosporic organisms; the following genera were among the most frequent encountered in the sediment: *Pythium*, *Catenophlyctis*, *Rhyzophlictis*, *Aphanomyces*, *Achlya*, *Dictyuchus*, *Saprolegnia*, *Rhizophlyctis*, and *Nowakowskiella* (Marano et al., 2008; Sierra, 2009).

Primary producers

Phytoplankton

The composition and dynamics of the phytoplankton communities in the rivers that traverse the pampean plains are modified principally by the physiography, the geochemistry, and the various uses of the land (Bauer, 2009). In the streams with current velocities lower than 0.4 m s^{-1}—and particularly in those segments with a greater concentration of nutrients—the phytoplankton density can exceed 10^4 cells ml^{-1}. These characteristics are often observed in streams that originate in shallow depressions, with minimal slope and slow, allowing a longer residence time and thus favoring phytoplankton development. In the sources of mountain streams a greater proportion of benthic algae are observed in the water column as a result of the drift of pennate diatoms, particularly *Navicula tripunctata*, *Rhoicosphenia abbreviata*, *Nitzschia fonticola*, and *N. recta*. The phytoplankton composition also varies with the water turbidity: the streams that originate in the plains usually contain a greater proportion of suspended solids, frequently resulting in the development of loricate euglenophytes (e.g., the genera *Strombomonas* and *Trachelomonas*). With an increase in the stream order, the chlorophytes and cyanophytes predominate, and the development of a true potamoplankton becomes observable.

The algal biomass, expressed as the amount of chlorophyll *a* (Chl *a*), is variable and ranges between <10 μg l^{-1} and >400 μg l^{-1} between sites of low and high anthropic impact, respectively.

The natural hydrochemistry of the lotic systems is also recognized as a significant influence on the characteristics of the resident phytoplankton: elevated concentrations of bicarbonate plus carbonate, calcium, and magnesium favor the development of species such as *Fragilaria acus*, *N. tripunctata*, *N. fonticola*, *N. recta*, and *Ulnaria ulna*; whereas low levels of these electrolytes are conducive to the growth of, for example, *Strombomonas treubii*, *Trachelomonas intermedia*, *T. volvocina*, and *Dictyosphaerium subsolitarium* (Bauer, 2009).

The frequent dredging of the streams and rivers of the pampean plains, in order to compensate for the excess to drain water accumulation in the floodlands, influence the characteristics of the phytoplankton. This dredging produces changes in the chemical composition and turbidity—and thus the light penetrability—of the water (Licursi & Gómez, 2009). Among the principal observable alterations are a reduction in the phytoplankton density, an increment in the phaeopigments, and a change in the composition of the phytoplankton community (Bauer, 2009).

Phytobenthos

The phytobenthos of the pampean lotic systems, and particularly those of shallow depth and low velocity, can harbor a diverse biota ranging from the customary benthic organisms to epiphytic species of plankton that survive and develop within the epipelon. The diatoms are one of the groups most widely represented in this community, but whose distribution is influenced by the stream's hydrochemistry. Thus, many of the described species have a preference for high concentrations of HCO_3^{1-}, Ca^{2+}, and Mg^{2+} (e.g., *Achnanthes minutissima*, *Amphora pediculus*, *Cocconeis placentula*, *Navicula capitatoradiata*, *N. tripunctata*, *N. gregaria*, *N. veneta*, *Nitzschia calida*, *Nitzschia dissipata*, and *Rhoicosphenia abbreviata*); carbonates (*Diadesmis confervacea*, *Navicula trivialis*, *Gomphonema gracile*, *Cymbella silesiaca*, *Pinnularia gibba*, *Gomphonema parvulum*, *Nitzschia brevissima*, *Caloneis bacillum*, and *Luticola mutica*); or chlorides (*Surirella striatula*, *Gyrosigma attenuatum*, *S. acuminatum*, *Nitschia compresa*, and *N. sigma*).

Contamination of the water also can modify the taxonomic profile of the affected stretches of a stream so as frequently to promote the abundant growth of species such as *Navicula subminuscula*, *Navicula pygmaea*, *Diadesmis confervacea*, *Achnanthes hungarica*, *Nitzschia umbonata*, *Sellaphora pupula*, *Gomphonema parvulum*, *Sellaphora seminulum*, and *Nitzschia palea* (Gómez, 1998; Gómez & Licursi, 2001; Licursi & Gómez, 2002). Seasonal variations have also been observed: Chlorophytes (e.g., *Cladophora glomerata* and *Spirogyra* spp.) and the filamentous cyanobacteria (e.g., *Oscillatoria limosa*, *O. tenuis*, and *Lyngbia limnetica*) can reach a major representation during the spring and summer.

The biomass of the phytobenthos (i.e., the Chl *a* levels) can vary as a function of the season (e.g., being greater in spring or fall) and the enrichment of the watercourses with organic material and nutrients. Giorgi (1998) mentioned values over the years ranging from 5 to 14 mg Chl *a* m^{-2} for some pampean watercourses studied (Fig. 2), although Sierra (2009) reported much higher values at more than 700 mg Chl *a* m^{-2} for enriched streams.

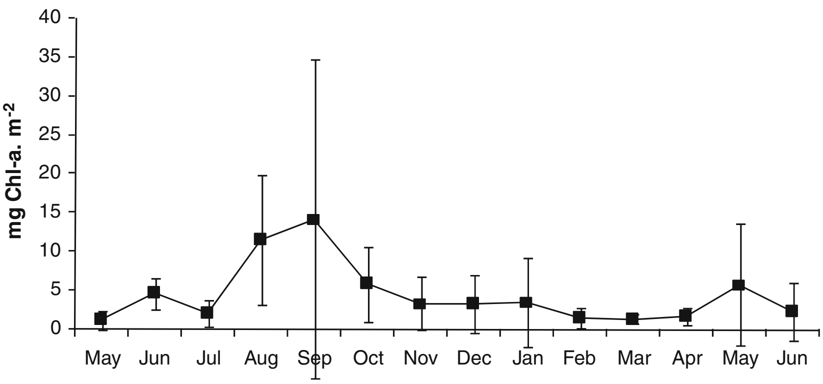

Fig. 2 Chlorophyll *a* variation of epipelic algae in Las Flores stream reach (1992–1993) (Data from Giorgi, 1998)

Epiphyton

The taxonomic richness of the epiphyton can vary in accordance with the species of macrophyte that is being colonized. *Ceratophyllum demersum* harbors more species than do *Potamogeton* and *Egeria densa*, with 10–20 species per plant normally being accommodated during the vegetal substrate's growth periods and as many as 100 species per plant when the epiphyton community has become stabilized. The following are among the species most often colonizing the macrophytes: *Cocconeis placentula*, *Eunotia pectinalis*, *Gomphonema angustatum*, *Melosira varians*, *Roicosphenia curvata*, *Ulnaria ulna, Spirogyra* sp., and *Oscillatoria* spp. (Giorgi, 1998). The biomass of the epiphyton depends on multiple parameters, with the most influential being: the type and variations in the plant substrate, the presence of floating plants that interfere with the penetration of light, the abundance of herbivorous forms, the competition for nutrients, and the effect of increases in the current flow velocity (Stevenson et al., 1996). Because of these influences the epiphyton biomass is highly variable, ranging from minimal values of 5 mg Chl *a* g^{-1} dry weight during the growth periods of the vegetal substrate to a maximum of 100 mg Chl *a* g^{-1} when the community becomes stabilized (Giorgi 1998) (Fig. 3). Finally, the maximal biomass can also vary in accordance with the nature of the substrate colonized: for example, during the same period greater biomasses have been registered for *Egeria densa* than for *Potamogeton* or *Ceratophyllum demersum* (Giorgi et al., 2005) (Fig. 4).

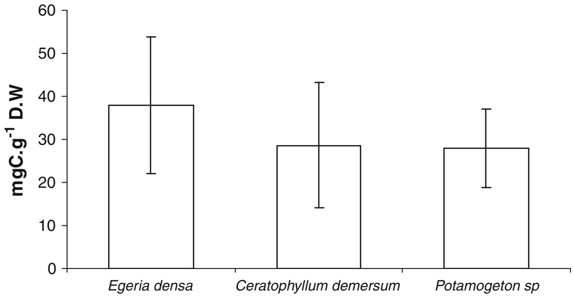

Fig. 4 Biomass (mean and standard deviations) of the epiphyton on three genera of macrophytes frequently present in pampean streams in natural conditions (colonization for 60 days). Samples of year 2004 at Las Flores stream (Data from Giorgi et al., 2005)

Metaphyton

The Zygnemateles (*Spirogyra* spp, *Zignema* spp) develop in the headwaters of streams and in certain rivers of greater order. The presence of these algae seems to be favored under conditions of high nutrient concentrations, low current velocities, and a sparse development of macrophytes. The group remains associated with the streambed during the cold season but detaches itself from the bottom at the beginning of spring to form mats of floating filamentous algae (Giorgi, 1998).

Macrophytes

The low current velocity, the absence of riparian trees, and the high concentrations of nutrients characteristic of pampean streams favor the development of dense macrophyte communities of broad diversity.

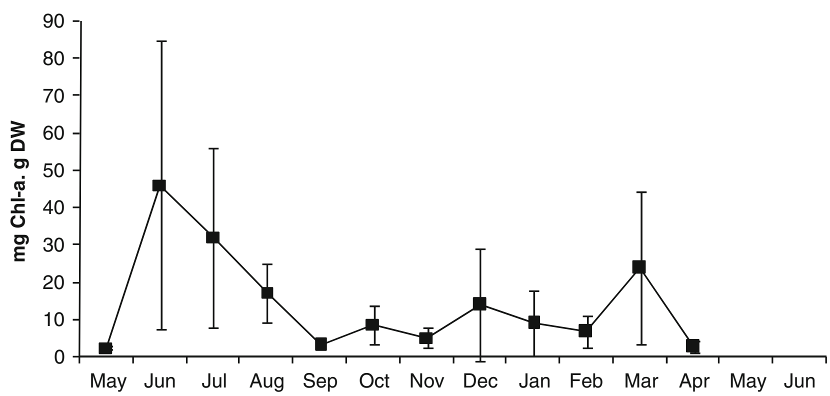

Fig. 3 Chlorophyll *a* variation of epiphytic algae in Las Flores stream reach (1992–1993) (Data from Giorgi, 1998)

Species richness varies markedly among streams and throughout the year (Feijoó & Lombardo, 2007). For instance, Gantes & Tur (1995) reported for Las Flores stream 16 species of macrophytes (10 rooted, three submerged, and three free-floating). The taxa most frequently observed are *Azolla filiculoides*, *Lemna* spp., *Potamogeton* spp., *Stuckenia striata*, *Ceratophyllum demersum*, *Rorippa nasturtium-aquaticum*, *Schoenoplectus californicus*, *Ludwigia peploides*, and *Hydrocotyle* spp. Almost all these taxa are native or cosmopolitan, and only *R. nasturtium-aquaticum* was introduced from Europe.

Although the pampean streams are typically characterized by low current velocities, this feature is influential in determining the spatial distribution of the aquatic vegetation patches (Gantes & Sánchez Caro, 2001). Species such as *S. californicus*, *L. peploides*, *Alternantera filoxeroides*, and *Typha dominguensis* are often found in middle and lower reaches, while *S. striata* predominates in stream segments with flow rates greater than 0.40 m s^{-1} (Rodrigues Capítulo et al., 2002). The macrophyte biomass varies throughout the year and is highest during spring and summer when submerged and emergent (rooted) species predominate (Fig. 5).

The composition of aquatic-plant communities within the pampean streams reflects the eutrophic status of their water and has been related to conductivity level and nitrate concentration (Feijoó & Lombardo, 2007).

Although the pampean streams have beds formed with fine sediments and only occasionally with pebbles or rocks; the environmental heterogeneity results not from the different types and sizes of the substrata but rather from the presence of aquatic plants of diverse architecture that shelter a rich and dense invertebrate community, mainly herbivores that feed on epiphytic algae (Rodrigues Capítulo et al., 2002; Tangorra, 2004).

Primary production

Primary production in the pampean streams can reach high levels because of the good light reception—this feature being favored by the scarcity of trees along the banks—plus adequate concentrations of nutrients. Nevertheless, an increment in humic substances and variations in the stream's discharge can modify the production values markedly. A study comparing the primary production per area of different communities (macrophytes, epiphyton, and phytobenthos) reported that the macrophyte contribution represented some 60% of the total primary production in summer and 40% in winter (Vilches & Giorgi, 2008). This production decreases after a significant increase in the stream's discharge because of the removal of the macrophytes. As a consequence, epiphyton production also decreases so that the epipelon production that remains becomes a significant contribution to the system's overall production. Vilches & Giorgi (2008), investigating the headwaters of a pampean stream, reported production values for macrophytes of above 14 g C m^{-2} day^{-1} during both summer and winter; for epiphyton of around 9 g C m^{-2} day^{-1} in summer, but above 16 g C m^{-2} day^{-1} during winter; and for epipelon below 0.5 g C m^{-2} day^{-1} in summer, but around 0.3 g C m^{-2} day^{-1} in winter. These production data, however, can vary significantly with the

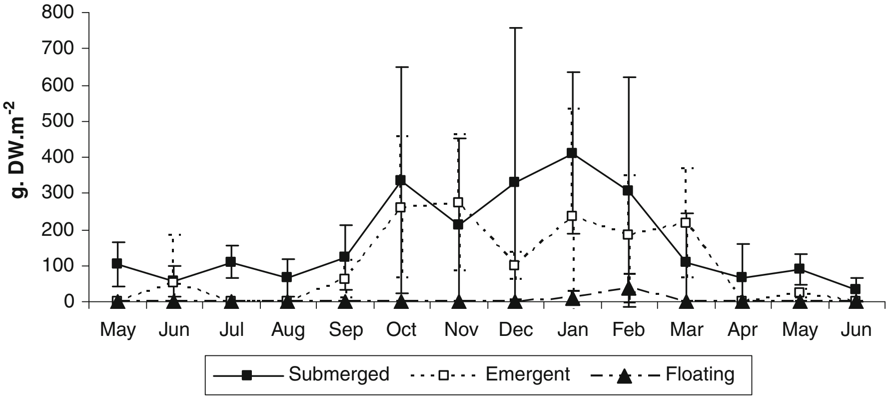

Fig. 5 Macrophyte biomass variation (mean and standard deviations) in a Las Flores stream reach (1992–1993) (Data from Giorgi, 1998)

nutrient concentrations available in the medium (Sierra, 2009).

A large macrophyte biomass is a significant ecologic feature of pampean streams. Although the plants can be used as a resource by herbivors (e.g., snails and phytophagic insects of terrestrial origin), most of the plant biomass is actually consumed by decomposers and detrivores. The dynamics of this decomposition, however, has still not been characterized.

Consumers

Zooplankton

The rotifers constitute one of the more broadly represented groups among the zooplankton and play a key role in the recycling of nutrients and in the secondary production in aquatic environments. Rotifers can use a wide variety of food sources including the algae, protozoa, and detritus and are thus important links for the transfer of carbon within the trophic chain (José de Paggi, 2004). The following species are the most frequently found in pampean streams: *Brachionus angularis*, *B. caudatus*, *B. rotundiformis*, *B. plicatilis*, *Filinia longiseta*, *Keratella cochlearis*, *K tropica*, *Synchaeta* spp., and *Polyarthra vulgaris*. The ciliates are also well represented by *Codonella cratera*, *C. fimbriatus*, *and Tintinidium fluviatile*. The tecamebas of the genera *Arcella*, *Difflugia*, *Centropixis*, and *Euglypha* constitute a tychoplanktonic group habitually present in the zooplankton (Modenutti, 1987). The profile of the planktonic microcrustaceans (copepods and cladocerans) in the rivers is reduced and is, in turn, conditioned by the current velocity and the particular solids in suspension that influence the filtering organisms (José de Paggi, 1984). The most frequently present taxa are: *Notodiaptomus imcompositus*, *Acantocyclops robustus*, *Moina micrura*, *Bosmina huaronensis*, *Ceriodaphnia dubbia*, and *Metacyclops mendocinus*.

Invertebrates

The low slope of the terrain; the absence of riparian vegetation along the banks; the predominance of clay and slime; and the presence of submerged, emergent, or floating macrophytes are the principal features that condition the development of an invertebrate aquatic fauna—an assemblage that could, in many instances, resemble the one present along the banks of the lentic environments of the region. Only in the mountain headwater streams of Tandil and Ventana and in those of the northeast of the Province of Buenos Aires are possibly found more rheophilic fauna.

The streams that both originate in the plains and are minimally impacted by anthropic activity are characterized by abundant plant detritus; which component attracts the presence of detrivors, such as the tubificid oligochaetes or nematodes, although the nadids of the following genera are also abundant: *Nais*, *Dero*, *Chaetogaster*, *Pristina*, and *Stylaria*. Among the filtering mollusks frequently present within the soft sediment are the nacriferous clam *Diplodon delodontus delodontus* (Pelecypoda) and the gastropod *Heleobia parchappei* (Rodrigues Capítulo et al., 2003).

Associated with the vegetation are the Planorbiidae (*Biomphalaria peregrina* and *Drepanotrema kermatoides*), the Ancylidae (*Uncancylus concentricus*), and the Ampulariidae (*Pomacea canaliculata*. Among the larger-sized crustaceans the decapods *Palaemonetes argentinus* and *Macrobrachium borellii* contribute a significant biomass, while the amphipod *Hyalella curvispina* is well represented particularly in the spring and summer (Fig. 6), (Giorgi, 1998; Rodrigues Capítulo et al., 2002).

Among the abundant microcrustaceans present are the copepods (Cyclopoida, Harpacticoida, and Ostracoda) and the cladocerans Chidoridae, Macrothricidae, and Daphnidae. Likewise, almost always represented are the leeches (Glossiphonidae) and the acarians (Hydrachnidae) (Rodrigues Capítulo et al., 2003).

Among the insects, normally abundant are the larvae of the mayfly families Caenidae (*Caenis nemoralis*), Polymitarcyidae (*Campsurus major*), and Baetidae (*Callibaetis guttatus*) of the order Ephemeroptera along with the preimaginal stages both of the families Ceratopogonidae, Ephydridae, and Chironomidae (*Chironomus*, *Goeldichironomus*, and *Tanypus*) of the order Diptera and of the families Hydrophilidae (*Tropisternus*, *Berosus*), Dytiscidae, and Elmidae of the order Coleoptera. Likewise, frequently encountered are the odonate families Coenagrionidae (*Cyanallagma bonariense*), Aeshnidae (*Aeshna bonariensis*), and Libellulidae (*Mycrathyria dydima*, *Orthemis nodiplaga*, and *Erythordiplax nigricans*) as well as the trichopteron families Polycentropodidae (*Cyrnellus* sp.) and Limnephilidae

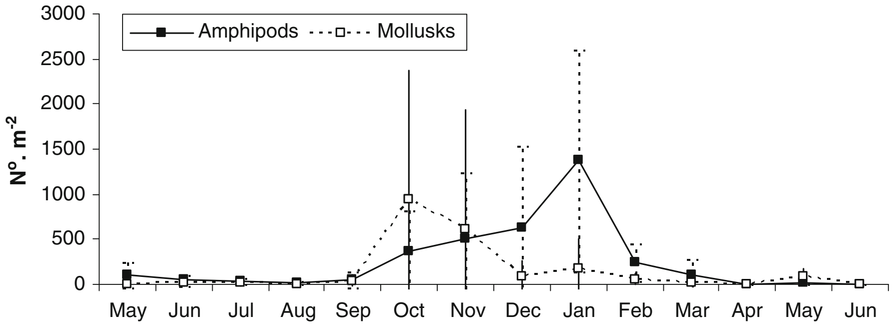

Fig. 6 Variation of amphipods (*Hyalella* sp.) and mollusks (*Heleobia piscium* and *Uncancylus concentricus bonaeriensis*) (mean and standard deviations) in Las Flores stream reach (1992–1993). (Data from Giorgi, 1998)

(*Verger bruchina*) in addition to a single species of Leptoceridae. Finally, the vegetation is frequented by the hemipteron families Hebridae (*Hebrus*), Belostomatidae (*Belostoma elegans*), and Notonectidae (Rodrigues Capítulo et al., 2003; Ocón & Rodrigues Capítulo, 2004).

The streams with sources in the pampean hills of the Province of Buenos Aires that have a current velocity of >0.5 m s^{-1} develop a more rheophilic aquatic vegetation and have a different fauna. The hydrophyte *Stuckenia striata* provides a high degree of coverage within the segments of greater slope in these systems and is colonized by numerous rheophilic invertebrates, such as the simulids (*Simulium bonariensis*), the mayflies (*Callybaetis*, *Baetis*), the zygopterans (*Oxyagrion hempeli* and *Andinagrion saliceti*), the caddis flies (*Hydroptila sauca*), rheotopic forms of chironomids (*Cricotopus* sp., *Rheotanytarsus* sp., *Hienemanniella* sp., and *Pentaneura* sp.), beetles (Elmidae), and gastropods (*Chilina* sp.) (Rodrigues Capítulo et al., 2002). In the rithronic mesohabitats with greater vegetal coverage, populations of the trichopteran filterer *Smicridea pampeana* (Hydropsychidae) are found at high density. Along the banks and within the pools, the emergent plants, such as *Schoenoplectus californicus* and *Thypa dominguensis*, are commonly present; where they support mollusks and odonates. In the lower segments of these hill streams with low current velocity, the macrophytes are abundant, covering between 15 and 60% of the stream beds. There, the macrophytes *Hydrocotyle ranunculoides*, *Alternanthera philoxeroides*, and *Ludwigia peploides* are colonized by the amphipods (*Hyalella curvispina* and *H. pampeana*), the beetles (*Berosus* sp. and *Tropisternus* sp.), the odonates (Libellulidae and Aeshnidae), the gastropods (Planorbidae, Ampullaridae, Hidrobiidae), and the mayflies (Caenidae).

The variation in the composition and relative abundances of the invertebrate assemblages is notable when the summer and winter periods are compared. For example, the Hydrophylidae, Gastropoda, and Chironomidae are the dominant taxa during the coldest months; while the Chironomidae, Simuliidae, and Baetidae are the most common families in summer. For its part, *Hyalella curvispina* is present at high densities within the intermediate stretches of these streams throughout the year (Rodrigues Capítulo et al., 2002) (Fig. 6).

While macrophytes play an important role in the composition of the biota of pampean streams, no obvious difference is apparent among the functional groups that feed directly on them, except for gathering–collector groups that are always dominant. Moreover, no significant changes are evident between the more natural lotic systems and those that have become enriched with organic matter and nutrients (Fig. 7).

Fish

The wider diversity and spatial differences encountered along the watercourses of the Province of Buenos Aires would arise from the direct connection of their lower segments with the Río de La Plata and the Paraná River. The high diversity among the fish that populate the streams of the pampean plains became emphasized in the recent study by Colautti et al. (2010) that identified a total of 24 species throughout four samplings performed at two sites of the La Choza stream in the Buenos Aires province.

The species composition of the ichthyic communities in the pampean plains is strongly linked to the Paraná-Plata basin of South America (Ringuelet, 1975). Of those species, 7% (approximately 24) reach the Salado River (Fig. 1) and its surrounding systems

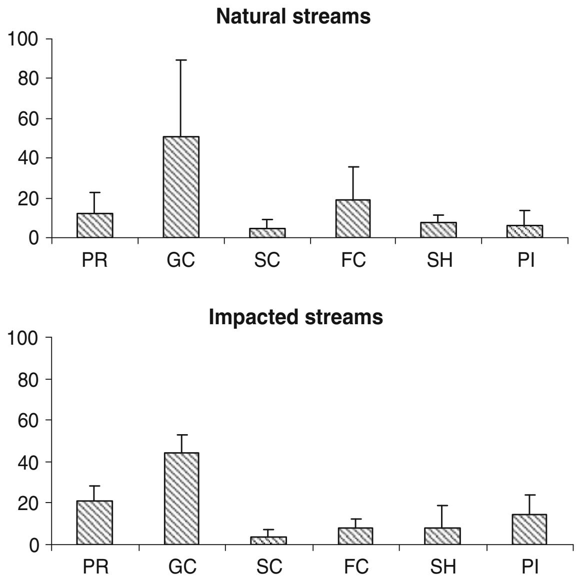

Fig. 7 Principal functional feeding groups of invertebrates (%) in natural and impacted urban streams of pampas. *PR* predators, *GC* gathering collectors, *SC* scrapers, *FC* filtering collectors, *SH* shredders, *PI* piercers (Data from Tangorra, 2004; García et al., 2010)

within the geomorphologic unit known as Depressed Pampa (*Pampa Deprimida*). According to Ringuelet (1975), the distribution of species there appears to coincide with an ecologic area where mainly the low temperatures and excessively salty character of the water become translated into limiting survival conditions.

The most widely represented fish groups are the Characiformes (three families, 10 species) with a predominance of *Cheirodon interruptus*, *Bryconamericus iheringii*, and *Pseudocorynopoma doriae* (Characidae) plus *Cyphocharax voga* (Curimatidae; Almirón et al., 2000; Di Marzio et al., 2003; Remes Lenicov et al., 2005; Fernández et al., 2008; López et al., 2008). Those taxa are predators predominantly of micro- and mesoinvertebrates (Escalante, 1983), and their abundance is favored by the presence of submerged or floating aquatic vegetation.

These characteristics of the habitat in combination with slow current velocities favor the development of the Perciformes (cichlids), likewise predators of micro- and mesofauna. In this regard, the ichthyophage predator *par excellence* within these environments is the species *Hoplias malabaricus* (family Atherinidae) (Ringuelet, 1975), though the ingestion of shrimp and macrophytes is common in its diet (Destefanis & Freyre, 1972; Oliveros, 1980).

The Siluriformes (three families, seven species) in general inhabit slime and clay streambeds and exhibit varied feeding regimens: they are algivorous, consuming micro- and mesoinvertebrates in the benthos, as well as detrivorous (Ringuelet, 1975). Among the Cyprinodontiformes, the species *Jenynsia multidentata* and *Cnesterodon decemmaculatus* have colonized the majority of the basins and would appear to be favored by the presence of hydrophytes, where they forage for food. These two species also seem in general to be relatively tolerant to desiccation, salinization, and lower oxygen concentrations. According to Escalante (1984), the diet of *C. decemmaculatus* is composed basically of the algae Chrysophyta, Chlorophyta, and Cyanophyta; whereas the trophic spectrum of *J. multidentata* is broader, including amphipods (*Hyalella curvispina*), microcrustaceans, and decapods along with the larvae of the chironomids and gastropods. The Symbranchiformes are represented by only *Symbrachus marmoratus* and in general feed on microcrustaceans and small fish in the benthos.

Climate change

The changes in the climatic variability and the frequency of extreme meteorological events must be considered in determining the probable impacts on flora and fauna and in assessing the adaptative adjustments the latter require to mitigate such perturbations. According to Hulme & Sheard (1999), the mean annual temperature in Argentina increased by 1°C during the last century, with the decade of the 1990s being the warmest. This warming has occurred throughout the entire year, though being more pronounced in winter (June to August). Along with the increase in warming, the frequency of frosts has been diminishing. On the basis of the different alternatives defined in the Special Bulletin Concerning Emission Scenarios (USA) of the Intergovernmental Panel on Climate Change (IPCC), the mean temperature of the Argentine pampean plains is expected to increase by 1°C under conditions of low impact [Scenario B1: a CO_2 concentration of 532 parts per million of volume (ppmv) giving a global elevation of 1.2°C by 2080], but will rise by between

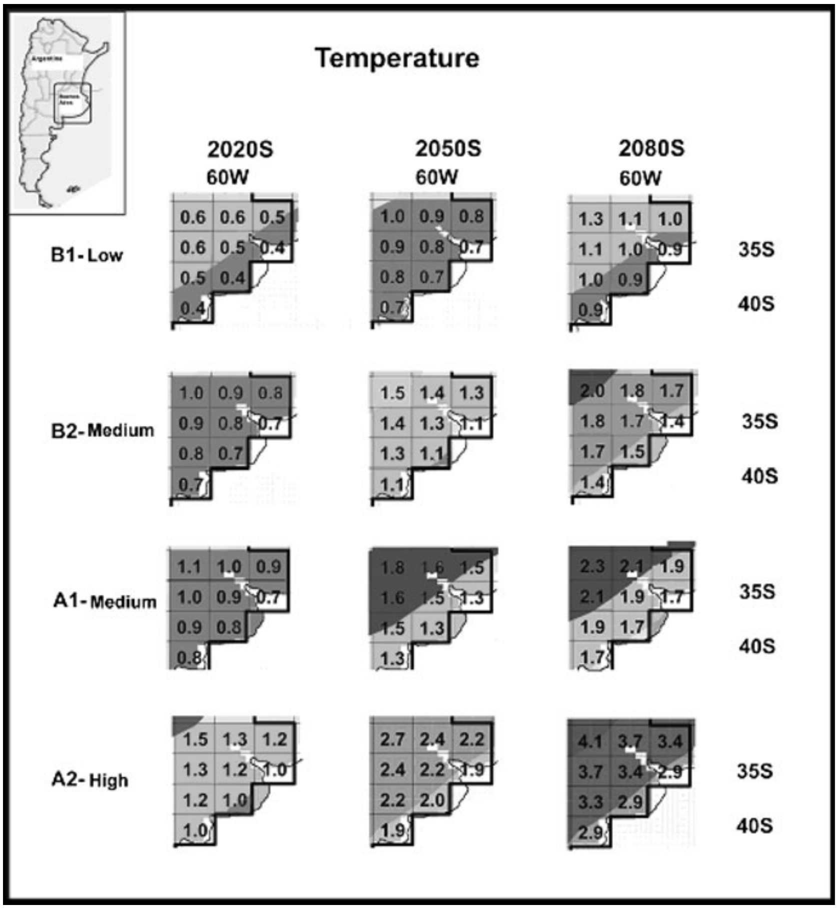

Fig. 8 The temperatures on different climatic outcomes (in pampean area) defined in the Special Bulletin Concerning Emission Scenarios of the Intergovernmental Panel on Climate Change (IPCC, USA)—pampean region (Modified from Hulme & Sheard, 1999)

2.9 and 3.4°C at high impact (Scenario A2: a CO_2 concentration of 721 ppmv yielding an increment of 3.9°C by 2080) (Fig. 8). Under Scenario B1, the precipitation will increase in the pampean region by <5% by 2080, but under Scenario A2 the increment in rainfall will reach nearly 17% by the same year (Fig. 9). These scenarios do not take into consideration "El Niño" events, which are known to affect precipitation in the pampean streams as well (Nuñez, 2009).

Consequences of global climate changes on pampean fluvial systems

The consequences of alterations in the global climate are especially critical in developing countries from the standpoint of the capacity of their constituent social groups to absorb or mitigate the effects of these changes. This circumstance represents a challenge with respect to the possibility of having the technology, the resources, an appropriate infrastructure, and the basic wherewithal for the adjustments required.

Global climate change will certainly affect the physical, chemical, and hydrologic properties of pampean lotic systems and consequently, the structure and function of the biological communities present.

These future climate-change scenarios proposed for the pampean area project an increment in rainfall that will strongly affect the biological communities. Higher rainfall can increase erosion and generate flooding; thereby increasing the transport of sediments, nutrients, and contaminants to the ocean so as to affect the degree of water mineralization. The changes in the discharge and in the turbidity of the water would affect the residence time and the light penetration of the water column.

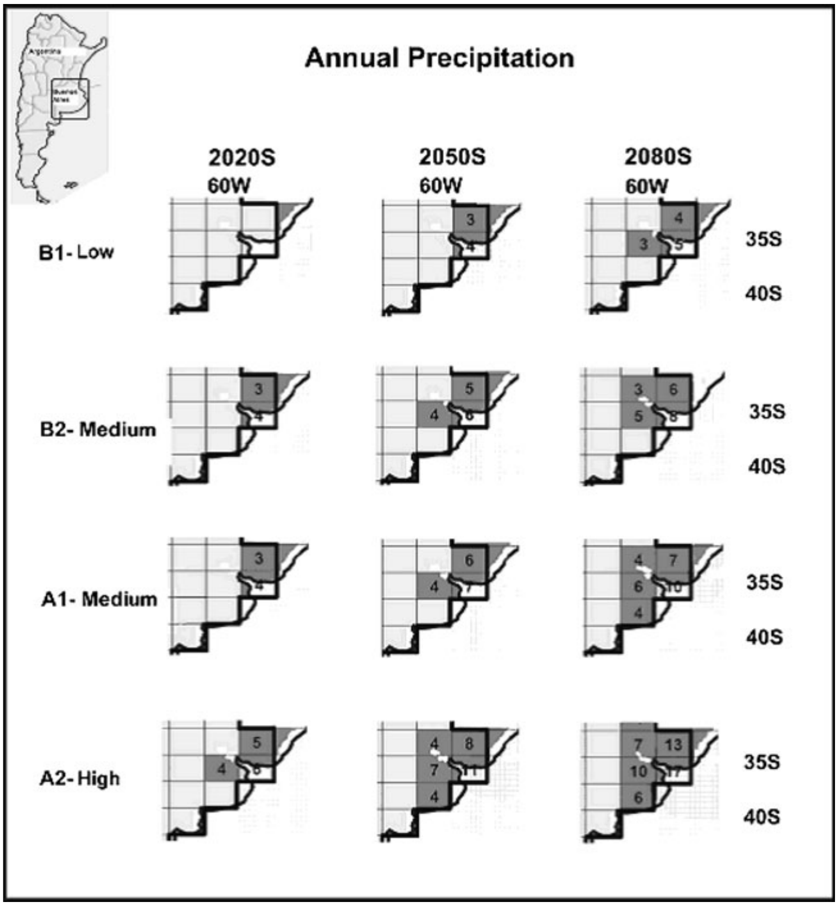

Fig. 9 The precipitations on different climatic outcomes (for pampean area) defined in the Special Bulletin Concerning Emission Scenarios of the Intergovernmental Panel on Climate Change (IPCC, USA)—pampean region (Modified from Hauer & Lamberti, 1996)

The modifications in the use of the soil will probably favor the input of nutrients. This latter effect will benefit autotrophy, particularly by those species capable of generating strategies for surviving in more turbid and enriched environments. An accelerated eutrophication will change the composition of the consumers in favor of herbivores and detritivores. Litter decomposition brought about by bacteria and fungi will become modified by the changes in temperature along with a greater availability of organic matter, both autochthonous and allochthonous. The fungi will make use of a major quantity of vegetal material for decomposition, which possibility would imply an elevation in cellulolytic and ligninolytic enzymes. The alterations in the processes of microbial decomposition will in turn modify the utilization of that material on the part of the invertebrates.

According to Bustingorry (2008), the overflowing of the bodies of water in the pampean plains would evoke a dilution with respect to the salinity without changing the concentration of the nutrients. With the aim of analyzing the effects of increasing nutrient levels within the pampean waterways, a nutrient-enrichment experiment was recently performed in the La Choza Stream, located between 34°39′14″ and 34°47′51″S and 59°10′00″ and 58°3′17″W; the basin's drainage surface is 15,200 ha. Sixty-four per cent of the basin is used for cattle raising and 34% for extensive agriculture, while the remaining 2% is divided between bird raising and urban use. The fertilization experiment was carried out between 2007 and 2008. The immediate objective was to simulate the increase in nutrients in a plains fluvial system with its headwaters subjected to unhabitual hydrologic irregularities attributable to global climatic changes resulting from human activity. The long-term aim was then to examine the resulting changes in the biological structure of the trophic network and the functioning of the metabolic processes in the resident communities. The experiment involved a study of two 100-m stretches of the stream (Control and Treatment) for a period of 9 months prior to the addition of quantities of phosphorus and nitrogen that would triple the average initial concentrations in the treated segment. After the stream fertilization in this manner, both stretches were then monitored for the subsequent 12 months in a follow-up study. This experiment analyzed not only the structural response in the producers (macrophytes, epiphyton, epipelon, and phytoplankton), the consumers (invertebrates and fish), and the decomposers (bacteria), but also both the functional response and the primary production plus the exoenzymatic activities of the epiphyton, phytoplankton, and epipelon communities.

The preliminary results suggest that the bacteria and the algae associated with the sediment responded significantly to the addition of the nutrients (Cochero et al., 2008) by doubling their biomass. An increment in the abundance of the browsers or herbivores within the macroinvertebrate community represented principally by the gastropod mollusks *Pomacea canaliculata* and *Heleobia* sp. also occurred, presumably as a consequence of the increase in the biomass of the primary producers (Rodrigues Capítulo et al., 2008). Changes in the structure of the diatom taxocenosis were also noted with a reduction in the number, diversity, and evenness of species such as *Nitzschia frustulum*, *N. inconspicua*, *N. amphibia* along with an increment in their density relative to the control values (Licursi & Gómez, 2009). In terms of functional responses, fertilization resulted in a duplication in the production of macrophytes and a 68% reduction, on the average, in the concentration of alkaline phosphatase in the treated segment relative to control values (Cochero et al., 2008; Vilches et al., 2008).

Another example of the expected results from a high-temperature scenario is found in the loricariid fish *Hypostomus commersoni*. This species has a low tolerance to cold water, which characteristic limits its southernmost distribution. An increment in the dispersal of this species toward the south and west from 1960s can be explained not only by the implementation of canals to drain off excess water, but also by the accompanying rise in temperature (López & Miquelarena, 1991; Gómez, 2008). Similar predictions can be made with respect to mollusks, insects, and crustaceans, whose distributions were previously relegated to subtropical zones. For example, the displacement of mollusks of the genus *Physa* (Physidae), of Anisoptera such as *Anax amazili*, and of dipteran like *Aedes aegypti* toward the south and west of the pampean area is presently underway (Rodrigues Capítulo, 1981). Another consequences of global warming is an elevation in the sea level. In addition to increasing the erosion of the coastline, this alteration would adversely affect the accessability of the mouths of rivers and streams so as to allow the entrance of estuarial fish into the continental network.

According to Kruse & Mas-Pla (2009), changes in the morphology of the coastal plain of the Pampean region would contribute to the deterioration of groundwater resources within the new climate-change scenarios. Rising sea levels would cause an alteration in groundwater level and a displacement of the border toward the continent, thus causing an incursion of salt water from the ocean into the aquifers. Other negative impacts associated with coastal flooding are storms that would lash the banks of the Rio de la Plata and the Parana River delta and in doing so affect the human activity in that area.

In order to satisfy the need for food resulting from the projected increase in the world population in the years ahead, an increase in agricultural production will be necessary. This situation, coupled with new climate-change scenarios, will lead to profound socioeconomic changes in the pampas region, causing a greater demand for water resources and land uses. These changes in the future are expected on the basis of the increase in pampean agricultural production that has occurred since 1950, partially as the result of an expansion of the agricultural western boundary. During the last decade, there were increases in the cultivated land area of approximately 100,000 km^2 and in the population of the province of Buenos Aires of some 8%, with a projected further rise of 4.4% in the latter parameter by the year 2015 (INDEC, 2004).

A final consideration is that even though climate changes can in general be predicted, alterations in the environment introduced by man can also occur at random and for that reason will remain only poorly predictable.

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