



Wicked Environmental Problems in Bañado La Estrella: Floods and Water Pollution of the Pilcomayo Basin and their Impact on Indigenous and Rural Communities

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Abstract

The Pilcomayo River is unique in several ways, including its massive sediment load, one of the world's largest alluvial fans, and a constantly changing channel that occasionally blocks and overflows over vast areas. Most of the northern half of the Province of Formosa (Argentina) is covered by the vast wetland system known as the Bañado La Estrella, in the middle Pilcomayo basin. Due to repeated obstructions of the channel that functioned as the border between Argentina and Paraguay, the Bañado La Estrella expanded from the 1920s until the 1990s, when both nations agreed to the Pantalón project: They divided the river in two out of concern over losing complete access to resources like water and fish. Since then, the middle Pilcomayo basin has been subject to constant engineering works to prevent further changes (dams, channel construction, and dredging), and efforts to promote conservation and ecotourism such as its declaration as one of the 7 New Natural Wonders of Argentina. This article analyzes three environmental problems of the middle Pilcomayo basin and Bañado La Estrella that mainly affect rural and indigenous communities. Using the conceptual framework of wicked problems, we state that these issues are often conceptualized or explained in contradictory ways, both within and between different social groups. Also, they do not present straightforward solutions, but are best addressed with more democratic and bottom-up approaches. Finally, we suggest that science's function should be to contribute to basin resilience by enhancing these approaches and informing decisions while preserving complexity in the discussion.

Keywords Gran Chaco · South America · Hydrosocial relations · Toba / Qomle'ec / Qom people

Introduction

*“Before the arrival of the whites, our river never overflowed. Livestock has replaced the animals we used to eat, formerly these were abundant and now we starve in our own hunting grounds. Before, the bad weeds did not hide the Pilcomayo. There were large grassy plains where herds of ostriches (*Rhea americana*;*

ñandú or suri) ran. You could also see the deer, of a beautiful presence and huge antlers. Now they too have disappeared into the big water. The Tobas and the Mataco will soon follow the deer into the great forests.” Qomle'ec chief Lagadik to Alfred Métraux, the first academic ethnographer of this group, in 1933 (Métraux 1973 p. 104)¹.

The **Bañado La Estrella** (BLE) is an extensive wetland system in the middle Pilcomayo River basin along the northern half of the Province of Formosa in Argentina (Fig. 1). Its name in Spanish means The Star Wetlands, which is mostly attributed today to its characteristic shallow and still waters that perfectly reflect the night sky. On the other hand, local people tell La Estrella was the name of the landmark from where the BLE started growing in the 1920s that is now lost. Its expansion occurred by successive upstream blockage of the Pilcomayo River course and consequent flooding

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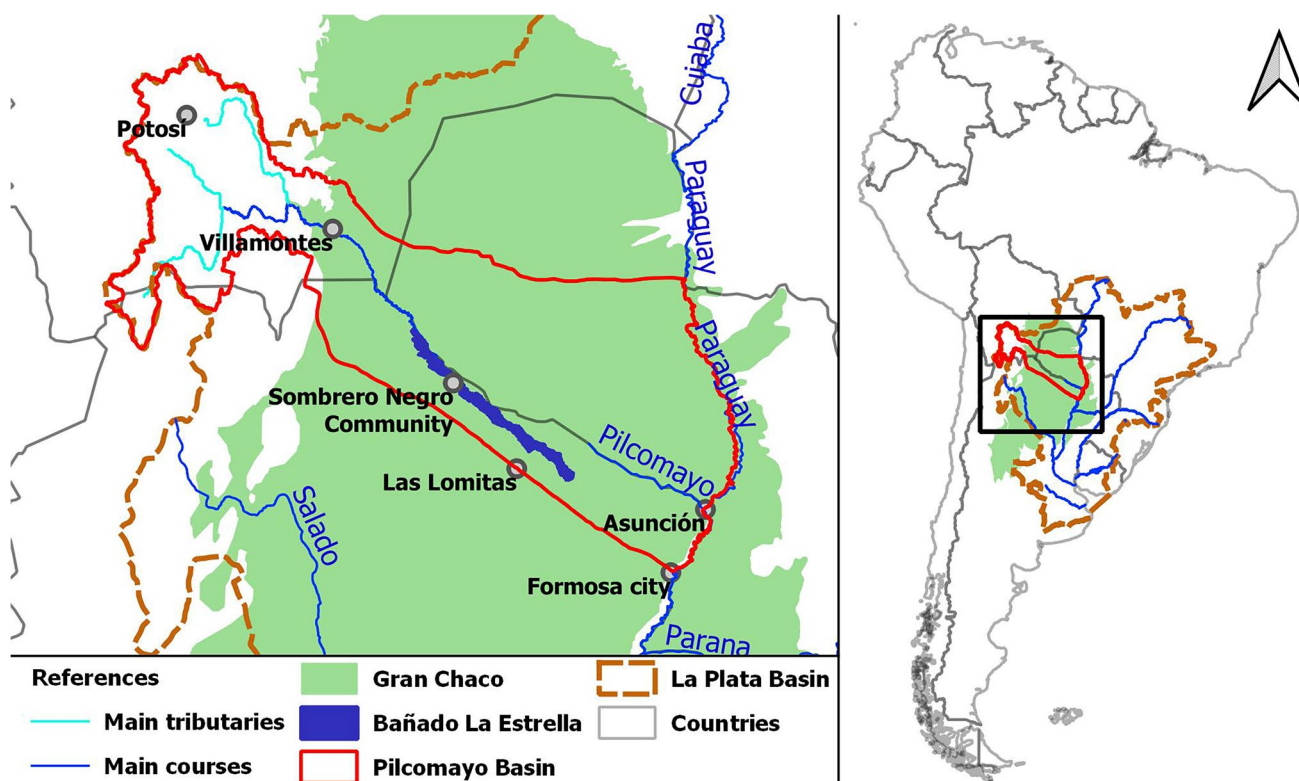


Fig. 1 General map of the Pilcomayo basin showing the main locations mentioned in the article

of extensive areas to the south (Iriondo 1993; Comisión Trinacional del Pilcomayo 2008a). Its estimated 400,000 hectares make the BLE the third most extensive wetland in South America, after the Pantanal (Paraguay and Brazil) and Iberá (Corrientes, Argentina), and the most important one in the **Gran Chaco** region (Brown et al. 2010).

Historically, the Gran Chaco region was one of the two “inner borders” that was annexed to Argentina in the late XIX century, the other being Patagonia, both inhabited by several indigenous groups to this day. One of these groups is the Qomle’ec² who controlled a big territory along the middle Pilcomayo basin for over 400 years since the Spanish conquest, in what are now the countries of Bolivia, Paraguay, and Argentina (Mendoza 2019). By the early 1900s, a fraction of this group migrated to Argentina due to military pressures from both Bolivia and Paraguay National States to retain control of the northern Chaco which escalated until the Chaco War of 1932–1935 (Gordillo 2010a). Nowadays, the Qomle’ec live mostly in Argentine territory and are

no longer considered a native ethnic group by Bolivia and Paraguay (Mendoza 2020). Approximately 3500 Qomle’ec people occupy an area to the northwest of the Argentine Province of Formosa in a community called **Sombrero Negro**. They live in the bush, approximately 50 km from the nearest town in several villages or scattered houses near the BLE (Gordillo 2005).

In 2018, severe flooding from the BLE reached out to most villages of the Sombrero Negro community (Fig. 2). Families evacuated to temporary settlements and lost the few material goods they owned (Télam 2018; Menna et al. 2019). During fieldwork for his doctoral dissertation about the community response to the floods, one of the authors (GGJ) conducted semi-structured interviews in which the opinions of people affected by the floods about the causes of the floods were recorded. Many possible causes were mentioned, including that these flood events and an increase in frequencies were due to global climate change. The emotional impacts of the floods on people and uncertainty about the future were also recorded. Would the river flood again? Should they go home when the water has receded or move and start over in a new place? Would these new places, that now seem safe, eventually flood as well?

At the same time, no deaths were registered in association with these floods, something that is seen both inside and outside the community as a victory of the Early Warning

² Qomle’ec is their autonym in Qom language which means “people”. Other names for this group include Toba, Qom, Toba-Pilagá, Western Qom, Bolivian Tobas. The term “Toba”, which means large forehead in Guaraní language, is now considered somehow pejorative, but it remains as their autonym when they speak Spanish.



Fig. 2 Flooded and filled with sediment Anglican church (left) and houses (right) in the village of El Churcal of the Sombrero Negro community. Photos provided by Adán García

System of the Pilcomayo River (SAT, for its acronym in Spanish) (Menna et al. 2019). However, many other viable solutions or adaptations to the floods were recorded in the field, many of which were contradictory to one another or the registered causes. For instance, the building of containment rings and barriers³ was proposed as a solution, but, at the same time, their failure was said to have made the situation even worse.

The variety and contradiction of the perceived causes and proposed solutions, particularly from people for whom so much is at stake (lives, material belongings, and means of life), bring up the concept of **wicked problems**. Wicked problems were first proposed by Rittel and Webber (1973) in the context of planning literature to differentiate between classic issues of policy planning solved by straightforward approaches (**tame problems**) and the more complex problematics of the last century that deal with both the previously implemented solutions and the current heterogeneous society.

Within the conceptual framework of wicked problems, this study identifies four goals. First, to describe the particularities of the Pilcomayo basin, including the origin and expansion of BLE and its social and environmental context. Second, to analyze the recurrent floods of Sombrero Negro and discuss their possible categorization as a wicked problem. Third, to compare these floods to other socio-environmental issues of the middle Pilcomayo basin, namely chemical pollution, and the building of the Provincial Route

³ Our translation of the local expressions *barreras de contención* and *anillos de contención*, which describe localized dams that redirect watercourses, usually protecting towns, roads, and other infrastructure.

28 that consequently flooded Pilagá communities (another indigenous group that is closely related to the Qomle'ec), which could differentially be interpreted as tame or super wicked problems. Fourth, to discuss how the wickedness of these issues should be tackled by more democratic and bottom-up solutions and what should be the role of science in the quest for environmental adaptation.

Wicked Problems

The characteristics of wicked problems are summarized as follows:

“First, wicked problems are often **symptomatic of deeper problems and often display circularity**, as in explaining educational problems by poverty, poverty by social class, and social class by educational achievement. Second, wicked problems **offer little room for trial-and-error learning**: once a neighborhood has been demolished, it can never be restored. Third, they **don't present clearly defined alternative solutions**; indeed available solutions are often used to define the problem, as in the idea of monetizing ecosystem services to address “market failure” in environmental protection. Fourth, they are **characterized by contradictory certitudes**, in that there are many different diagnoses of the problem and many different prescriptions for solving it, often ones that are incompatible; for example, the recent banking crisis has been blamed on both too much and too little regulation. Fifth, wicked problems tend to have **redistributive implications for entrenched interests**, such as those

of the fossil fuel industry in relation to greenhouse gas mitigation.” (Rayner 2017 p. 1), bolding is ours.

Another characteristic of wicked problems that is often neglected, but clearly implied in their discussion, is that “wicked problems involve multiple actors and are socially and politically complex” (Peters 2017 p. 388). To add nuance to the problem, other authors propose a special subcategory that consists of super wicked problems (Lazarus 2009; Levin et al. 2012). This concept emphasizes the particular wickedness of some problems concerning the timing of expected solutions and who is expected to address them. Their properties are summarized as follows:

“(1) Time is running out; (2) There is no central authority, or only a weak central authority, to manage the problem; (3) The same actors causing the problem seem to solve it; and (4) The future is discounted

radically so that contemporary solutions become less valuable.” (Peters 2017 p. 388).

After many years of discussion around these terms, they were rapidly and largely included in the environmental sciences to address socioenvironmental issues. The archetypical case of a wicked environmental problem is climate change, and it is often contrasted with the comparatively tame problem of the ozone hole, both being globally scaled issues that must be solved through (but not only) international cooperation (Grundmann 2016). On one hand, the ozone hole problem presented clear science linking a certain type of molecules as ozone destructors. In turn, these molecules were associated with certain industries and, therefore, global measures to reduce the use of these substances were taken, which proved to be largely successful. On the other hand, climate change fulfills all the characteristics of a super wicked problem, as summarized in Table 1, where we explain each attribute by means of this example.

Table 1 The accomplishment of the characteristics for wicked and super wicked problems, using climate change as a paradigmatic example (Grundmann 2016)

	Characteristics	Climate change
Wicked problems	Are symptomatic of deeper problems and often display circularity	One way to adapt is development, and many countries plan to do so through the use of fossil fuels, the use of which is both the cause of the problem.
	Offer little room for trial-and-error learning	We must take action today, which will be sustained into the future, and even then we would not see results for decades.
	Do not present clearly defined alternative solutions	The two main solutions are mitigation and adaptation. While the former must be global, the latter takes different forms in different regions and societies, but both must be implemented.
	Are characterized by contradictory certitudes	Numerous practical solutions have been suggested: switching to nuclear, solar, wind or biofuels; a transformation of our lifestyles; a carbon tax; geoengineering; and even the abolition of capitalism. All cite the scientific consensus that anthropogenic climate change is real, but if some of these solutions were implemented, they could lead to worse catastrophes.
	Have redistributive implications for entrenched interests	Whatever action is taken, it will affect different groups unequally. In addition, there is strong political lobbying by the main drivers of the problem to prevent change in the status quo.
	Involve multiple actors and are socially and politically complex	It is a global problem that potentially affects everyone and there is a vast diversity of opinions about it.
Super wicked problems	Time is running out	We have approximately 10 years to reduce emissions and avoid an average global warming of 1.5 °C. However, most countries have made commitments until 2050.
	There is no central authority	The IPCC is only a community of scientists, with no decision-making power. These are in the hands of individual countries or composites.
	The same actors causing the problem seem to solve it	It is the same countries that developed using fossil fuels that must make decisions about the future.
	The future is discounted radically	Distrust in decadal climate forecasts is one of the main arguments to avoid taking action.

Beyond global issues such as climate change, there has also been a call in the last decade to include the complexity of socio-environmental systems in the hydrological literature at the local and regional levels (Akamani et al. 2016). Especially among early-career researchers working at the basin level, who tend to consider the analysis of wicked problems as a new discipline of socio-hydrology (Levy et al. 2016). This approach recognizes two main problems: the complexity of the interacting systems and the increased uncertainty of the work (Kosow et al. 2022). To address uncertainty, one must improve measurements and modeling over time and increase the relevance of these results for decision-making and policy advice. To better represent complexity, research on the interrelationship between hydrological and socio-environmental systems should be enhanced, in addition to including, as far as possible, the social sciences and the stakeholders themselves. Both of these problems require research that does not fall within disciplinary boundaries to be funded and published (Levy et al. 2016; Kosow et al. 2022). By analyzing the wickedness of the Pilcomayo's socio-environmental problems and their relationship with current and historical human decisions, we hope to contribute to working with complexity at the basin level.

Historic and Environmental Context

“Never speak of prairies of tall and thick weeds, the Great Fire could hear you and by eating them would set the world on fire.” Kedok to Alfred Métraux in 1933 (Métraux 1973 p. 128).

The Gran Chaco is an inland region in central South America that is distributed among the countries of Argentina, Paraguay, and Bolivia (Fig. 1). Particularly in the Pilcomayo basin live approximately 1.5 million people of which 60% are below the poverty line and 30% are under extreme poverty (Laboranti 2011). While most of this population lives in cities and does not recognize itself as indigenous, most people living in rural areas belong to either of those peoples or to the local group called *criollos*. *Criollos* are settlers of European or mixed-ancestry descent who live as small cattle ranchers isolated from one another and resemble the traditional Gauchos of the Pampas (Dasso 2010). Despite local recurrent disputes over land use and land rights, *criollos* and indigenous peoples usually adhere to the same political claims against big farming companies and local governments (Salamanca 2011; Iñigo Carrera 2012).

The Qomle'ec belong to the Guaycuruan language family but are geographically and linguistically separated from the other people whose autonym is also Qomle'ec or Qom (Carpio and Mendoza 2018). The Qomle'ec traditionally

consisted of nomadic and exogamic bands that subsisted on the gathering carried out by women and supplemented by hunting, fishing, and honey harvesting by men (Mendoza 2002). While now most Qomle'ec families have temporary jobs and governmental subsidies, they still supplement their diet with products from traditional hunting and gathering during the summer (the season of abundance in the forests), fishing (the main subsistence activity in winter), and family-scale horticulture and animal husbandry (Arenas 2003; Lanza et al. 2013).

Major indigenous groups from the Argentine Gran Chaco besides the Qomle'ec include the Pilagá people (that together with the Qomle'ec belong to the Guaycuruan language family) and the Wichí people (Mataco-Mataguayo language family) with similar past and present ways of living (Miller 1999). Other language groups of the Gran Chaco, in general, include the Zamuco, Tupí-Guaraní, Maskoi, and Lule Vilela families across the three countries (Braunstein 2005). These common characteristics of its diverse population - that is, poverty, subsistence economy, and private commerce limited to small-scale husbandry and agriculture - makes them particularly exposed to two common regional hazards: changing climatic fluctuations (including climate change), and national and regional economic ups and downs (Laboranti 2011).

All these indigenous groups were traditionally hunter-gatherers and nomads who adapted well to the seasonal nature of the Gran Chaco. Watercourses and food resources from the forests are particularly abundant during the rainy season from October to March. The dry season encompasses the remaining months of the year, when the availability of food and water is mostly restricted to river courses. The first historical records of the Qomle'ec can be tracked back to the early 15th century in the present-day Bolivian Gran Chaco. Ethnohistorian Mendoza (2019) summarizes these early descriptions, showing that this group experienced demographic processes of fission and temporary fusion following the said seasonality. In summer (the rainy season) the Qomle'ec divided into small kin groups to explore and exploit the forests, and in winter they gathered along the Pilcomayo River for group fishing and cultural activities. Since these early descriptions, the seasonality of the Gran Chaco has remained unchanged, but not the environment nor certain cultural aspects. Seasonal migrations have stopped since different Christian congregations evangelized and sedentarized the indigenous groups (Miller 1979). Also, different national and subnational states divided and sold the land and frequently the indigenous communities only got a small portion of their ancient territories, if anything at all (Giordano 2004; Matarrese 2012).

The environment has also changed. Before the 20th century, the Gran Chaco presented extensive grasslands that

coexisted with strips of forest and jungle, usually on the banks of rivers and wetlands (Scarpa and Arenas 2004). Recent ethnographic works registered personal recollections of these past environments. For instance, in the surroundings of the Pilcomayo River during the early 20th century, there were high pastures between 15 and 20 km wide on each side of the river with some islands of forest, according to Qomle'ec elders (Gordillo 2010b). They also spoke of *dóle aló* or the Great Fire, creator of open spaces, who once destroyed the world and will do it again someday (Métraux 1973).

The vast dry forest ecosystem that dominates today is the product of environmental degradation resulting from the colonization of the Gran Chaco by cattle and goats, mostly associated with *criollo* settlers, despite some family-scaled husbandry performed by indigenous people. However, cattle production began with large *estancias* and *puestos* with thousands of animals each and reached the highest amount of animals by the 1930 and 1940 s (Adamoli et al. 1990). Large-scale breeding began near Qomle'ec territory for the first time in 1902 in Colonia Buenaventura, 150 km upstream (Gordillo 2010b). The preference of livestock for palatal grasses eventually led to the depletion of this resource, and then the animals switched to shrubs and trees, disseminating this type of species. These actions added to the suppression of fire dynamics, and changes in watercourses favored the development of xerophytic woody species (Morello et al. 2013).

However, the environmental changes observed in the last century were not made to a pristine or natural biome, but rather on the constructed landscape of past societies (Boivin et al. 2016). As for the Gran Chaco, there is evidence of human-induced changes as early as 7000BP including deforestation, weed clearing, and widespread fires. These landscape changes along with climatic changes led, for instance, to the local extinction of the late Pleistocene and early Holocene megafauna related to open spaces, followed by short-term recolonization, and later final extinction (Coltorti et al. 2010). There is also archaeological evidence not only of human settlement pattern changes according to changes in watercourses, but also of human-induced changes in local topography and watercourses. These changes include artificially elevated areas (*cerritos* or *montículos*), canalizations, and artificial ponds surrounding (or including) human settlements (Lamenza 2015; Lamenza et al. 2019).

The Middle Pilcomayo Basin and the Bañado La Estrella

“Others, on the contrary, commented that perhaps the river would be dug by the being that in the past opened the original channel of the Pilcomayo: Lék, the water boa, which is considered capable of digging the earth with its head.” Gordillo and Leguizamón on the dif-

ferent opinions of the Qomle'ec informants about the recent loss of the Pilcomayo course (2002 p. 74).

As part of the main Río de la Plata Basin, the Pilcomayo River begins as an extensive network of mountain tributaries in the Bolivian and Argentine Andes (the upper basin) (Fig. 1). It enters the Gran Chaco region near the Bolivian city of Villamontes and, from there to the southeast, drains one of the largest alluvial fans in the world (middle and lower basin) (Iriondo et al. 2000; Latrubesse 2015). The presence of colossal alluvial fans or megafans is associated with rivers with channel instability, large fluctuations in seasonal discharge or precipitation, and significant climatic changes through the geological record (Leier et al. 2005; Latrubesse 2015). In the Gran Chaco, humid climates that favored the generation of soils and stable fluvial courses were repeatedly succeeded by drier climates that led to widespread sedimentation along ephemeral channels and large spill-outs, producing the largest alluvial fans in South America (Iriondo 1999).

As the Gran Chaco is a broad flat region and the Pilcomayo River has a high sedimentary load, it is common that this river changes its course by siltation. This process has greatly influenced the surrounding geography and there is no continuous course between the upper basin and the river's mouth. On one hand, the middle Pilcomayo is nowadays a series of interconnected marshes and creeks whose water level varies according to the water inlet of the Pilcomayo and the local atmospheric and geomorphological conditions (Iriondo 1999). On the other hand, the lower Pilcomayo is an actual watercourse that drains the Chaco into the Paraguay River near the Paraguayan capital of Asunción, but it seems to be disconnected from the upper and middle basin (Laboranti 2011).

These peculiarities of the Pilcomayo basin were not known (and understood) by the national States that tried to annex the Gran Chaco in previous centuries and the explorers they sent to navigate it. The records of sailing expeditions date back to the middle Sixteenth Century until the golden age of the Pilcomayo expeditions between 1843 and 1910 (Fig. 3). They describe a continuity of shallow water through wetlands and marshes and, consequently, a lack of depth for sailing which risked or impeded the completion of these expeditions (Martín-Vide et al. 2014). These quests were mostly influenced by the necessity to find a waterway across the Gran Chaco⁴ and the idea of how a river should behave, summarized in the expression “the search for the *true* Pilcomayo” (Gordillo and Leguizamón 2002).

The area where the current middle Pilcomayo River has no actual course and spreads out in many channels and

⁴ This was of particular interest to Bolivian authorities after losing access to the Pacific due to the war with Chile. The Pilcomayo was pictured as the most direct waterway from the mining hotspot around Potosí to the Atlantic.

Fig. 3 Map of the Pilcomayo published in the book of the Bolivian Expedition of 1883. No digital version of this book is available and so this digital reconstruction was made by adding three A4-sized scans done with a portable scanner on a “not for rental” copy of the Florentino Ameghino Library (National University of La Plata, Argentina). Many maps were drawn during the golden age of the Pilcomayo expeditions that normally accompanied the writings of the explorers and mainly showed the recognized course of the river, the route of the expedition, and the indigenous groups and natural resources encountered along the way. However, differences among the different expeditions and the western conceptualization of the expected behavior of a river led to “the search for the true Pilcomayo”, resulting in perfectly drawn rivers on the explorers’ maps but of dubious realism



marshes to the south of its former location is the BLE, but it has not been the only associated large wetland since many before were known as the Estero Patiño (Patiño Swamp). At the beginning of the last century, the river kept its bed functional as far downstream as 250 km from Asunción, where the Estero Patiño existed at the time. In the period 1947–1976 the bed progressively silted, losing 150 km of its

length, with a maximum rate of 12 km yr⁻¹ in 1968–1976 and a maximum loss of 22 km in 1976, resulting in the drying of the last Estero Patiño. In the period 1975–1990, another 150 km were lost, with a maximum of 45 km in 1984. All course retreats happened in the humid season and their severity depended on the peak flow and associated floods each year. This self-obstruction of the river bed with

sediment and its continuation as an overland flow has been called the “Collapse of the Pilcomayo River” (Martín-Vide et al. 2014). In turn, each loss of channel length implied an equivalent westward expansion of the BLE.

The threat of completely losing the river channel and its resources (mainly water and fish) produced a series of complaints and political frictions between Argentina and Paraguay, which urged these countries to an agreement in 1991. It was decided to dig a pair of divergent straight canals that equally divided the waterflow between the said countries: the *Proyecto Pantalón* (Pants Project). This project remains successful to this day and the receding of the Pilcomayo course has stopped, but with large maintenance costs related to the continuous building and dredging of channels (Laboranti 2011; Martín-Vide et al. 2014). However, the distribution of water has rarely been fair. Between 1992 and 1993, the Paraguayan canal worked inefficiently due to design errors and the Pilcomayo drained completely to Argentina into the BLE. The consequent floods in Argentina and droughts in Paraguay generated social unrest in the Gran Chaco population, each blaming the other for the local problems. After tense negotiations and amending engineering works on both sides, the opposite happened and in 1995–1996 the BLE completely dried (Gordillo and Leguizamón 2002).

The continuing issues with water distribution and the regional context of transnational integration (MERCOSUR) encouraged the three countries to develop by 1995 the Agreement of the Trinational Commission of the Pilcomayo, which was signed in La Paz (Bolivia) and took the La Plata Basin Treaty as a reference (Laboranti 2011). With the formation of the Trinational Commission, a water distribution system was designed through a dam near the tri-national border. This project remained in the study, design, and pre-feasibility stage until a flood in 1998 showed the ineffectiveness of the model. However, this idea was maintained, and the system was re-studied twice more, placing the model further downstream each time. The project was never executed because it was shown that the volume of sediment would fill any dam in one or two years (Amarilla and Laboranti 2011).

Despite delayed local funding due to regional economic crisis at the beginning of the century, one achievement of the Pilcomayo Trinational Commission was the baseline in 2006 that detected the main socioenvironmental issues of the basin, namely geological hazards (floods, earthquakes, erosion), river course changes, deforestation, water pollution, fishing resources degradation, biodiversity loss, and social inequalities, among others (Comisión Trinacional del Pilcomayo 2008b). This baseline and the following Pilcomayo basin Master Plan, however, were never put into operation. In fact, the Master Plan was never approved by three governments that make up the basin. For this reason, an international consultancy is currently being developed

to redefine it (Ing. Claudio Laboranti, personal communication). The Province of Formosa, where the whole BLE is located as well as a large portion of the south middle and lower basin, was never interested in acknowledging the authority of the Trinational Pilcomayo Commission since the government considers that once the water enters the provincial territory, it becomes a provincial resource that must be managed by the local government. This argument is based on the Argentine constitution of 1994, which assigns the ownership of all natural resources to the individual provinces.

Socioenvironmental Issues of the Middle Pilcomayo Basin

Case I: Multiple Causes and Solutions for the Floods of Sombrero Negro

“That time we saw that the water was very red, with sand. We could not drink it. [...] Then the next year it was worse, the fish died. [...] It must be because the water was very dirty. [...] Then in the third year there was a tree that turned over on the sand. It seems that it was already touching the riverbed. It seems that the river is shallow. Later we saw that there was sand in the middle of the river. Then the water came this way, inside the forests. Then in what was called Misión El Toba, the water came in first. How the water came in, stronger! And the people suffered a lot. [...] My uncle made an embankment as if to cover the water, working day and night. [...] The water still came in, came out from below and ate up the embankment. The water came in where we were, and we put all the things in a cowhide. And we came here.” Qomle’ec man to anthropologist Gastón Gordillo in 1999 on the flood of El Toba Anglican Mission and nearby villages in 1975 (Gordillo and Leguizamón 2002 p. 54).

The founding of the El Toba Anglican Mission in 1930 on the southern shore of the Pilcomayo marks the beginning of the sedentary lifestyle for the Qomle’ec Community of Sombrero Negro, and it is recognized by the elders as the major event in their recent history. The time before the mission is called *el tiempo de los antiguos* (the time of the ancient ones), as a way to distance themselves from their nomadic and not God-fearing ancestors (Gordillo 2005). The second relevant event was marked by the silting of the Pilcomayo Riverbed and the consequent flooding of the Mission in 1975 (Gordillo 2005; Leake 2012). The community refers to the times of the Mission as *cuando había río* (when there was a river) since now the old channel, and current border between

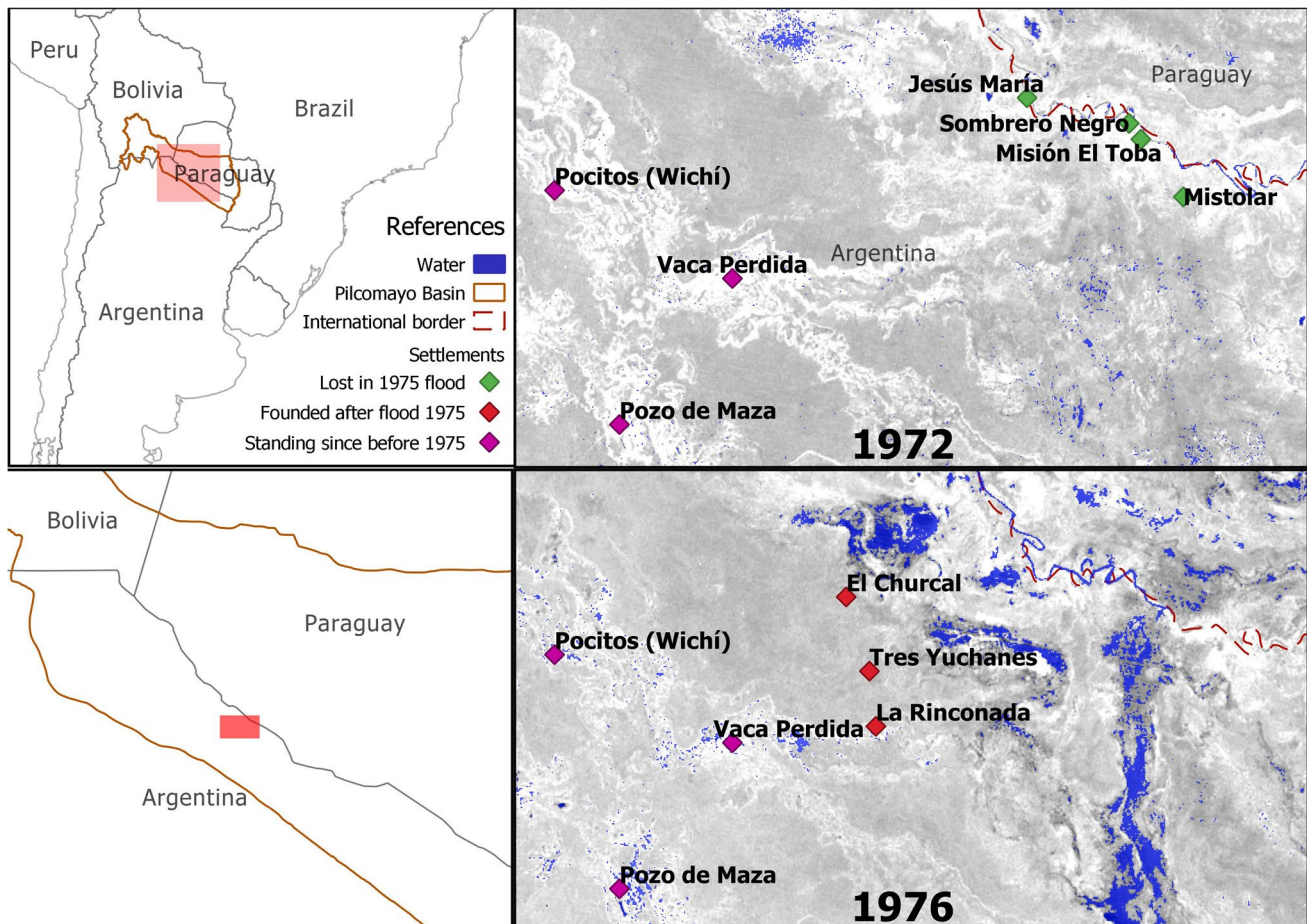


Fig. 4 Most probable areas with water around the villages of the Sombrero Negro Community according to Landsat images of 1972 and 1976, that is before and after the floods of 1975 when the Pilco-

mayo lost its course in that region. Associated changes in the human settlements are also depicted

Argentina and Paraguay, is dry and the river gets lost in the BLE. After the floods, they migrated approximately 20 km to the southwest and founded several villages to the south of these new wetlands (Gordillo and Leguizamón 2002) (Fig. 4). Then, the community claimed these lands to the Province of Formosa, on the basis of the “Integral Aboriginal Law” (Formosa 1984).

Nowadays the community of Sombrero Negro owns 35,000 ha⁵ of territory with a population of up to 3000 people (Lanza and Valeggia 2014). In January 2018, a flood occurred in the Sombrero Negro area that affected the surrounding villages of the BLE, causing many families to evacuate to temporary settlements. This flood occurred during the wet season (during the Southern hemisphere summer), and some inhabited areas were destroyed and buried under meters of sediment. In 2019, the flood reached again the same places,

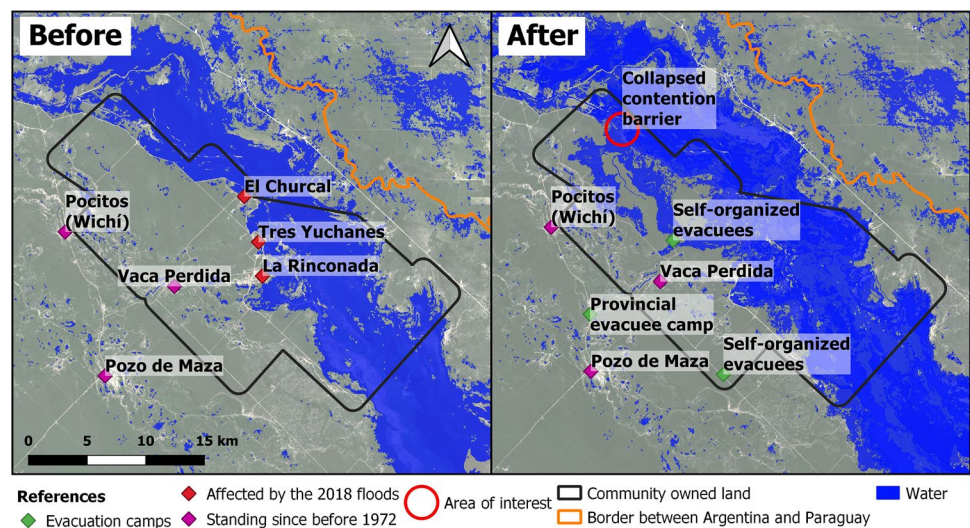
but it was not so catastrophic, because people no longer occupied those places, the speed of the water was lower, and the deposition of sediments in inhabited areas was lesser (Fig. 5).

One of the authors (GGJ) made three fieldtrips to Sombrero Negro, in April and October 2018, and in July 2019. Visits were made to villages, families, and settlements of those affected by the flood, as well as tours of the environment recorded in a field diary. Semi-structured interviews were conducted with those affected and other key informants⁶ in the shadows of the trees close to their houses. In addition, relevant socioenvironmental information was recorded during environmental tours, from both in situ personal appreciations and the situated recall of the informants.

⁵ This area represents approximately 10% of their territory prior to colonization and political division of the three countries.

⁶ In Anthropology, (key) informants are persons that collaborate with the anthropologists during fieldwork by several means including giving interviews, showing cultural processes, and discussing topics in daily talks. They are usually people who are very knowledgeable about the region and its people (Vivanco 2018).

Fig. 5 Areas with water before (08/01/2018) and after (25/02/2018) the floods of the Sombrero Negro Community. Area of collapse of the containment barrier, affected villages, and evacuee camps are also depicted



Throughout the fieldwork, participant observation was also carried out in daily social and subsistence activities.

Data were recorded in three ways: formal interviews were recorded, immediate notes were taken in a field notebook, and more notes were added at the end of each day's activities as a reflection of the activities of the entire day. Forty days of field journal were written and ten in-depth interviews each longer than one hour were recorded with men who are Qomle'ec family leaders and were directly or indirectly affected by the floods. Based on this corpus, the causes and solutions to floods expressed by the interviewees were interpreted, classified, and analyzed. The causes were classified by us as proximate, remote, and final.

First, **proximate causes** involve physical processes that triggered the floods locally. The most evoked cause of all was the silting up and overflowing of the BLE. This is the process by which the Pilcomayo loses its course according to hydrological bibliography (Testa Tacchino 2015). Then, the affected people from the village of El Churcal also tell that they heard an explosion minutes before their homes flooded. This can be attributed to a containment barrier that broke, and the water came at great speed with an excessive amount of sediment through dirt roads inside the forest and covered the village with up to 2 m of sediment (Menna et al. 2019). A third such cause was observed in situ during the fieldwork of October 2018, when after heavy rain the village of La Rinconada was severely affected. This village is surrounded by a ring-shaped containment barrier that did not allow the water to flow out.

Second, all the interviewees added **remote causes** involving processes that have taken place distant in time or space from the floods, but ended up generating them through a chain of events, related to anthropogenic changes in the environment. These causes include climate change (as a process that increases the frequency and intensity of extreme events), the process of damming villages, river changes as part of the

“Pantalón” project, as well as mining and deforestation in the upstream basin. These would result in sediment remobilization that the river carries away and/or an increase in the speed with which the floods arrive, increasing the probability of flooding and worsening its impacts. Some people recalled that two years before the floods of 1975, the previously clear water started coming more and more cloudy, coinciding with an increase in upstream extractive activities: mining and deforestation.

Third, the **final causes** imply that the floods were a consequence of the desire of (and carried out by) some entity and not an unexpected outcome of an anthropogenic process or a natural event like the previous ones. These include conspiracies and the action of divine or mythical beings. One conspiracy is that neighboring Paraguayans do not want their share of water from the *Pantalón* Project to dedicate the flooded land to agriculture and therefore blocked their canals on purpose. Another conspiracy states that the companies that canalize the river are actually flooding them on purpose so that they voluntarily move, and then these companies will be able to exploit the traditional oil fields that are below their land. On the other hand, the action of mythical entities includes that the floods are a divine punishment from the Christian God for certain sins that occurred in the affected villages (interviewees named different sins such as excessive fishing, raping, religion changing, and reproduction between a Qomle'ec and someone outside their community), and also the action of some *dueños* (Spanish for owners). *Dueños* in the Qomle'ec culture are beings with agency that coexist with the Qomle'ec and are related to different species, landscape features, or specific places (Tola 2016). In this interpretation, the river itself or its owner acts as a trickster, that is, a shape-shifter that deceives and harms people (Santo 2016).

A similar phenomenon exists for solutions, a multiplicity of proposed and/or applied ones. Some of these strategies

come from their indigenous knowledge but were only applied by a few families with elders. For instance, some families have two households, one close to the river for the dry season and another kilometers inside the forest, which recalls their semi-nomadic tradition (Mendoza 2002; Arenas 2003), while others build their houses in areas that are topographically elevated which is a strategy also found in archeological studies (Lamenza 2015; Lamenza et al. 2019). They recognize areas that are less likely to be flooded by the type of sediment (*ue'em* describes a sandy hill) and forest (*βiaq tadaik* describes tall and closed forests) (Scarpa and Arenas 2004). Other implemented solutions include assistance by the State in water, food, and construction material, the said SAT, and river canalizations and containment barriers (Fig. 6).

Some people from the community also propose alternative solutions that have not been so far implemented. For instance, reforesting upstream areas to slow down the river, deforesting in straight lines that canalize most of the water to areas far from towns, and moving the river to an area south of their towns where it is supposedly trying to reach since it lost its course. As already stated in the introduction, the SAT (early alert system) was the most efficient adaptation strategy implemented. The SAT includes several communication channels developed and supported by indigenous and criollo communities of the Pilcomayo basin together with several NGOs of the area (FYI <https://youtu.be/fciPWGdODXM>) (Tye 2021).

Case II: Provincial Route 28

“There comes a time when the water progresses badly and instead of going out to the other side it will come out there, where the cemetery is. The water is going to stir everything up and it is washing the earth and it is going to harm the bones of our grandparents.” Pilagá



Fig. 6 Canalization of the Bañado La Estrella in the Sombrero Negro community with a containment barrier to the left. Photo taken by the first author

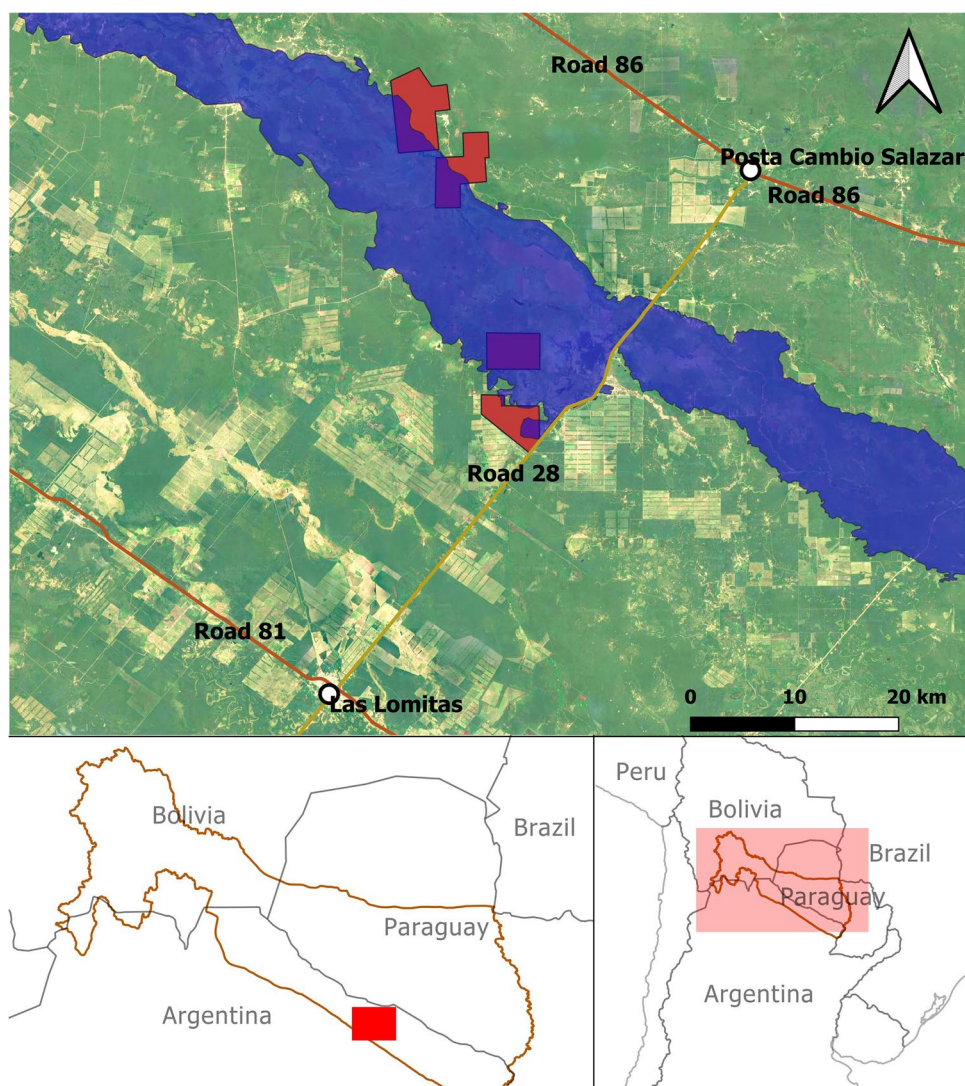
informant to anthropologist Marina Matarrese in 2007 (Matarrese 2013a, p. 146).

The construction and improvement of the Provincial Route 28 of the Province of Formosa (from now on Route 28) since the 1990s lead to a series of socioenvironmental issues whose description and analyses have been published only in Spanish so far. A chapter written by the recently deceased Gran Chaco historian Beck (2009) and the doctoral dissertation of anthropologist Marina Laura Matarrese (2013b) stand out. Route 28 is located approximately in the center of the Province of Formosa. It is an almost straight line with a northeast-southwest direction whose extension goes from the Bermejo River (the interprovincial border with Chaco) to its intersection with National Route 86, close to the international border with Paraguay. The controversial sector of Route 28 corresponds to its northern half, a 70 km stretch between the city of Las Lomitas and the town of Posta Cambio Salazar (Fig. 7). Las Lomitas is the second-most populous town in the Province of Formosa, and it is located in its geographical center on the National Route 81, the Province's main and most extensive road. The rural population around Las Lomitas consists mostly of *criollos* and Pilagá communities.

Until the 1990s, Route 28 was a dirt road and could be used only during the dry season, since it crossed the BLE without any water-management structures. It was in the interest of both the government and the private sector that the connection worked throughout the year. There was also an interest in generating some form of water delivery system to supply the towns on Route 81. In 1992, the provincial government ordered to raise the route and build a 700 m long bridge at BLE, even though the flooded area was more than 2000 m long. In addition, gates were placed under the bridge to be opened and closed at will, rather than allowing the natural passage of water. A water channel was also built parallel to Route 28 and on the west side (upstream) that connects the wetlands with Las Lomitas despite the negative slope to the south (Beck 2009).

As both locals and experts predicted, neither the diversion channel nor the bridge functioned as the government expected. The channel almost immediately collapsed and was obstructed with sediment and thousands of upstream hectares were soon flooded. The economic losses of both *criollos* and Pilagá included cultivated fields, livestock, and the harder-to-assess forest resources, none of which were compensated by the Provincial State. Recurrent floods associated with the overflowing of the Pilcomayo broke the barrier in several places in 1995, 1999, and 2001, making the road impassable all year round. The provincial government then decided to raise the road even more and cover with asphalt the 70 km stretch by 2003. This new project was financed by the Inter-American Development Bank (IDB)

Fig. 7 Map of the Route 86 (yellow) showing the current state of the Bañado La Estrella (blue) and the affected land owned by Pilagá communities (red). Campo del Cielo Viejo is the red square completely under water



through Loan Agreement 1118/OC-AR (<http://servicios.infoleg.gov.ar/infolegInternet/anexos/95000-99999/97438/norma.htm>) under the “emergency program for the recovery of areas affected by floods” that was paradoxically used to worsen a human-made flood.

This new project was full of irregularities since the beginning. The environmental impact assessment was carried out by the provincial Ministry of Economy (that is, from another institution inside the same government that proposed the project) and it minimized all negative impacts. A public hearing was held without prior notice and after the work had already begun. These actions were against the Province’s Ecology and Environment Law number 1060 (Formosa 1993) which states that the assessment must be done by an independent entity and the affected must know the details of the project at least one month before the public hearing. The affected Pilagá communities and criollos denounced these irregularities in both provincial and national judicial systems. While the Province rejected any action due to

jurisdictional reasons, they still got a federal preventive suspension of the work, which nevertheless continued (Zoom 2004). The Province of Formosa responded to these actions through normative and pressure actions. On one hand, laws 1429 and 1439 were passed, declaring, the former, that the reconstructions of Route 28 were of provincial interest and the latter, that all necessary surfaces for the execution of the work were public utility (Formosa 2004a, b). On the other hand, certain social leaders were forced to travel away from their communities and sign documents without knowing the full extent of their contents (Matarrese 2013a).

Finally, the Province of Formosa declared BLE a natural reserve by means of Provincial Law number 1471 (Formosa 2005). Since then, it has promoted the area as an ecological and cultural tourist destination in an effort to show the promotion of sustainable economic activities as denoted by its official slogans *Formosa Hermosa* (a play on words meaning beautiful Formosa) and *El Imperio del Verde* (the Empire of the Green) (Aurand 2010). More recently, these

efforts were crystallized in its declaration as one of the seven Argentine Natural Wonders by popular vote under the project 7MAR developed by the New7Wonders Foundation in 2019 (Piotrkowski 2019). However, only the sector around the Route 28 has been promoted for tourism since the damming makes the area the only one with water all year round. In addition, according to law analyses, this reserve violates the rights of the inhabitants, especially the *criollos*, who could not defend their properties, contrary to the indigenous communities, which were protected by the national constitution (Candia 2009).

The execution of the Route 28 reconstruction brought several negative consequences for the Pilagá and *criollo* communities and their environment. As expected, thousands of hectares of land were permanently flooded and hundreds of thousands of hectares of land changed their flooding hazard status to high or very high (Comisión Trinacional del Pilcomayo 2008c). Regarding the economic and food sovereignty impoverishment of the affected communities, the change in the traditional seasonal flooding towards a constant flooding situation canceled agricultural activities that could only be held in the area seasonally irrigated. For example, due to the general aridity of the region, these seasonally flooded fields used to be quickly covered with high-quality grasses for livestock feeding during the winter (the dry season) which was an invaluable resource at that time of year in a predominantly wooded area (Beck 2009).

Local fish communities and fishing activities were also negatively impacted. The communities reported that the populations of some species of local value declined (mainly *sábalo*, *dorado*, *surubí*), while the numbers of different species of *palometas* (piranhas, *Serrasalmus* spp.) that affect cattle, even causing death, have risen (de la Cruz and Acosta 2004). Migratory and economically relevant fish like *sábalo* (*Prochilodus lineatus*) are mostly affected during the dry season, when they move upstream and find the impassable elevated route with all connections closed. This produces recurrent mass die-offs by suffocation, particularly during dry years (Comisión Trinacional del Pilcomayo 2008d; Diario Río Negro 2020). The comprehensive analysis of this issue for the baseline study of the Pilcomayo basin showed that the local impact on fish populations is huge and that the mitigation measure implemented so far (for instance, fish ladders) has not been effective (Comisión Trinacional del Pilcomayo 2008d). They also describe that the *sábalo* catches of Bolivian fisheries (the only industrial-scaled fishing activity of the basin) were only lightly affected by the Route 28 reconstruction while other environmental variables such as climatic and hydrological variations better explained the variations in production.

It should be noted that the Pilagá community called Campo del Cielo was particularly affected by the reconstruction of Route 28. They collectively own two pieces of land, which they call Campo Nuevo and Campo Viejo. Before the elevation of

the Route, only Campo Viejo was seasonally flooded and used for cattle feeding when dry, and as a cemetery, while in Campo Nuevo there were the community villages and the forest. After reconstruction, much of Campo Nuevo is now temporarily flooded and its forest gone, and most of Campo Viejo is constantly flooded, with many graves having been turned over during the ground movements for the Route (Fig. 7). Not only did this community lose access to resources for their survival, but also it was emotionally affected since they vindicate their claims to the land based on the presence of the remains of their ancestors. Now, these remains are lost and came into contact with the water which, according to some people in the region, has increased the number of spirits present that are prone to attack or sicken the living for their desecration. This caused that now the Pilagá avoid going to Campo Viejo, drink its water, bathe in it, and even consume the fish because it can carry diseases (Matarrese 2013a, b).

Case III: Pilcomayo Water Pollution

So far, the only comprehensive analysis of the water and sediment pollution for the Pilcomayo basin and its consequences for the aquatic life is the corresponding chapter (Comisión Trinacional del Pilcomayo 2008e) in the environmental and socioeconomic baseline study (Comisión Trinacional del Pilcomayo 2008b). The issue of pollution in the Pilcomayo basin has been mostly related to the mining of silver and other metals in the Cerro Rico near the Bolivian city of Potosí (Strosnider et al. 2011). Traditionally, the mining tailings and effluents were directly released into the Tarapaya River, which is a tributary of the upper Pilcomayo River. Another origin of pollution in the Pilcomayo basin is that of urban effluents from big cities like Potosí and Sucre, which have seen a significant increase in their population in the last three decades (Urquidi-Barrau 2015). Other polluting agents include pesticides, but the Trinational Pilcomayo Commission concluded that only mining presents widespread and relevant impacts throughout the basin (Comisión Trinacional del Pilcomayo 2008f).

Mining in Potosí can be traced back to the 10th century and is estimated to have produced several thousand tons of silver in precolonial times encompassing the late Tiwanaku, Inca, and in-between cultures (Abbott 2003). Then, during colonial and republican times Potosí has produced between 30,000 and 50,000 tons of silver, including some decades when production was low or negligible and others when it represented up to 80% of the world's silver extraction (Lindgren and Creveling 1928; Pretes 2002; Strosnider et al. 2011). Water and sediment pollution with heavy metals related to smelting (Pb, Sb, Bi, Ag, Sn) are recognizable since 1000 A.D. in lake sediments near Potosí, with three pollution peaks showing periods of intensive exploitation in 1100–1150, 1540–1590, and 1850–1930 A.D. (Abbott 2003).

In the last 50 years, changes in metal pollution were associated with two technical incorporations in mining activities. First, the Crushing-Grinding-Flotation (CGF) method increased contamination progressively since its inclusion in 1985 due to governmental restructuring of mining operations (Smolders et al. 2003). This process implies the reduction of grain size, addition of reagents, and an increment in pH that either adds heavy metals or increases their bioavailability in effluent mining waters. Second, in 2004 several tailing impoundments were constructed and started operating, leading to a lower lead concentration in water, sediment, and live specimens (Stassen et al. 2012). However, tailing dam failures are known to occur frequently throughout the upper Pilcomayo basin, causing short-term episodes of high pollution levels and social unrest (Villarroel et al. 2006; Preston 2012).

One of the consequences of the contamination in the Pilcomayo River that has generated social unrest is the massive death of fish and other forms of aquatic life. For instance, a comprehensive study between 1997 and 1999 in different sectors of the Pilcomayo found lower biodiversity (97% of the specimens were chironomid larvae) and a thousand times higher mean concentrations of heavy metals (Pb, Cd, Cu, Zn) in water, sediment, and invertebrates in sectors close to mines in comparison to both downstream and other upstream sectors where no mining activities are held (Smolders et al. 2003). They also reported that since the introduction of the CGF method, several episodes of high contamination and biodiversity decline can be recognized in the lower basin sediments. These results are in accordance with those of Hudson-Edwards et al. (2001), who found a similar pattern of pollution and also reported that the upstream accumulations of toxic waste will eventually be remobilized by geomorphologic and hydrological processes, and therefore the most significant impact of pollution in the lower basin is yet to come.

Regarding fish, during the 1990s a notorious decline in *sábalo* population (*Prochilodus lineatus*) greatly affected the middle basin, where fisheries economically exploit this resource near Villamontes (Bolivia), and many rural and indigenous populations depend on it for subsistence (Smolders et al. 2002, 2013). Some studies did find higher concentrations of heavy metals than international standards in *sábalo* close to fisheries (Lavilla and Ghioni 1999; Rosenberg et al. 2005). However, when other variables were considered, *sábalo* population dynamics were better explained by hydrological and climatological conditions, namely the connectedness of downstream courses and El Niño Southern Oscillation (Smolders et al. 2000, 2002; Stassen et al. 2010).

Impacts on human populations have also been assessed through drinking water, irrigation water, and human samples. Miller et al. (2004) found high concentrations of Pb in water, soil, and crops in polluted upstream sectors, and Smolders et al. (2013) found high concentrations of Pb (and other heavy

metals) in hair samples of downstream human populations that rely on fish for subsistence. Regarding other pollution agents, Archer et al. (2005) found high concentrations of arsenic (As) in urine, hair, and irrigation waters irrespective of location. Consequently, while Pb pollution can be related to mining activities, As pollution cannot and is probably explained by natural conditions like the volcanic sediments that make up the aquifer (loess) (Archer et al. 2005).

The only study analyzing consequences of metal exposure in human populations in the lower Pilcomayo basin reported higher lead and cadmium concentration in infants and children in the Weenhayek people, an indigenous group in the Bolivian Gran Chaco who rely heavily on Pilcomayo water and fish, than in other populations that are not exposed to mining effluents. It also reported a higher frequency of small families, suggesting an impact on fertility (Stassen et al. 2012). In this study, the authors conclude that the heavy metal accumulation on this human population and its impacts could not be derived from present conditions in the environment as concentrations in water and fish have decreased since the implementation of better tailing dams in 2004, and therefore the high concentrations in infants were due to metabolic remobilization in their mothers' bones.

Some cultural differences make downstream populations more exposed to mining pollution, even though the hazard itself is higher the closer to the mines. On one hand, upstream populations are highly aware of the threats related to mining that affect the main effluents of the Pilcomayo, they mostly use water for drinking and irrigation from other available sources as they live in mountainous areas, and fish only represents a small portion of their diet since their main economic and subsistence activity is farming (Miller et al. 2004; Archer et al. 2005). On the other hand, downstream populations living near to the Pilcomayo consist mostly of traditionally hunter-gatherer peoples that depend on fish for their subsistence and use whatever water they can get for consumption (Smolders et al. 2003; Stassen et al. 2012). These exposing conditions are worsened by the fact that downstream waters are heavily polluted during the dry season (that coincides with the southern winter) as the mining effluents are less diluted (Smolders et al. 2002) and it is then that these peoples depend mostly on water and fish from the Pilcomayo since other sources of food and water in winter are scarce or nonexistent (Arenas 2003; Arenas and Scarpa 2007; Vallenggia et al. 2010). However, some of these populations and fisheries in the Bolivian lower basin are not keen to denounce pollution from mining. Based in past political decisions, they feel that mining activities would be favored by governments, and they would have more to lose. For instance, if pollutants in fish were to be officially recognized, indigenous would be made to restrain from an abundant and high-quality protein source such as *sábalo* while fisheries would be made to stop production (Guevara Ramírez 2016).

Discussion

DeFries and Nagendra (2017) analyzed ecosystem management as a wicked problem and they stated that “*Tame, type I problems such as controlling point source pollution are amenable to technical solutions. Wicked, non-type I problems that involve inherently unpredictable complex ecological systems, compounded by human behavior and socioeconomic complexities, require incremental and adaptive approaches to continually reframe their definition and develop incremental solutions*” (p. 266). While we generally agree with the article’s content and discussion, we found the first sentence of the selected paragraph not compatible with our description of the Pilcomayo issues. As we summarize in Table 2, the three problems described here fit squarely the concept of problem wickedness, including water pollution related to localized mining activities that initially offers the straightforward technical solution of controlling the source of pollution. We propose the following conclusion as an outcome of the previous analysis: any environmental problem that affects the Pilcomayo basin is wicked, since it encounters diverse societies and many landscape elements with complex and intertwined histories. Any proposal of solutions, adaptations, or mitigation plans for this basin should acknowledge and address this complexity.

Controlling point source pollution has been a good measure for amending water quality in the Pilcomayo basin. However, it is far from being the end to the whole problem. As explained in this case, accidents occur, historically polluted sediments and fixed areas can be remobilized and become new hazards, and the effects of pollution on ecosystems and human beings do not stop when their source stops. The social dimensions of the problem are also extremely important. Polluted waters are not necessarily chemically or biologically dangerous, but rather considered hazardous

according to what it has been in contact with. For instance, “normal flows” usually follow a known and fixed path with homogenous waters, while flooding events often carry other substances that the water encountered or remobilized through its not-so-normal flow, becoming polluted (Krause 2016). In the case of the middle Pilcomayo, despite scientific disputes around it, society clearly associates pollution with the recurrent fish massive death, sudden overflowing events, and, in the case of the Route 28 floods, being in contact with human remains.

The first two problems described deal with floods; both related to the elusive course and seasonal nature of the Pilcomayo and its dynamics once it enters the BLE. However, wetlands are mostly associated with flood-preventing ecosystem services, rather than producing them. In a review of the association between wetlands and floods (Acreman and Holden 2013), the authors concluded that this general assertion about wetlands does not consider their distinct types according to both natural and human management conditions. In general, while upland wetlands are associated with increased flooding risk for the lowlands, floodplain wetlands (as the BLE) mainly act as a water reservoir and flood risk inhibitor by slowing down water velocity and holding most of the excess water. These characteristics can be altered by management and landscape change activities. For instance, in floodplain wetlands damming increase flood risk upstream (as with the case of Route 28), canalization increase flood risk downstream, and nearby deforestation reduces friction and increases overland flow (as with the case of Sombrero Negro) (Acreman and Holden 2013).

Merten et al. (2021) analyzed recurrent flooding events that affect indigenous communities in Sumatra. They state that even though water always rose from time to time, it was in recent years that these “risings” previously considered manageable became “floods” considered hazards to human

Table 2 The accomplishment of the characteristics for wicked and super wicked problems in the three socioenvironmental issues considered in this article

	Characteristics	Socioenvironmental issues		
		Recurrent floods	Pollution	Route 28
Wicked problems	Are symptomatic of deeper problems and often display circularity	Yes	Yes	Yes
	Offer little room for trial-and-error learning	Yes	Yes	Yes
	Do not present clearly defined alternative solutions	Yes	No	Yes
	Are characterized by contradictory certitudes	Yes	No	Yes
	Have redistributive implications for entrenched interests	Yes	Yes	Yes
	Involve multiple actors and are socially and politically complex	Yes	Yes	Yes
Super wicked problems	Time is running out	Yes	Yes	Yes
	There is no central authority	Yes	Yes	No
	The same actors causing the problem seem to solve it	No	Yes	Yes
	The future is discounted radically	Yes	Yes	Yes

health and property. This happened by continuous privatization and subdivision of land for intensive agriculture purposes and industrial alteration of physical water flows which made traditional societies dependent on water redistribution in new uneven power relations. This is also completely related to the floods described in this article. The current situation of inter- and sub-national borders and private property limits the mobility of both traditional societies (Qomle'ec and Pilagá) and *criollos*, which had great adaptive value to the changing nature of their environment before the State control of the Gran Chaco by the modern countries. The Sombrero Negro and Campo del Cielo communities collectively own their lands (even though it is a small fraction of their ancient expansion) and, in other contexts, it has been observed that these forms of land ownership and use not only increase the resilience of the population (indigenous and non-indigenous) to different risks (climate or other), but also favor biodiversity conservation, fairer and more equitable access to resources, and greater food sovereignty and diversity (Fischer et al. 2014; Hoffman et al. 2021).

It is generally stated that wetlands in the Americas are mainly under natural conditions while in the Old World they are mainly anthropized, with the extreme example of the polders from The Netherlands. While this is not true (in the Americas most basins have been hydrologically altered and their surroundings often include dense urban areas, intensive agriculture, industrial activities, or altered ecosystems), it should also not matter, since newly created, restored, or altered wetlands can provide as good ecosystem services as “untouched” ones (Otte et al. 2021). Furthermore, this type of classifications and the contrast of *natural vs. disturbed* (or other similar expressions) wetlands do not usually consider non-western management and cultural practices around these landscapes, where wetlands are known to be shaped by, and at the same time they also shape, cultures around them (Pyke et al. 2018).

The Pilcomayo basin is often thought of as in a “natural state”, while active modification of the watercourses, water quality, and the surrounding environment have been going on for centuries, even since before the Spanish conquest of southern South America. This idealization of wetlands recalls the colonial perspective on rivers (Cunha 2018), whereby Western society assumes them as running water channels with defined banks and floods as extraordinary events. The “ideal” river in the Pilcomayo case is just an instance of its hydrological cycle, when, mostly during the wet season, there is a main channel of running water with lateral *albardones* (naturally or artificially elevated margins) that separate what is water from what is land, and therefore habitable and productive. The dominance of this vision implied the attempt to adjust the Pilcomayo to that ideal through engineering works that prevented the extension of the BLE. This strategy ended up causing devastating

results downstream. These results can be better understood through anthropological perspectives on communities living in close relationships to rivers, which state that social relations are hydrological, and hydrological relations are social as well. This becomes plainer during floods and the application of mitigation and adaptations to them, when one group's flood defense can quickly turn into increased flood risk for another group. In that sense, reducing flood risk can no longer be conceptualized as an engineering or cultural solution to a natural hazard, but rather as a socio-hydrological intervention in a chronological and spatial continuum of socio-hydrological relations, with physical and social consequences on the other elements of the system (Krause 2016).

The Pilcomayo basin has also been thought of as static by considering only its seasonal changes in a circular timeline, and not its constant changes in linear time. Not only the centuries-old search for the “real Pilcomayo” implied the existence of a “fixed course” (Fig. 3), but also the recent engineering works and associated regulations seem to forget that the reason for their existence is precisely the unpredictable behavior of this river. For instance, the law that named the BLE a Natural Reserve and its regulatory decree established that the maximum line of flooding was to be defined in order to delimit the protected area. A preliminary study was carried out in 2006 for this purpose, but the BLE expanded to the south considerably since 2006. Nowadays, the geographical limits of this area are not clear. They may appear clear on paper or official maps, but what is the use of setting a limit that changes from year to year?

In this sense, we follow anthropological insights based on the temporality of landscape perspective (Ingold 1993) that understands the land-water nexus as “*as a set of rhythms of drying and wetting, of human engagement with land-becoming-water and vice versa, and thereby open up possibilities of understanding how people experience, make sense of, and inhabit amphibious places*” (Krause 2017, p. 7). For instance, in the article about the “Collapse of the Pilcomayo River”, the authors use a popular saying of the region to describe the dynamic nature of the Pilcomayo water-land nexus: “*whoever takes a share of water, takes a share of sediments as well*” (Martín-Vide et al. 2014, p. 161). That means that water comes down the river also with land and, in the Pilcomayo basin, this translates into quick siltation of the riverbed (or wetland bed), and continuous creation of new land- and waterscapes.

Indigenous people of the Gran Chaco have also been described as in a “natural state” as they have been differentially described by distinct scientific approaches as staunch ecologists, “good savages” that live in perfect harmony with the natural world, or as nature exploiters who, based on their hunter-gatherer tradition, always

expect “the environment” to provide, which makes them intrinsically poor (Gordillo 1993). Today, we can think of them as environmentally unequal, and their situation as the result of historically unequal economic, political, and environmental relationships (Matarrese 2018). They are also nowadays using these Western discussions to argue for their political and environmental causes, as described both in the case of the Route 28 and also in a recent paper on the relocation of a Uranium dioxide processing plant nearby an indigenous community in the eastern Pilcomayo basin near the indigenous neighborhood Namqom (Varela 2021). The affected indigenous communities in these cases have used a mixture of native conceptions of reciprocity with the environment and modern environmental rhetorics to carry out political action and position themselves as natural protectors of their ancient territories.

Final Words: Building Basin Resilience Rather Than Engineering New Problems

So far, we have shown how not only the discussed socioenvironmental issues in the middle Pilcomayo basin can be conceptualized as wicked, but also that the whole behavior of the basin, its inhabitants (mainly marginalized), and the external pressures (mainly for cheap commodities) are extremely complex and intertwined with one another. These territories, historically borderless, become over the years increasingly fractioned and ready to sell at cheap prices (De Marzo et al. 2021). Also, the Pilcomayo River in its mountainous area continues to receive massive amounts of polluted materials from one of the hotspots for mining activities in South America that end up in its lower basin. And last, but not least, engineering works applied so far in the lower basin have not followed advice from the locals and even ignore the particularities of the basin, which ends up generating socioenvironmental conflicts often only a few months or years after their implementation. This area can be understood as a sacrifice zone, that is, an area inhabited by certain social groups (poor, indigenous, rural) that are destined to hold the most polluting and environmentally disrupting activities necessary to support the better life quality of people living in other areas (Lerner and Brown 2012).

A comparable case study to the lower Pilcomayo basin has been recently published about course-shifting rivers, changing wetlands, and floods in the Grijalba River basin in southern Mexico (Nygren 2021). We make their conclusions also extensive to this article: environmental alterations related to extensive resource making and river engineering end up creating or worsening hazards and increasing the vulnerability of the basin inhabitants. Then, how do we approach these wicked problems when most solutions

applied so far are actually more hydrological interventions with unintended consequences up and down the basin? With respect to this issue, the scientific bibliography on wicked problems proposes clumsy solutions to address them, mostly through bottom-up research and dialogue-based strategies for designing and applying solutions, associated with post-normal science approaches (Ney and Verweij 2015). However, why should we wait for “the science”, post-normal or not, to solve pressing socioenvironmental issues? Aren’t there already similar strategies being implemented that could be enhanced and accelerated?

As described in this case study, several NGOs, the Trinational Pilcomayo Commission, and the very same indigenous and *criollo* communities are working on the application of solutions based on traditional knowledge or more pluralistic approaches to the same issues whose technocratic solutions have already failed. We, therefore, adhere to the words of Dapilah et al. (2020, p. 55): “*Social networks and groups have an important role to play in the resilience of communities, not least in resource dependent communities facing climate variability and change. Therefore, fostering these activities and connections is a useful activity for NGOs and other institutions wanting to use groups and social networks to facilitate adaptation to climate change and variability*”.

McEwen et al. (2017) propose these social networks help build community resilience to the several basin hazards through individual and shared experience and remembering. They state that this should be done vertically between culturally homogenous generations living in the same area, but, in increasingly complex socially mediated ecosystems, it is also crucial that this is done horizontally across different social groups with intertwined actions in the area. We extend this horizontally collaborative perspective to the scientific community and ask what our role should be in helping build basin resilience. While we are still looking for an answer to this, if there is one, we are certain that publishing in a foreign language for a specialized audience does not contribute much to local resilience. That is why, along with this article, we publish a “Summary for stakeholders” in Spanish (called *Resumen para actores locales*) as Online Resource 1, which will be shared directly with the local interested parties via personal communication and through the Pilcomayo Early Warning System.

On one hand, in the three examples presented here, we showed that environmental issues in the Pilcomayo basin are approached by policies of different jurisdictions (national, subnational) that only see part of the problem and act accordingly. Furthermore, the fact that each State manages its natural resources (such as water) as its own and not as common goods imposes additional limitations. We have also shown that various idealizations about the river, such as the

search for or creation of a “true” river course, the “pristine” environment and its “naturally adapted” population, condition the way in which these environmental issues are perceived and tackled. By using the framework of wicked problems, it was shown that these socioenvironmental issues have been approached without a look that includes complexity, but from the application of simplistic technocratic solutions. This lack of complexity in the analysis only increased the wickedness of the problems. By adding complexity and reflection into discussions about these issues with all stakeholders, more informed and democratic decisions could be implemented in the future.

On the other hand, we presented social networking strategies and clumsy solutions that are feasible to address local problems like floods, such as the Early Warning System through radios, social media, and other means that has prevented fatalities, fostered intra-basin collaboration, and facilitated prevention in the face of extraordinary events. However, these strategies have not yet proved useful for environmental problems with causes and effects that are distant in time and/or space, such is the case of mining contamination in the Bolivian Andes that later affects the Gran Chaco.

This analysis was based on local or regional problems, while regional (at basin or ecoregional level) and national/global phenomena were invoked as explanatory. This shows that any problem is in fact multiscale and that it is therefore necessary to extend the analysis to, for example, the La Plata basin, of which the Pilcomayo is a sub-basin. In the La Plata basin, Brazil represents the greatest economic and population power and, as an upper basin country, imposes its hegemony through the construction of infrastructure and the signing of treaties. In a recent analysis, da Silva and Hussein (2019) show how it is not possible to analyze these activities as simple cases of cooperation or conflict, but rather they represent a *continuum* of political interactions implemented with different objectives and by different actors that becomes impossible to disentangle. For example, there are 14 international organizations, four technical committees and a groundwater commission that co-manage the basin, and by extension the Guaraní aquifer, and yet there are only a few joint projects under analysis or implementation, which (added to the lack of transparency and information in this regard) casts doubt on the true roles of these institutions (Villar et al. 2018). A trend from centralized forms of water governance to more federal and participatory forms has also been observed in this region. This can be good (more information available and more democratic decisions), but it can complicate national and supranational decision-making and policy implementation, especially in Brazil where federalism is stronger (Trimble et al. 2021).

We also encourage this approach beyond the La Plata Basin to address pressing environmental issues in relation to water. South America in general often plays a role as a world supplier of raw materials to global economic centers, the latest example being the lithium triangle in the Andes of Bolivia, Chile and Argentina. The exploitation proposed for this area uses enormous amounts of water in an extremely arid area and continues to reproduce a rhetoric of prosperity and modernization analogous to the one used to promote fossil fuel extraction, but this time adding concepts such as *green jobs* or *climate friendly*. This represents an effort to hide local socio-environmental problems for the “greater good” of the energy transition necessary for the mitigation of global climate change, in what has been called *green extractivism* (Voskoboynik and Andreucci 2022). Finally, these complexity perspectives can also be useful in basin analyses around the world, in the context of the Sustainable Development Goals of the 2030 Agenda, in particular goal 6 about ensuring access to water and sustainable sanitation for all. Wicked problems and their study at the basin level allow interweaving ecological phenomena with the governance of the area, its inhabitants and resources at a multiscale level (Herrera 2019).

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Declarations

Conflicts of Interest/Competing Interests The authors declare that they have no known conflicts of interest or competing interests.

Ethics Approval Not applicable.

Consent to Participate One of the authors (GGJ) made three fieldtrips to the Sombrero Negro community, in April and October 2018, and in July 2019. After explaining the purpose of the research and the methodologies to be employed to chiefs/leaders of the villages in the Sombrero Negro community, information sheets about the research were delivered that clearly explained the goals, methods, participation, confidentiality, duration, benefits, and contact with the researchers. Then, informed consent of each informant was obtained orally with a witness present, given that for current and historical socio-cultural and political reasons of these populations, the signing of documents has a negative connotation, while the word has more value (Braunstein 1993).

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