Biota Along the Suquía River Basin

M.A. Bistoni, F. Chiarini, A. Mangeaud, M. Tatián, R. Torres, and A. Visintín

Abstract The biota inhabiting the Suquía River Basin is described in this chapter. Comments on the species of fish, birds, invertebrates and aquatic plants registered in this system are included. Along the basin, different factors generate a noncontinuous mosaic of abiotic conditions at temporal and spatial levels, which, in turn, structure the biotic communities. The Suquía hydrological system consists of three sections: the upper basin in a mountainous area with headwaters and torrential rivers flowing into the San Roque Reservoir; the middle basin with drainage areas belonging to the eastern slope of the Sierras Chicas, together with the drainage area of the city of Córdoba; and the lower basin which is located downstream from the city of Córdoba flowing into the Mar Chiquita Lake, where the river meanders exhibit little flow. The species of the different groups change according to the characteristics of each section. In this chapter, endemic and

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introduced species are discussed. The bivalve species that inhabit the Suquía River are not native, and the cause of their introduction is explained. Authors also specify the anthropic factors that negatively impact water, bird and invertebrate species in the river.

Keywords Aquatic birds, Aquatic biotic, Aquatic macroinvertebrates, Aquatic plants, Ichthyofauna

Contents

1 Ichthyofauna

In the Suquía River Basin, 24 fish species, in permanent and casual forms, are accepted in the literature (Table 1). These species are distributed in 14 families and 8 orders [1]. The richest groups were the Characiformes (10 species) and the Siluriformes (6 species). Regarding the abundance of each order, the Cyprinodontiformes was the best represented order (50%), followed by the Siluriformes and the Characiformes (24.68% and 24.18%, respectively). However, the Cyprinodontiformes have only four species.

It is important to note that *Phalloceros* sp. was registered for the first time by Hued and Bistoni [1]. This is important because, according to Ringuelet et al. [2], the geographical distribution of this species comprises the Province of Misiones and the city of La Plata, in the Province of Buenos Aires, Argentina. It is also found in southern Brazil, Uruguay and Paraguay [2]. Hued and Bistoni [1] mentioned that only two females were found in the Villa Giardino area (upper basin) (31°02′00″S 64°29′00″O) on the San Francisco Stream (tributary of the Suquía River Basin) (Fig. 1). Further studies are necessary to determine if this species is established in the basin.

Table 1 Fish species richness in Suquía river, Córdoba province, Argentine t1.1

Order	Family	Species	t1.2
Cypriniformes	Cyprinidae	*Cyprinus carpio*	t1.3
		Ctenopharyngodon idellis	t1.4
Characiformes	Characidae	*Cheirodon interruptus*	t1.5
		Oligosarcus jenynsi	t1.6
		Astyanax eigenmanniorum	t1.7
		Astyanax hermosus	t1.8
		Astyanax cordovae	t1.9
		Bryconamericus iheringi	t1.10
		Bryconamericus eigenmanni	t1.11
		Odontostilbe microcephala	t1.12
		Parodon tortuosus	t1.13
	Erythrinidae	*Hoplias malabaricus*	t1.14
Siluriformes	Heptapteridae	*Pimelodella laticeps*	t1.15
		Rhamdia quelen	t1.16
	Pimelodidae	*Pimelodus albicans*	t1.17
	Trichomycteridae	*Trichomycterus corduvense*	t1.18
	Callichthyidae	*Corydoras paleatus*	t1.19
	Loricariidae	*Rineloricaria catamarcensis*	t1.20
		Hypostomus cordovae	t1.21
Atheriniformes	Atherinidae	*Basilichthyes bonariensis*	t1.22
Cyprinodontiformes	Anablepidae	*Jenynsia multidentata*	t1.23
	Poecilidae	*Gambusia affinis*	t1.24
		Cnesterodon decenmaculatus	t1.25
		Phalloceros sp.	t1.26
Synbranchiformes	Synbranchidae	*Synbranchus marmoratus*	t1.27
Perciformes	Cichlidae	*Australoheros facetum*	t1.28
Salmoniformes	Salmonidae	*Oncothynchus mykiss*	t1.29
		Salvelinus fontinalis	t1.30

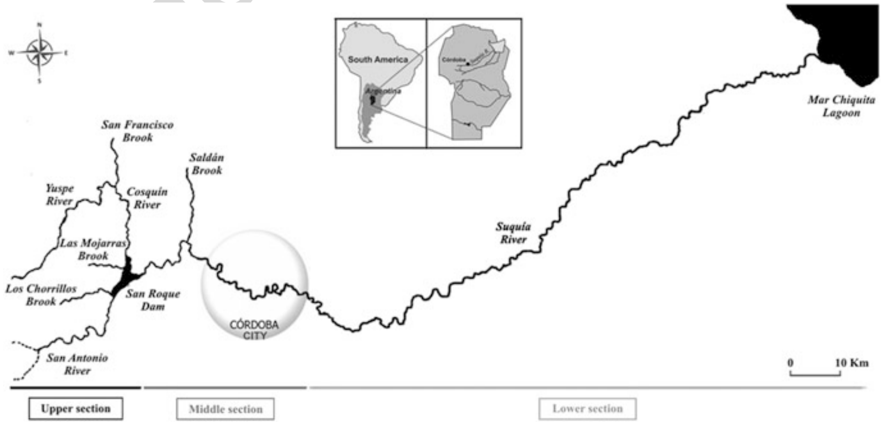

Fig. 1 Rio Suquia Basin showing different sections along of the basin

Fig. 2 Ichthyological provinces of Argentina. Adapted from López et al. [3] with permission

At the biogeographical level, five ichthyological provinces of the Argentinean freshwater fauna are recognised [3] (Fig. 2): Andino-Cuyana, Patagónica, Aymara, Grandes Ríos and Pampeana. According to these authors, the Pampeana province includes the Provinces of Tucumán and Córdoba, as well as an extensive area of the Provinces of Santiago del Estero, San Luis, Buenos Aires and La Pampa. It also includes the south-eastern region of the Provinces of Salta, Catamarca and La Rioja and the south-western region of the Province of Santa Fe. According to this classification, the Suquía River Basin is located fully in the Pampeana ichthyological province (Fig. 2).

1.1 Distribution of the Ichthyofauna Along the Suquía River Basin

From the headwaters down, communities are structured along the abiotic factors that characterise each section, such as altitude, river order, stream gradient and distance from the source. These abiotic factors influence not only species richness but also trophic composition [4]. In the Suquía River Basin, three sections can be recognised according to their geomorphological conditions: upper, middle and lower sections (Fig. 1). The upper section extends from 1,900 m.a.s.l. to 650 m.a.s.l. and the middle section from 643 m.a.s.l. to 352 m.a.s.l. The lower section starts at 300 m.a.s.l. and runs down to the mouth of the Suquía River in the Mar Chiquita Lake (70 m.a.s.l.). Fish fauna of the middle and lower sections was comprehensively surveyed by Haro and Bistoni [5] and the upper section by Hued and Bistoni [1]. Streams located in high altitude places support cold water fish assemblages, and as streams run down the mountains, this assemblage changes to warm-water taxa. In the first case, the dominant species is trout. Trout inhabits areas near the headwaters because of their specific living requirements of oxygen, pH and temperature [6]. Thus, the headwaters can be classified as 'trout zones'. A few kilometres downstream from the headwaters, this species rapidly declines in abundance, mainly because stream temperatures become warmer [7, 8]. Numerous studies indicate injury to native fish communities by the introduction of salmonids [9–11]. These studies indicate that trouts change the communities' composition of native fish by competing for resources or predation. Further studies in the mountain river in the Province of Córdoba are necessary to confirm this aspect.

Continuous change in fish assemblages along the river seems to prevail in the middle and lower sections. Among the fish species present in downstream areas, *Hoplias malabaricus* and *Cyprinus carpio* are observed in the plains from 600 m downstream. The Siluriformes order is registered along the basin, but they are more diverse in the lower section of the basin with respect to upstream locations.

1.2 Endemism

Astyanax cordovae is a remarkable endemism in the Córdoba province, and it was described for the first time by Gunther in 1881 for Córdoba rivers (Fig. 3). Ringuelet [12] stated that this species had not been seen since its original description. In 1988, Bertolio and Gutiérrez published a detailed redescription of this fish. They note that *A. cordovae* has a geographical distribution restricted to the basins of the Suquía and Xanaes Rivers. Its presence is more easily observable in the Suquía River, even though it is not as common as the other two species of the same family, *Astyanax eigenmanniorum* and *Bryconamericus iheringi*. It inhabits deep wells and has also been captured in flowing water in the channelized area of the Suquía River, running through the city of Córdoba (middle basin, Fig. 1) [13].

Miquelarena et al. [14] described for the Suquía River Basin a new endemic species, *Astyanax hermosus* that was registered only in the San Francisco River, in the Valle Hermoso locality (37° 07’ S-64° 29’ W). This site is located at 900 m.a.s.l. and it is a typical mountain stream with a fast-flowing current and gravelly, rocky and sandy bottoms (upper basin, Fig. 1).

1.3 Introduced Fish in the Suquía River

Species that move, whether intentionally or accidentally, due to human activities, from its native area to a different region are considered alien species [15].

Fig. 3 *Astyanax cordovae*. Endemic species in the Suquía River. Scale bar, 3 cm

Out of 28 fish species, five were introduced: *Cyprinus carpio*, *Ctenopharyngodon idella*, *Gambusia affinis*, *Odontesthes bonariensis*, *Oncorhynchus mykis*s and *Salvelinus fontinalis*. The last two mentioned species were introduced in Argentina from the United States for sport fishing. They were introduced as embryonated eggs at the beginning of the twentieth century [16]. Nowadays, they are distributed in almost all mountain rivers of the Province of Córdoba. On the same hand, *C. carpio*, a species indigenous to China, was introduced in Argentina in 1930. It is considered a naturalised species because it sustains self-replacing populations for several life cycles. Besides, another cyprinid, *C. idella*, was introduced in the San Roque Dam since 1989, and it is considered a casual species because it does not form self-replacing populations in the invaded region and its persistence depends on repeated introductions. It is detected in sporadic catches by sport fishermen in the San Roque Dam.

G. affinis, a species native to Mexico and the southern region of the United States, was introduced in Argentina to fight diseases such as malaria and yellow fever, because of its recognised deficiency as a larvivorous fish. It is a small-sized fish (3–4 cm), common along the Suquía River, which inhabits pristine as well as contaminated sites, where it becomes the dominant species [17]. Silverside (*O. bonariensis*) is native to the Río de la Plata River (Argentina). This fish species was introduced, mainly in lakes of the Province of Córdoba, for sport fishing. Now, it is considered a naturalised species, with a permanent population in the lakes. From the San Roque Lake and through the Suquía River as a dispersal route, silverside arrived to the Mar Chiquita Lake, where it settled. This last lake showed a hypersaline condition 20 years ago [18]. At the time, the average concentration of salt in the lake was around 300 g/L (hypersaline stage), making it impossible for this species to settle there. Around 1970, the Mar Chiquita Lake received a significant amount of freshwater from their tributaries, as a result of a marked increase in precipitation throughout the basin, and its salinity decreased to 30 g/L, a concentration similar to seawater levels. This mesohaline condition allowed *O. bonariensis* and others species, such as *Jenynsia multidentata*, to colonise this lake [18]. The silverside population grew rapidly in the lake; therefore, the Government of the Province of Córdoba authorised commercial fishing in the area [19]. These authors note that in 1997 the level of the Mar Chiquita Lake decreased, and the salinity increased again. These reasons, among others like fishing pressure, population dynamics and limnology, caused a decrease in the silverside population in the lake, so commercial fishing was markedly affected. Nowadays, it is difficult for local fishermen to find silversides in the Mar Chiquita Lake (personal observation). Reati et al. [18] estimated that *O. bonariensis* will disappear from the Mar Chiquita Lake in a few years if the increasing trend raising the water salinity continues, probably before concentrations of 60 g/L are reached. Therefore, the presence of silverside in the Mar Chiquita Lake seems to be cyclical. During extended periods of low salinity, this species adds economic importance to the region.

1.4 Ecological Types

Ringuelet [12] made a classification integrating habitat and trophic level of freshwater fish in Argentina, and they denominated it 'ecological types'. We modified the classification made by these authors according to our experience. Therefore, the Suquía River species can be classified into several 'ecological types'. So 'bottom fish' includes species with an iliophagus diet, such as *Prochilodus lineatus*, and it also includes the most characteristic species of this group: the armoured catfish *Rineloricaria catamarcensis*, *Hypostomus* sp. and *Corydoras paleatus*. Besides, the ecological type comprising 'fish that frequent the bottom' encounters opportunistic carnivores, which are very common in the bottom of streams with a slow velocity. This type includes species such as catfish *Rhamdia quelen*, *Pimelodella laticeps* and *Pimelodus albicans*, which have long sensitive barbells that allow them to perceive their preys. Considering the diet and habitat of *C. carpio*, it could be included in this ecological type. The ecological type 'open and vegetated waters' includes the predator *H. malabaricus* as well as a group of small fish with an insectivorous diet. This group also includes a different genus such as *Astyanax*, *Bryconamericus* and *Cheirodon*. Other species included in this group are *Australoheros facetum* and small fish of the order Cyprinodontiformes such as *J. multidentata*, *Cnesterodon decemmaculatus* and *G. affinis*. In recent times, it has been observed that mosquitofish (*G. affinis*) is the most resistant to pollution among all the Cyprinodontiformes species, and it seems that native species decline in abundance while alien species increase. However, no studies have been conducted yet to confirm this observation. Also, a special ecological type called 'air-breathing fish' includes species with the ability to breathe atmospheric oxygen. Members of this ecological type found in the Suquía River Basin include *Synbranchus marmoratus* and *C. paleatus*. Finally, the ecological type 'cold water fish' includes *Trichomycterus corduvense*. This species inhabits the fastest section of the river, with rocky and sandy bottom. This little catfish shares the habitat with trouts, which have the same environmental requirements and can compete for different resources.

2 Aquatic Birds

The literature about waterbirds specifically present in the Suquía River Basin is almost non-existent; much of the concepts expressed herein correspond to observations made by the authors.

2.1 Species Richness

Birds, and particularly aquatic birds, are known for their great dispersal capability compared to other groups of vertebrates. In this way, 69% of aquatic birds cited for the Province of Córdoba can be observed in the Suquía River Basin ([20–24], [25, pers. obs.]), totalling 79 species belonging to 18 families in eight orders. However, it is possible that the remaining 35 species, which are rare or occasional in Córdoba, will ever be observed.

Some families are particularly rich around the world and the situation in the Suquía River Basin is not an exception. Thus, most waterbird species belong to the families Anatidae (15 species) and Scolopacidae (13 species, Table 2).

Additionally, 25 species of birds not considered as aquatic birds sensu stricto (i.e. those with physiological and anatomical adaptations to aquatic habitats) also inhabit the basin. These species, however, exhibit behavioural adaptations for living in wetlands and rivers and can hardly be observed outside such environments. Nine families, in three orders, contain species of this type in the basin, being six species of the family Tyrannidae the richest ones (Table 3).

2.2 Distribution Along the Suquía River Basin

As mentioned previously (Sect. 1), from the headwaters in the highlands of the Sierras Grandes at 1,900 m.a.s.l. to the mouth in Mar Chiquita, a saline lake at 70 m. a.s.l., the Suquía River runs through markedly different regions (Fig. 1). The upper portion of the basin is part of a highland plateau dominated by grasslands interspersed with rocky outcrops (locally named 'Pampa de Achala'), where the headwaters flow as small streams. The flat topography in this region makes watercourses flow at a low speed and allows the formation of small wetlands with palustrine vegetation. These wetlands are inhabited by some birds that colonised them from lowland regions, as the plumbeous rail (*Pardirallus sanguinolentus*) and the sedge wren (*Cistothorus platensis*). Instead, birds like the Córdoba cinclodes (*Cinclodes comechingonus*), the white-winged cinclodes (*C. atacamensis schocolatinus*) and the Olrog's cinclodes (*C. olrogi*), which travel along the rocky banks of streams, searching for small aquatic invertebrates, are endemic to the highlands of the mountains of Central Argentina [22]. Two species, the buff-necked ibis (*Theristicus caudatus*) and the tawny-throated dotterel (*Oreopholus ruficollis*), inhabit the humid grasslands near streams and constitute biogeographic singularities since they belong to local, isolated breeding populations, separated by hundreds or even thousands of kilometres from the nearest breeding populations in the lowlands of Eastern Argentina and Patagonia, respectively [22, 26]. The cast of grassland birds is completed with the widely distributed southern lapwing (*Vanellus chilensis*), as common here as in the lowlands.

Table 2 Aquatic birds sensu stricto in the Suquía River basin

Order	Family	Species
Anseriformes	Anhimidae	*Chauna torquata*
	Anatidae	*Coscoroba coscoroba*
		Cygnus melancoryphus
		Dendrocygna bicolor
		Dendrocygna viduata
		Anas bahamensis
		Anas cyanoptera
		Anas discors
		Anas flavirostris
		Anas georgica
		Anas platalea
		Callonetta leucophrys
		Amazonetta brasiliensis
		Netta peposaca
		Oxyura vittata
		Nomonyx dominicus
Podicipediformes	Podicipedidae	*Podicephorus major*
		Podilymbus podiceps
		Rollandia rolland
Phoenicopteriformes	Phoenicopteridae	*Phoenicoparrus andinus*
		Phoenicoparrus jamesi
		Phoenicopterus chilensis
Suliformes	Phalacrocoracidae	*Phlacrocorax brasilianus*
Pelecaniformes	Ardeidae	*Ardea cocoi*
		Ardea alba
		Egretta thula
		Bubulcus ibis
		Butorides striata
		Nycticorax nycticorax
		Syrigma sibilatrix
		Tigrisoma lineatum
	Threskiornithidae	*Plegadis chihi*
		Phimosus infuscatus
		Theristicus caudatus
		Platalea ajaja
Gruiformes	Aramidae	*Aramus guarauna*
	Rallidae	*Aramides cajanea*
		Pardirallus sanguinolentus
		Gallinula galeata
		Gallinula melanops
		Porphyrio martinicus
		Fulica armillata
		Fulica leucoptera
		Fulica rufifrons

(continued)

Table 2 (continued)

Order	Family	Species
Charadriiformes	Charadriidae	*Vanellus chilensis*
		Pluvialis dominica
		Pluvialis squatarola
		Charadrius semipalmatus
		Charadrius collaris
		Charadrius falklandicus
		Charadrius modestus
		Oreopholus ruficollis
	Recurvirostridae	*Himantopus mexicanus*
	Scolopacidae	*Gallinago paraguaiae*
		Limosa haemastica
		Bartramia longicauda
		Tringa melanoleuca
		Tringa flavipes
		Tringa solitária
		Calidris alba
		Calidris fuscicollis
		Calidris bairdii
		Calidris melanotos
		Calidris himantopus
		Tryngites subruficollis
		Phalaropus tricolor
	Jacanidae	*Jacana jacana*
	Rostratulidae	*Nycticryphes semicollaris*
	Stercorariidae	*Stercorarius parasiticus*
	Laridae	*Chroicocephalus maculipennis*
		Chroicocephalus cirrocephalus
		Larus atlanticus
		Larus dominicanus

Downstream from Pampa de Achala, watercourses become faster as the slope becomes steeper. The aquatic birds at these sites are limited to the backwaters, where fish, tadpoles and invertebrates are caught by Neotropic cormorants (*Phalacrocorax olivaceous*), snowy egrets (*Egretta thula*) and striated herons (*Butorides striata*). Among ducks, the speckled teal (*Anas flavirostris*) is by far the most common in this region. In some sites, the cliffs over rivers, both rocky and gravelly, are utilised for nesting by the Speckled Teal, the buff-necked ibis and the ringed kingfisher (*Megaceryle torquata*), together with several nonaquatic species (not listed in Tables 2 and 3) like the peregrine falcon (*Falco peregrinus*) and the introduced rock dove (*Columba livia*). In this section of the basin, several reservoirs of variable dimensions add a previously non-existent feature to the original

Table 3 Other birds dependent on aquatic environments in the Suquía River basin

Order	Family	Species
Accipitriformes	Pandionidae	*Pandion haliaetus*
	Accipitridae	*Rostrhamus sociabilis*
Coraciiformes	Alcedinidae	*Megaceryle torquata*
		Chloroceryle amazona
		Chloroceryle americana
Passeriformes	Furnariidae	*Cinclodes fuscus*
		Cinclodes comechingonus
		Cinclodes olrogi
		Cinclodes atacamensis
		Phleocryptes melanops
	Tyrannidae	*Serpophaga nigricans*
		Pseudocolopteryx dinelliana
		Tachuris rubrigastra
		Lessonia rufa
		Hymenops perspicillatus
		Fluvicola pica
	Hirundinidae	*Tachycineta leucorrhoa*
		Riparia riparia
		Petrochelidon pyrrhonota
	Troglodytidae	*Cistothorus platensis*
	Thraupidae	*Sporophila collaris*
		Sporophila hypoxantha
	Icteridae	*Amblyramphus holosericeus*
		Agelasticus thilius
		Chrysomus ruficapillus

landscape. These deep waters were colonised mainly by Neotropic cormorants, great grebes (*Podicephorus major*) and pied-billed grebes (*Podilymbus podiceps*). At the mouths of rivers, the marshy vegetation thrives and birds like the red-gartered coot (*Fulica armillata*), the white-winged coot (*F. leucoptera*) and some ducks are commonly associated with it.

When the river reaches the lowlands, it becomes very sinuous and forms a broad alluvial plain, with marshes and small lagoons as associated wetlands (lower basin, downstream from Córdoba City, Fig. 1). The aquatic avifauna is richer than in the previous regions. Besides Neotropic cormorants, snowy egrets and striated herons, other piscivorous birds, such as the great egret (*Ardea alba*) (Fig. 4) and the beautiful cocoi heron (*A. cocoi*), are frequently observed along the river. The lagoons exhibit a great spatial heterogeneity, and several distinct habitats (open deep waters, shallow waters, reed beds, floating plants and humid grasslands) allow the coexistence of a diverse fauna of birds. Thus, open deep waters are mainly frequented by the pied-billed grebe, the white-tufted grebe (*Rollandia rolland*), the white-cheeked pintail (*Anas bahamensis*), the lake duck (*Oxyura vittata*), the rosy-

Fig. 4 Great egret (*Ardea alba*)

billed pochard (*Netta peposaca*), the red-gartered coot and the white-winged coot, whereas shallow waters are visited by several egrets and herons, the white-faced ibis (*Plegadis chihi*), the southern screamer (*Chauna torquata*) and the black-necked stilt (*Himantopus mexicanus*). The red-fronted coot (*Fulica rufifrons*), the common gallinule (*Gallinula galeata*) and the spot-flanked gallinule (*G. melanops*) swim through the dense reeds, whereas the plumbeous rail prefers walking, pushing through them. The limpkin (*Aramus guarauna*) and the snail kite (*Rostrhamus sociabilis*) search for amphibious snails that lay their eggs on the reeds. Reedbeds are also inhabited by a diverse fauna of small birds that eat and nest in them, like the wren-like rushbird (*Phleocryptes melanops*), the many-coloured rush tyrant (*Tachuris rubrigastra*) and the yellow-winged blackbird (*Agelasticus thilius*). Finally, floating plants are the substrate for the specialised wattled jacana (*Jacana jacana*), while humid grasslands are the home of the South American painted-snipe (*Nycticryphes semicollaris*), the South American snipe (*Gallinago paraguaiae*) and the whistling heron (*Syrigma sibilatrix*).

In its final section, the Suquía River is divided into two branches, both of which flow into the Mar Chiquita Lake (lower section, Fig. 1). Several small lagoons near the mouths harbour an avifauna similar to the one described above, while in the mouth itself, the silty beaches are exploited by a great number of shorebirds species, both permanent and migratory. The collared plover (*Charadrius collaris*) is one of the few breeding permanent species, together with the two-banded plover (*C. falklandicus*), which have an isolated breeding population in Mar Chiquita [27], a thousand kilometres away from the nearest breeding population in Patagonia and, thus, constituting another biogeographic singularity. The rufous-chested dotterel (*C. modestus*) can be observed in winter as coming from Patagonia, but the vast majority of species arrive from North America in spring, being the Wilson's phalarope (*Phalaropus tricolor*), the greater yellowlegs (*Tringa melanoleuca*), the lesser yellowlegs (*T. flavipes*), the white-rumped sandpiper (*Calidris fuscicollis*), the Baird's sandpiper (*C. bairdii*) and the pectoral sandpiper (*C. melanotos*) the most common ones. The brackish waters in estuaries are used by the Chilean flamingo (*Phoenicopterus chilensis*) for feeding, and they are visited in winter by the Andean flamingo (*Phoenicoparrus andinus*) and the James's flamingo (*P. jamesi*), which come from their breeding grounds in the Andean puna. As beautiful as flamingos are the black-necked swans (*Cygnus melancoryphus*) and the coscoroba swan (*Coscoroba coscoroba*), which, together with the brown-hooded gull (*Chroicocephalus maculipennis*) and the grey-hooded gull (*C. cirrocephalus*), prefer deeper waters near the mouths.

2.3 Anthropic Factor Influencing the Occurrence of Waterbirds in the Basin

Contamination and deforestation are the main pressures on the biota of the Suquía River Basin. The headwaters in the upper section of the basin are the more pristine habitats; however, overgrazing magnifies water erosion, leading to an increase in the sediments transported towards the lower sections of the basin. When these nutrients reach the San Roque Reservoir, they get combined with sewage from Carlos Paz city, causing an increase in the densities of bacteria and algae, with occasional blooms, whose toxins are dangerous to all living beings, including waterbirds. Nevertheless, the main sources of contamination of the Suquía River are the industrial activities and sewage discharges of Córdoba City. Some data indicate a great reduction in richness, abundance and diversity of aquatic birds in the river in Córdoba city when compared to sections upstream and downstream [20]. This reduction, however, is also influenced by others anthropic disturbances, as the presence of homes and busy routes close to the river and the reduction in the cover of riparian vegetation. In any case, the community composition was quite different between the sections' upstream and downstream of the city, with predominance of piscivorous species upstream from the city and of invertivorous species downstream from the city, probably reflecting a rise in invertebrate abundance and a decline of fish as a consequence of pollutants in the water [20].

Deforestation was widespread in all plains of the centre and east of the Province of Córdoba, including the Suquía River Basin. The remnant forest fragments are dispersed throughout the plains, the riparian zones of the river and the associated lagoons. These forests form a corridor that allows the penetration from the North of aquatic birds, typical of subtropical areas. In this way, in the lagoons near Río Primero city, it is possible to observe species such as the Brazilian teal (*Amazonetta* *brasiliensis*), the rufescent tiger heron (*Tigrisoma lineatum*) and the purple gallinule (*Porphyrio martinicus*), all of them common and widespread in Northern and Eastern Argentina but rare in Córdoba. Finally, in lagoons close to Córdoba City (downstream, in Chacra de la Merced, Fig. 1), species like the bare-faced ibis (*Phimosus infuscatus*) are observable.

3 Aquatic Macroinvertebrates

Rivers are dynamic systems where communities respond spatially and temporally to the interaction between external factors, determined by their drainage basin, and internal factors, defined by the riverbed and valley characteristics [28]. According to the size and type of lotic environment, these factors generate a noncontinuous mosaic of biotic and abiotic conditions at the temporal and spatial levels [29], which determines the distribution of the populations, especially those related to the bottom of the river [30].

The biological quality of rivers can be evaluated through the biotic communities they harbour. Macroinvertebrates, particularly insects, are an important component of both biodiversity and the functioning of freshwater ecosystems [31]. Several authors studied the communities of aquatic invertebrates in lotic environments in the Province of Córdoba, considering different aspects such as distribution and ecology [32–36]. Regarding the Suquía River, the most comprehensive studies were approached by Mangeaud [37].

Here, the relative composition in phyla and orders of the macroinvertebrate community is similar to other rivers in the central region of Argentina. Even though the number and abundance of the taxa differ, its comparable to rivers in other regions but under arid or semi-arid climates. Along the basin, a total of 51 taxa were recorded distributed in six phyla, nine classes and 41 families (Table 4), with diversity (H′) values ranging from 0.8 to 3.2 in different points. Diversity and number of taxa increase from the headwaters to the mouth, and when contaminants enter the basin, these variables decrease.

In the entire basin, Arthropoda is well represented (more than 88%), followed by Annelida and Mollusca with much lower relative abundances (8% and 2%, respectively). In the basin sites considered as contaminated (mainly downstream from cities), a higher proportion of Annelida and a decreased proportion of Arthropoda is observed, which might be possible since the first group is more tolerant to pollution. The non-polluted sites mark the general tendency of the basin.

Insecta is the most numerous group of macroinvertebrates in the Suquía River, with 37 recognised Families of benthic insects, belonging to eight orders, and constituting about 99% of the arthropods of the watershed. Diptera is the order with the highest abundance (more than 50% of the benthos abundance), followed by Ephemeroptera (33%), Trichoptera (10%) and Coleoptera (4%). Such composition varies in the different subbasins of the upper section (Fig. 1) with small changes in the community structure, but more important ones regarding dominant taxa.

t4.1 **Table 4** Benthos in the Suquía River basin

	Phylum	Class	Order	Suborder	Family
t4.2	Phylum	Class	Order	Suborder	Family
t4.3	Annelida	Hirudinea			Glosiphoniidae
t4.4		Oligochaeta			Lumbriculidae
t4.5					Naididae
t4.6					Tubificidae
t4.7	Arthropoda	Arachnida	Acarina		Hygrobatidae
t4.8		Insecta	Coleoptera		Elmidae
t4.9					Dytiscidae
t4.10					Psephenidae
t4.11					Gyrinidae
t4.12					Hidrophilidae
t4.13			Diptera		Chironomidae
t4.14					Ceratopogonidae
t4.15					Dolichopodidae
t4.16					Empididae
t4.17					Ephydridae
t4.18					Psychodidae
t4.19					Simuliidae
t4.20					Syrphidae
t4.21					Tipuliidae
t4.22			Ephemeroptera		Baetidae
t4.23					Caenidae
t4.24					Leptohyphidae
t4.25			Hemiptera		Naucoridae
t4.26					Notonectidae
t4.27					Nepidae
t4.28					Corixidae
t4.29					Belostomatidae
t4.30					Veliidae
t4.31			Lepidoptera		Pyralidae
t4.32			Neuroptera		Sysiridae
t4.33			Odonata	Anisoptera	
t4.34				Zygoptera	Coenagrionidae
t4.35			Plecoptera		Perlidae
t4.36			Trichoptera		Calamoceratidae
t4.37					Glossosomatidae
t4.38					Helicopsychidae
t4.39					Hidrobiosidae
t4.40					Hidropsychidae
t4.41					Hydroptilidae
t4.42					Leptoceridae
t4.43					Odontoceridae
t4.44					Philopotamidae
t4.45					Polycentropodidae

(continued)

Table 4 (continued)

Phylum	Class	Order	Suborder	Family
Crustacea	Malacostraca	Amphipoda		
Mollusca	Gastropoda			Physidae
				Ancylidae
				Hydrobiidae
	Bivalvia			Corbiculidae
				Mytilidae
Platyhelminthes	Turbellaria	Tricladida		Dugesiidae
Nematomorpha	Gordiacea			

Camelobaetidius (Ephemeroptera: Baetidae) seems to be one of the dominant genus upstream in the upper section, but it is poorly represented downstream of the same section of the river. On the other hand, in this last part of the basin, the dominant genus is *Leptohyphes* (Ephemeroptera: Leptohyphidae), while Chironomidae is dominant in all the upper section.

3.1 Distribution Along the Suquía River Basin

Variation in diversity, number of taxa and abundance is observed when the stream order increases and the altitude decreases. Causes of this zonation are given by a complex combination of variables such as current velocity, substrate, stream flow, temperature, dissolved oxygen and nutrients, alkalinity and other chemical factors, as well as interactions with other organisms [37, 38].

The altitude range in which taxa are recorded presents great variability. Hirudinea, Annelida, Chironomidae, Acari, Elmidae, Dytiscidae, *Smicridea* (Trichoptera: Hidropsychidae) and *Leptohyphes*, among others, are well represented in the upper section of the river (from 600 up to 1,800 m.a.s.l.). Even though some taxa like *Leptohyphes*, Hirudinea, *Hydroptila* (Trichoptera: Hydroptilidae) and Dytiscidae present an inverse relationship between abundance and altitude, meaning that, although their optimal conditions come from the middle or lower sections, some individuals are able to tolerate conditions the upper section Another group develops only in the lower or middle sections area, and in the upper section up to 1,000–1,200 m.a.s.l. They are *Protoptila* (Trichoptera: Glossosomatidae), Zygoptera, Anisoptera (Fig. 5), *Nectopsyche* (Trichoptera: Leptoceridae), *Marilia* and Mollusca. A third group only inhabits mainly the middle section: Empididae, *Maruina* (Diptera: Psychodidae) and *Polycentropus* (Trichoptera: Polycentropodidae), while *Ochrotrichia* (Trichoptera: Hydroptilidae) develops in the upper section exclusively above 1,200 m.a.s.l.

Supraspecific groups such as Trichoptera, Leptohyphidae, Ephemeroptera and Mollusca show a significant decrease in abundance in relation to altitude. On the other hand, Coleoptera decreases in abundance when the order of the river

Fig. 5 Dragonfly (*Odonata, Anisoptera*). Scale bar, 3 cm

increases. The abundance of Diptera and Annelida seems unrelated to these two variables.

Plecoptera is known worldwide as a species exclusive of upstream regions since their nymphs depend intimately on cold temperatures to develop [39]. In spite of the appropriate environmental conditions, this Order is poorly represented in Córdoba. Summer droughts can cause significant increases in macroinvertebrates abundance. When this occurs, algae and macrophytes that are attached to the rocky bottom of streams are not removed by summer floods, as is the case with aquatic invertebrates. An abundant layer of plants covers the bottom of streams leading to a great heterogeneity of benthic habitats [40], and the higher the plant biomass, the greater the number of macroinvertebrates [41].

To summarise, benthic macroinvertebrate communities are neither stable nor constant with regard to diversity, number of taxa and abundance in the Suquía River, presenting a great temporal and spatial variability. Community structure becomes more complex in an altitudinal gradient, from up to downstream. In the places where contaminants enter the basin, diversity and number of taxa decrease. Some taxa are more abundant in the upper section, while others increase their abundance in the middle and lower sections. Some others are present along the basin, regardless of altitude. In the upper section there is a limit (1,000–1,200 m.a.s. l.) above which a change in fauna is produced.

3.2 *Invasive Bivalves*

Invasive species are one of the most significant causes of biodiversity loss and changes in ecosystem services, which underline the importance of their detection and study. Freshwater systems are particularly subject to invasion by exotic invertebrate species, which use water current for dispersion throughout these systems. Among these invertebrates, bivalve molluscs are a group with high potential for invasion: they can develop massive populations in all kinds of fresh waters, consuming microalgae and substantially affecting the amount and composition of primary producers. Interactions radiating out from the primary producers can affect nearly every part of the ecosystem. Their activity also entails habitat modification, competition and extinction. Besides the characteristics of natural ecosystems, they can affect human structures, impeding domestic and industrial water supply infrastructure. Human activity, such as the construction of shipping canals for trade, building of reservoirs for water storage and power production, promotes the spreading of these species and facilitates pulses of spreading which seem to be not continuous [42].

In the last decades, two species of freshwater bivalves have been reported as invasive in inland waters of South America: the golden mussel, *Limnoperna fortunei* (Dunker 1857), and the Asian clam, *Corbicula fluminea* (Müller 1774).

In the case of *Limnoperna fortunei*, its sudden appearance in the Río de La Plata Estuary was first reported at the beginning of the 1990s [43], spreading into Argentina, Uruguay, Paraguay, Bolivia and Brazil. *Corbicula fluminea* started to colonise South America in the 1960s, when the bivalve arrived in Argentina and Brazil, through the Río de La Plata River, and subsequently spread into Venezuela, the northern part of the Pantanal in Southwest Brazil, and lower areas of the Amazon River Basin, among other areas [44]. Nowadays, they are one of the dominant freshwater benthic macrofauna in an area extending from Lake Superior in North America to Patagonia in South America. Such golden mussels and Asian clams have been reported in central Argentina. In Córdoba, their distribution is still scattered, not having been observed, for instance, in the upper reaches of the main rivers and reservoirs. It is estimated that their distribution will be more extensive in the case of species with a wide range of physiological tolerance and adaptability to different environments.

The mechanism that enabled the introduction of invasive bivalves in the Suquía River and other basins of central Argentina is uncertain, since they are geographically disconnected from the arrival area. Thus, the accidental introduction by human activities is the most probable cause. They are successful invaders that can be dispersed through natural means over large areas in a short time. Through their larvae, they could spread into reservoirs connected to the arrival area and from there, to other rivers and reservoirs like the San Roque Reservoir, most probably transported in hulls of boats for recreational or fishing purposes.

The systematics of *Corbicula* is controversial and especially the study of lineages in the New World, where three morphotypes have been distinguished. These are forms A and B, present throughout the continent, and form C, only present in South America and known as *C. largillierti*. According to Lee et al. [45], there are hybrids between the different forms. Pfenninger et al. [46] proposed that different lineages of *Corbicula* may be an initial state of a group of species rather than a defined species. Morton [47] considered that the observed variability could correspond to a single species. Following the analyses of different outer and inner characters suggested by previous authors [48–50], Reyna et al. [51] reported the presence of two corbiculid species, *C. largillierti* and *C. fluminea* in the Suquía River Basin. Among the previously reported characters, rib number was useful to differentiate the two species. Besides, conventional and geometric morphometric analyses to assess inter- and intraspecific differences in shell shape revealed a clear morphometric differentiation between *C. fluminea* and *C. largillierti* (Morán et al. in prep) (Fig. 6).

When present in high abundance, *L. fortunei* produces occlusions in piping systems, such as pipes or hoses, as well as in bars, turbines and water intakes with imaginable consequences. They can also affect the speed of vessels due to a loss in hydrodynamics. In all cases, a necessary step then is to spread the problem to take preventive measures. The invasions of freshwater molluscs are a real problem in different areas of the world: in the Northern Hemisphere, the zebra mussel

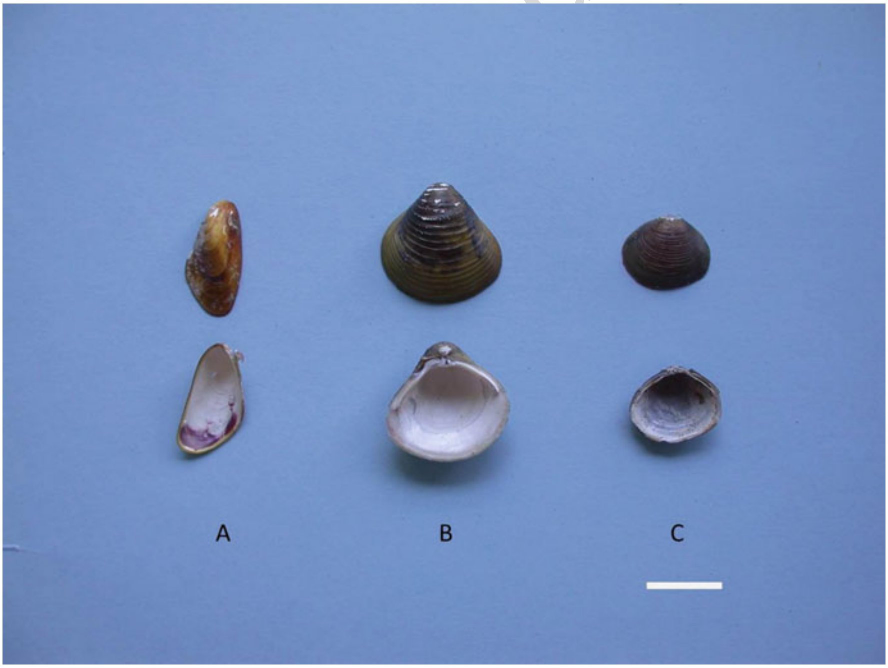

Fig. 6 Inner and outer sides of shells from different bivalves. (**a**) *Limnoperna fortunei;* (**b**) *Corbicula fluminea*; (**c**) *C. largillierti*. Scale bar, 3 cm

Dreissena polymorpha produces similar effects as the golden mussel. In the United States, the use of aggregates with abundant dead *Corbicula fluminea* shells in the construction business caused the weakening of concrete structures. From an ecological perspective, the filtering capacity of freshwater molluscs (necessary for the feeding activity) causes a decrease in the turbidity of water bodies since they eat phytoplankton and particulate matter in general, and their droppings can be an important part of the nutrient cycling. While the golden mussels are typically epifaunal animals that normally attach themselves to hard substrates through byssal threads, the Asian clams are infaunal species. In both cases, they potentially constitute a substrate competitor for other species, since they can colonise large areas. Although native bivalves are present in other areas of Argentina (i.e. clams *Cyanocyclas* and *Anodontites*), none were reported in the Suquía River. So far, the vector of parasites that affects human health or other species is unknown. In other close areas, certain species of birds and teleost fish, such as *Pterodoras granulosus* and *Leporinus obtusidens*, predators of clams and mussels, respectively [44], can constitute natural controls for mollusc populations.

Strategies for the prevention and control of mollusc populations must be adapted to each circumstance, because once they appear, they are difficult to eliminate. Regular cleaning or the use of anti-fouling paints on the hulls of boats used for recreational or fishing purposes may limit accidental spillage. Other uses of these organisms, such as fishing bait or aquarium, should be avoided. In closed systems, biocides (chemicals), temperature or salinity alteration can be used. In natural environments, the control of these factors becomes difficult, and the predator action is limited. For this reason, the most effective method is manual removal.

Bivalve density varies with substrate type: while golden mussels typically attach themselves to natural and artificial hard substrates, clams bury themselves in sediments, preferably in sandy substrates. However, *C. fluminea* can colonise a wide variety of substrates: rocks, gravel, boulders, sand and clay. Darrigran [52] found that in environments with a substrate composed of silt sediment, *C. largillierti* dominates over *C. fluminea*.

Other parameters, such as fluctuation in water level and contamination, can also determine the presence and density of these animals and produce alterations in their population structure. Given the particular characteristics of the Suquía River Basin, i.e. presence of diverse substrate types, fluctuations in the flow regime and the impact of human activities, the presence, distribution and density of invasive bivalves vary throughout this extensive area.

Making a first diagnosis on the status of the invasion of corbiculids in the Suquía River Basin, Reyna et al. [51] studied their distribution and density at different sites. Variations in population structure (density, biomass, spatial distribution and size classes) during a whole year were also studied in Córdoba city. Results of that study revealed that *C. fluminea* is restricted to a lentic environment (the San Roque Reservoir), apparently coexisting with *C. largillierti*, although only empty shells of this latter species have been found in this site. In rivers and brooks, only *C. largillierti* was detected. The absence of living specimens and the presence of empty shells in diverse sites could be due to the water dynamics and flow, which depend on rainfall that mostly occurs during summer time in the Southern Hemisphere (from November to March). The reduction of the river flow during the dry winter season exposes the sandbanks where molluscs live buried and causes their death. The species *C. largillierti* showed variations in average density between the different sites and also variations in biomass and size classes throughout the year period. The average density of 302 ind./m^{2}observed in Córdoba city was similar to the density observed in a tributary lentic environment of the Río de La Plata Basin (459 ind./m^2 [52]), but it was considerably less than the mean density of *Corbicula* observed in the Río de La Plata Basin (2.5 ind./m^2 [53]). A great number of medium-sized animals were found in Córdoba city during the year period. As stated by Boltovskoy et al. [54], the absence of small and large-sized individuals and the high density of medium-sized individuals may be caused by contamination, affecting the larvae and preventing the growth of individuals. This site is located in Córdoba city, where the river is flanked on both sides by frequently used highways and is connected to the city rainwater channels, through which garbage and sewage waters are illegally introduced.

Darrigran [52] found *Corbicula* in lentic environments, with *C. fluminea* restricted to shallow, well-oxygenated coastal waters. Besides, abundant populations of *C. fluminea* were detected in the headwaters of micro-basins and rivers with a stronger flow [55]. The distribution of *C. fluminea,* restricted to the San Roque Reservoir, within the Suquía River Basin is surprising, considering the wide, rapid spread of this species in other areas. On the other hand, *C. largillierti*, which was distributed in most of the sampling sites along the Suquía River, was restricted to a few sites in Argentina [52, 56]. That species seems to be better adapted to brook environments. The absence of *Corbicula largillierti* downstream of Córdoba city (31° 25′50″S/64°01′57″W) could be due to high contamination. The accumulation of city garbage and agricultural pesticides, sewage discharge (WWTP) of Córdoba city at Bajo Grande with low oxygen levels (5 ± 2.1 mg l^{-1}) detected in that area [57] are probable stress conditions. They would limit the survival of juvenile and adult bivalves and, therefore, their dispersion from the upper to the lower basin. Studies on the potential distribution and the influence of contamination are necessary in order to comprehend the processes structuring changes along the Suquía River.

4 Aquatic Plants

Despite having conquered the land, some vascular plants have ventured back into fresh waters: it is estimated that they represent ca. 1% of the angiosperms and 2% of the pteridophytes, according to how strictly an aquatic plant is defined. Since plants from aquatic environments have a diversity of habitats and plasticity, it is difficult to determine a biological classification for such a heterogeneous group. However, a more generalised scheme divides them into the following categories [58–60]: