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Declining Rio de la Plata Water Quality: Need to Mitigate the Environmental Impact of Deforestation, Cultivation, Invasive Species, Soil Erosion and Sedimentation

Kenneth Ray Olson

College of Agricultural, Consumer, and Environmental Sciences, University of Illinois, Urbana, USA
Email: krolson@illinois.edu

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Abstract

Río de la Plata is an estuary of the Paraná and Uruguay rivers and an intrusion of the Atlantic Ocean on the east coast of South America between Argentina and Uruguay. The Río de la Plata receives waters draining from one-fifth of the surface of the continent or a 3.2 million km^2 basin that covers much of south-central South America. Buenos Aires, the capital of Argentina, is on the southwestern shore and Montevideo, the capital of Uruguay, is located on the northern shore of the estuary. The primary objective is to mitigate the environmental impact of deforestation, cultivation, invasive species, soil erosion, and sedimentation on declining Rio de la Plata water quality. The current trajectory of increased environmental side effects of agricultural intensification in the Rio de la Plata region has increased food production per unit area of land. The decoupling of crop and livestock production systems, which have replaced previously established crop-pasture rotations and native grasslands. Ecological intensification based on multi-functional and diverse agricultural landscapes including integrated crop livestock systems is the way forward. This intensification pathway must be reconsidered.

Keywords

Rio de la Plata, Argentina, Uruguay, Sedimentation, Cultivation, Soil Erosion, Buenos Aires, Montevideo, Estuary

1. Introduction

The Rio de la Plata is an estuary formed at the confluence of the Paraná and Uruguay rivers on the east coast of South America (Figure 1). The waters of the estuary drain into the Atlantic Ocean. The estuary extends for 290 km, widening out from about 2 km wide near its source to nearly 220 km wide near its mouth. The Rio de la Plata is a natural border between Argentina and Uruguay (Figure 2). The surrounding watershed is the most densely populated areas in both countries. Many significant port cities of Uruguay and Argentina, as well as their respective capital cities of Montevideo and Buenos Aires, are located along this estuary. Nearly 70% of Uruguay's population lives near this region. South America's largest port, Buenos Aires, handles 96% of the country's coastal traffic. The Rio de la Plata supports a wide variety of animal and plant life. East of the Rio de la Plata, the Upper Paraná river zone, supports the growth of forests rich in evergreen trees such as the Paraná Pine. The lower reaches of the Paraná Basin are mainly comprised of vast tracts of grasslands previously cleared of trees for animal grazing and crop cultivation.

Figure 1. Rio de la Plata basin with tributary rivers identified. Photo Credit: Kmusser.

Figure 2. Map of Argentina. Photo Credit: World Atlas.

Central Argentina, Uruguay, and southern Brazil comprise the Rio de la Plata region. Modern agriculture developed around 1900 with the advance of cropping areas over native grasslands. Highly specialized agriculture has succeeded in intensifying yields. However, significant ecosystem losses because of decoupled livestock and crop production have occurred. The pollution of these waters from sewage and industrial wastes and fertilizer and pesticide run-offs from agricultural lands has led to a sharp decline in water quality. Many people are dependent on the waters of the Rio de la Plata and its rivers for their domestic water consumption. The use of mechanized agricultural practices and large-scale deforestation of land, along the course of the Paraná and Uruguay rivers have triggered soil erosion and sedimentation throughout the Rio de la Plata Region. Ships harboring non-native species from Asia and Africa, like golden mussels, in their keel, chains, and hulls threaten to replace the native aquatic flora of the Rio de la Plata wetland ecosystem (**Figure 3**). Invasive species are displacing the native species of the region and their ecological roles and disturbing the food chain.

Figure 3. Rio de la Plata Delta wetlands. Photo Credit: Encyclopedia of Britannica.

Muniz *et al.* [1] found "*The input of metals in the environment derives from many natural and anthropogenic sources. Transitional environments between the continent and the ocean are characterized by strong gradients of all physical and chemical parameters that govern the fate of metals, leading to their sedimentation and modification. Estuaries are recognized as some of the most productive environments on the planet, supporting many different ecosystem goods and services. The problem of human occupation in coastal zones is of special concern to developing countries, where population increase and coastal occupation are combined with industrial activities, representing a challenge for any sustainable development and environmental management. In general, anthropic activities impacting the ecosystem are responsible for the environmental health or contamination level of the system*".

The primary objective is to mitigate the environmental impact of deforestation, cultivation, invasive species, soil erosion, and sedimentation on declining Rio de la Plata water quality.

2. Study Site

De Faccio-Carvalho *et al.* [2] described "*Río de la Plata* (**Figure 1**), *a tapering in-*

trusion of the Atlantic Ocean on the east coast of South America between Uruguay to the north and Argentina (**Figure 4**) *to the south. While some geographers regard it as a gulf or as a marginal sea of the Atlantic, and others consider it to be a river, it is usually held to be the estuary* (**Figure 5**) *of the Paraná and Uruguay rivers* (*as well as of the Paraguay River, which drains into the Paraná*). *The Río de la Plata receives waters draining from the basin of these rivers, which covers much of south-central South America; the total area drained is about 3.2 million km*^{2}, *or about one-fifth of the surface of the continent* (**Figure 3**). *Montevideo, the capital of Uruguay, is located on the northern shore of the estuary, and Buenos Aires, the capital of Argentina, is on the southwestern shore.*"

Figure 4. Elevation map of Argentina. Lowlands are green and uplands are brown.

Figure 5. Map of sediment laden Rio de la Plata. Photo Credit: New World Encyclopedia.

"*The delta of the Paraná and the mouth of the Uruguay meet at the head of the Río de la Plata. The breadth of the estuary increases from the head seaward, a distance of about* 290 *km*: *it is 50 km from the city of Punta Lara on the southern* (*Argentine*) *shore to the port of Colonia del Sacramento on the northern* (*Uruguayan*) *shore, and* 220 *km from shore to shore* (**Figure 5**) *at the Atlantic extremity of the estuary. To those who regard the Río de la Plata as a river, it is the widest in the world, with a total area of about 35,000 km*^{2}."

"*Prior to the arrival of Europeans, the land in and around the Rio de la Plata area was occupied by the indigenous people of South America. The first detailed exploration of this estuary was carried out by Spanish and Portuguese explorers in the 16th Century. Even though many people are dependent on the waters of the Rio de la Plata and its rivers for their domestic water consumption, the pollution of these same waters from industrial wastes and sewage, as well as pesticide and fertilizer run-offs from agricultural lands, has led to a sharp decline in the water quality here. Large-scale deforestation of land, and the use of mechanized agricultural practices* (*cultivation*), *along the course of the Uruguay and Paraná Rivers have triggered soil erosion and sedimentation throughout the Rio de la Plata Region* (**Figure 6**). *Introduction of non-native species from Asia and Africa, like golden mussels, into the waters of the Rio de la Plata by ships harboring these species in their hulls, chains, and keel further threatens to replace the native aquatic flora of the wetland ecosystem. Such invasive species are disturbing the food chain, and thus displacing the native species of the region and their ecological roles*" [2].

Figure 6. Muddy Rio de la Plata. Photo Credit: Wikipedia.

Current Agricultural Intensification Pathway

The Rio de la Plata region, a 70 M·ha watershed in South America, is a grassland ecosystem. It covers the great plain of southern Brazil, Uruguay and east-central Argentina [3]. Extensive cattle grazing of native grasslands has been the main economic activity in the region since Iberian colonization. In addition to providing moderate financial returns, it enabled the development of a unique culture with a transnational character represented by the "gaucho" rancher and has allowed the conservation of the area [4]. In Argentina, native grasslands were replaced by sown pastures, cash crops, and afforestation [3]. Large changes have occurred, over the past 30 years, with the intensification of both livestock production and agriculture in the Pampean region [5] [6].

Agricultural systems (**Figure 6**) during the 1960-1990 were primarily characterized by annual crop rotations under multi-pass tillage coupled with extensive production of ruminant livestock and extensive livestock production on native grasslands [7]. Annual crops slowly expanded until the 1990s, and a large proportion of the land remained covered by native grasslands and perennial pastures [8]. However, multi-pass tillage and low crop production triggered high soil organic matter losses [9]. In the 1990s, agriculturalization resulted in the decoupling of crop and livestock production systems. A rapid expansion of cropping and specialization occurred with the adoption of no-tillage technology and use of glyphosate-resistant soybean [10]. In Uruguay, greater than 85% of the land area of 17.4 M·ha is devoted to agriculture [11]. Land use by different agricultural sectors depends mostly on infrastructure, socioeconomic issues and soil use capacity. Ruminant livestock production on grasslands occupies 82% of the agricultural area (14.3 M·ha). Less than 80% of this grassland area is covered by regenerated or native pastures and less than 20% by cultivated or improved pastures.

Although cash crops such as maize (*Zea mays*), rice (*Oryza sativa*), soybean (*Glycine max*), barley (*Hordeum vulgare*), canola (*Brassica napus* subsp. *napus*), and wheat (*Triticum aestivum*) cover a small part of the area, the cropping area, since 2000, has increased from 0.6 M·ha to a peak of 1.7 M·ha in 2014-2015 and later stabilized at 1.3 M·ha [11]. Cropland is concentrated mostly in regions with soils of the highest use capacity (2.4 M·ha) [12]. Irrigated rice (0.2 M·ha) is cultivated mostly in marginal lowland soils.

Integrated crop-livestock systems (ICLS) are characterized as agroecological systems in which the agricultural activities align with the natural processes of the ecosystem [13]. Composed of outputs and inputs in a cycle that continuously benefits all components of the farm operation, ICLS is considered a sustainable agricultural system [14]. Thus, each output of one land unit becomes an input for another part of the system like the cover crop residue for cattle feed and cattle manure for field fertilizer. The area under soybean cultivation decreased by 30% between 2013/2014 and 2019/2020 while the area of cultivated pastures increased [11]. As ruminant livestock production (mainly beef cattle and sheep) is predominantly conducted on native grasslands, ICLS has been adopted by only a few farmers representing 18% of the total land used for livestock production [11]. The initial increase in cropping area in Uruguay was based on the expansion into new areas and rotation intensification (double cropping and conversion of pastures to no-till cropping in integrated crop-livestock systems; ICLS) [15]. However, the drop in international grain prices, in addition to soil degradation in poorly designed rotation systems [16]-[19] and soil use and management regulations [20], stabilized the cropping area and favored ICLS expansion over the last five years.

3. Natural and Cultural Resources

3.1. Geography

The Río de la Plata begins at the confluence of the Paraná and Uruguay rivers at Punta Gorda and drains eastward into the South Atlantic Ocean [21]. The International Hydrographic Organization defines the eastern boundary of the Río de la Plata as "*a line joining Punta del Este*, *Uruguay and Cabo San Antonio*, *Argentina*" [4]. The upper river contains several islands, including Solís Islands and Oyarvide Island in Argentine waters and Islote el Matón, Martín García Island, Juncal Island and Timoteo Domínguez Island in Uruguayan waters. The islands in the Río de la Plata generally grow over time because of sediment deposition, from the heavy stream load carried down from the river's tributaries.

A submerged shoal, the Barra del Indio, divides the Río de la Plata into an inner freshwater riverine portion and an outer brackish estuarine portion [11]. The shoal is located approximately between Punta Piedras and Montevideo (the northwest end of Samborombón Bay). The inner fluvial zone is up to 80 km wide, about 180 km long and with a depth from 1 to 5 meters. The depth of the outer estuary zone increases from 5 to 25 meters [11]. The river's discharge prevents saltwater from penetrating to the inner portion [12].

3.2. Rio De La Plata Coastal Plain Soils

The 5- to 10-km wide Río de la Plata coastal plain strip extends nearly 200 km along the right bank of the estuary in northeastern Buenos Aires Province, Argentina [22]. The climate is temperate humid (mean annual rainfall and temperature: 1040 mm and 16.2˚C). The coastal plain is covered with materials derived from intense sedimentation and littoral transport. These factors have interacted with marine ingressions and regressions occurred after the Last Glaciation Maximum. A large part of the coastal plain is covered with hydromorphic soils (**Figure 7**) whose response to environmental factors and geochemical properties are not totally understood.

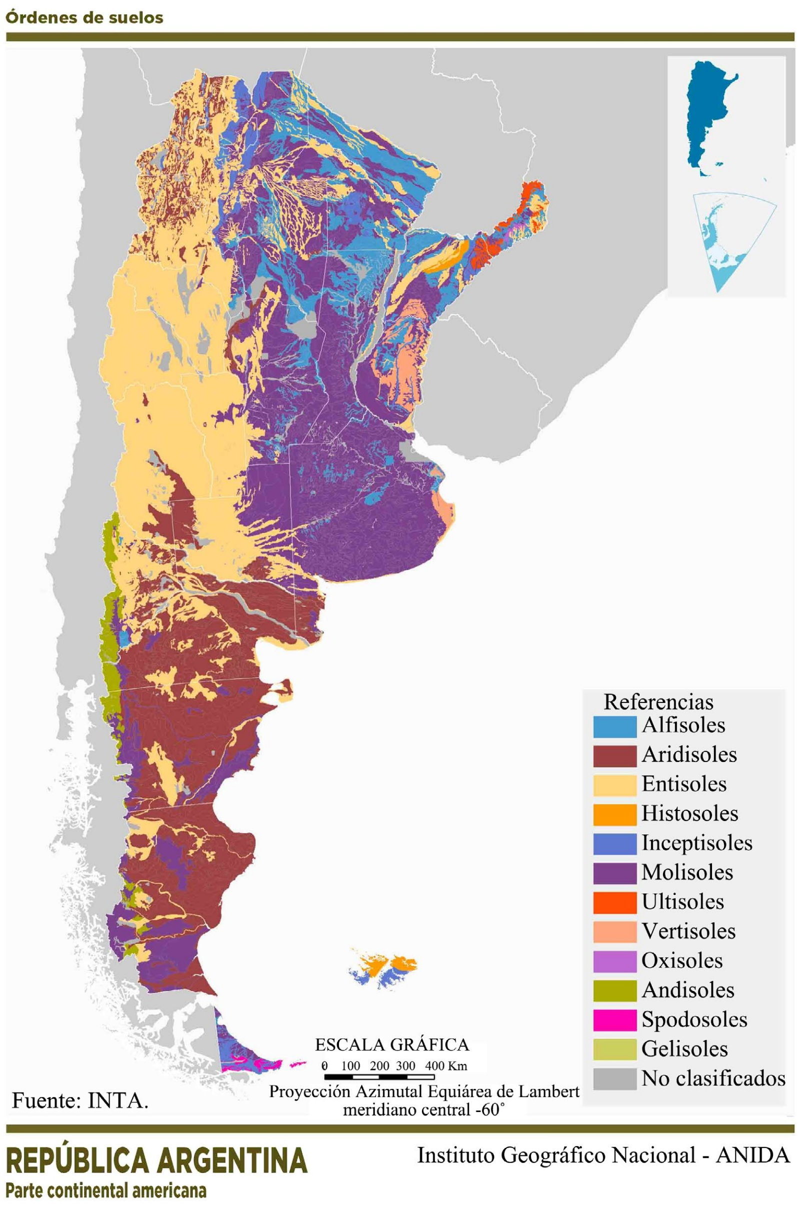

Figure 7. Argentina soils map. Photo Credit: Instituto Geografico Nacional, Republic, Argentina.

The evolution of moisture and Fe^{2+}, Mn^{2+}, Eh, pH was analyzed monthly during two years in two representative soils: a Natraquert developed in estuarine clays of a mudflat and a Fluvaquent formed in fluviatile sands of the alluvial plain of Río de la Plata. Both soils exhibit different stability regarding their hydromorphic dynamics. The Fluvaquent is a very unstable system due to its coarse texture, which allows rapid water movement from diverse sources (rain, phreatic water and floods), showing a heterogenous distribution of the redoximorphic features in the soil [22]. The lowest horizon (2Cg) is nearly permanently saturated and reduced by phreatic water; it exhibits homogenous low-chroma colors and has the lowest Eh mean value. The overlying horizon (2Cxg), where the anoxic conditions fluctuate, has mottles and localized hardening due to the precipitation of Fe and Mn oxides, indicating oxidizing conditions during some part of the year. These changes are reflected rapidly in Eh values, but not in Fe^{2+} and Mn^{2+} contents, which involve physico-chemical equilibria that are not instantaneous. Floods (**Figure 8**) affect mainly the two upper horizons and there is little influence of evapotranspiration. The Natraquert exhibits more stable geochemical conditions due to its clayey texture, which prevents a rapid oxygen access, even during summer when a short deficit period occurs. It has homogenous reduced colors in the matrix. This soil is affected by waterlogging without influence of floods, whilst the phreatic water only affects the deepest horizons. High Eh values and Mn^{2+} segregation are observed. Evapotranspiration has an influence on the upper horizons.

Figure 8. Flooding on a tributary stream of Rio de la Plata. Photo Credit: World Atlas.

3.3. Hydrology

Manuel-Navarrete [10] stated "*The Río de la Plata behaves as an estuary in which freshwater and seawater mix. The freshwater comes principally from the Paraná River (one of the world's longest rivers and Rio de la Plata's main tributary) as* *well as from the Uruguay River and other smaller streams. Currents in the Río de la Plata are dominated by tides reaching to its sources and beyond, into the Uruguay and Paraná rivers. Both rivers are tidally influenced for about* 190 *km* [5]. *The tidal ranges in the Río de la Plata are small, but its great width allows for a tidal prism important enough to dominate the flow regime despite the huge discharge received from the tributary rivers*".

The river is a salt wedge estuary in which saltwater, being denser than freshwater, penetrates the estuary in a layer below the freshwater, which floats on the surface. Salinity fronts, or haloclines, form on the surface and at the bottom, where fresh and brackish waters meet. The salinity fronts are also pycnoclines due to the water density discontinuities. They play an important role in the reproductive processes of fish species [11].

3.4. Drainage Basin

Figure 5 shows a satellite image of the Uruguay and Paraná rivers emptying into the Rio del la Plata. Due to the relatively calm surface and the angle of the Sun relative to the satellite, the current of the river draining out into the Atlantic is visible. The Río de la Plata's drainage basin [15] [16] is a 3,170,000 km^2 [5] to 3,182,064 km^2 hydrographical area that drains to the Río de la Plata. It includes the entire country of Paraguay, southeastern Bolivia, areas of southern and central Brazil, most of Uruguay and northern Argentina. The estuary is the second largest drainage basin in South America (after the Amazon basin) and one of the largest in the world and making up about one-fifth of the continent's surface [6].

3.5. Climate

New World Encyclopedia [23] found "*The climate in the northern basin area is generally hot and humid with rainy summers* (*October to March*) *and mostly dry winters* (*April to September*). *More than 80 percent of the annual rainfall occurs in summer with torrential downpours that are accompanied quite often by hail. The annual amount of precipitation is from* 100 *cm in the lowlands of the west to 200 cm inches in the eastern mountain region. The upper basin temperatures range from a minimum of about* 37˚ *F to a maximum of* 107˚ *F and an annual mean of* 68˚ *F or above. The middle and lower basins are subtropical to temperate and maintain a* 70 *percent humidity level. Rainfall is somewhat less than that of the upper basin, however, it occurs throughout the whole year. The mean rainfall along the entire Río de la Plata is* 110 *cm*."

3.6. Flora and Fauna

3.6.1. Plant Life

New World Encyclopedia [23] noted "*The plant life within the vast Río de la Plata region is greatly diversified. To the east in the upper Paraná basin and higher elevations are forests with valuable evergreens such as the Paraná pine tree which is valued for softwood lumber. The western region is mainly grassland used for cattle* *grazing. In the flooded areas are plants that thrive in wetlands like the beautiful water hyacinth, Amazon water lily, trumpetwood, and guama. All along the rivers and streams are palms such as the muriti and the carandá and various species of quebracho trees valued as a source of tannin. In the Gran Chaco, the western region of Paraguay where the land is used mainly for cattle raising, are clusters of trees and bushes and herbaceous savannas, along with drought-tolerant thorny shrubs. Throughout eastern Paraguay are lapacho trees and the evergreen shrubs called ilex paraguariensis whose leaves are used to make yerba maté, a stimulating tea-like beverage popular in many South American countries*".

3.6.2. Animal Life

The dorado, which resembles a salmon and many species of fish include catfish, pejerrey, pacu, corbina, surubí, manduva, patí, meat-eating piranha, and the most prized species [23]. The Río de la Plata is a habitat for the rare La Plata Dolphin and various species of sea turtles (*Caretta caretta*, *Chelonia mydas*, and *Dermochelys coriacea*). The area is populated with numerous game birds, storks, and herons as well. There is also an abundance of reptiles throughout the region such as rattlesnakes, water boas, two caiman species, yararás, frogs, toads, iguana lizards, and freshwater crabs.

3.7. Cultural History

New World Encyclopedia [23] determined "*The river's first sighting was in 1516 by Juan Díaz de Solís, a European Spanish seaman born in Lebrija, Seville who made the discovery of the river during his search for a passage between the Atlantic and the Pacific Oceans. He served as navigator on expeditions to the Yucatan in* 1506 *and Brazil in* 1508 *with Vicente Yáñez Pinzón. He became a pilot-major in* 1512 *following the death of Amerigo Vespucci. Two years after appointment to this office, Díaz de Solís prepared an expedition to explore the southern part of the new continent. His three ships and crew of* 70 *men sailed from Sanlucar de Barrameda on October* 8, 1515. *With two officers and seven men, he followed the eastern coast as far as the mouth of the Rio de la Plata, which he reached in 1516, sailing up river to the confluence of the Uruguay and Paraná Rivers.*"

"*The small party disembarked in what is today the Uruguayan Department of Colonia and were attacked by the natives (probably Guaraní although for a long time the deed was adjudicated to the Charrúas). Only one of them survived, a* 14-*year-old cabin boy named Francisco del Puerto, allegedly because the natives' culture prevented them from killing elderly people, women, and children. De Solís' brother-in-law, Francisco de Torres, took charge of the remaining ships and crew and returned to Spain.*"

"*Years later, from a ship commanded by Sebastian Cabot, 'a huge native making signals and yelling from the coast' was seen; when some of the crew disembarked, they found Francisco del Puerto, brought up as a Charrúa warrior. He went with the Spanish crew, eventually returning to Uruguay, after which there is no further* *record of his whereabouts.*"

"*The area was visited by Francis Drake's fleet in early* 1578, *in the early stages of his circumnavigation. The first European colony was the city of Buenos Aires, founded by Pedro de Mendoza on February* 2, 1536, *abandoned, and re-established by Juan de Garay on June* 11, 1580."

"*The British invasions of the Río de la Plata were a series of unsuccessful British attempts to seize control of the Spanish colonies located around the La Plata Basin. The invasions took place between* 1806 *and* 1807, *as part of the Napoleonic Wars, when Spain was an ally of France. The invasions took place in two phases. A detachment from the British Army occupied Buenos Aires for* 46 *days in* 1806 *before being expelled. In* 1807, *a second force occupied Montevideo, following the Battle of Montevideo* (1807), *remaining for several months, while a third force made a second attempt to take Buenos Aires. After several days of street fighting against the local militia in which half the British forces in Buenos Aires were killed or wounded, the British were forced to withdraw. The resistance of the local people and their active participation in the defense, with no support from the Spanish Kingdom, were important steps toward the May Revolution in* 1810, *and the Argentine Declaration of Independence in* 1816."

"*An early World War II naval engagement between the German 'pocket battleship' (heavy cruiser) Admiral Graf Spee and British ships, the Battle of the River Plata, started several miles off the coast of the estuary. The German ship sailed up the estuary and was put into port. A few days later, rather than fight, she was scuttled in the estuary*" [23].

3.8. Demographics

3.8.1. People

Once roaming the Paraguay and Alto Paraná rivers and throughout the Pantanal were the nomadic hunter-gatherers, the Guayacurú and Bororo. Guaraní established more permanent villages farther south where they raised crops such as manioc (cassava) and maize (corn), which are still main staples in the region today. The Pampas of Argentina and the Gran Chaco of western Paraguay were home to the nomadic Abipón and Lengua [23].

The Portuguese and Spaniards interbred with the indigenous women, due mainly to the extensive wartime loss of Paraguay's male population, creating a population of mostly mestizos. The Guaraní language is still spoken by 90 percent of the population of Paraguay in conjunction with Spanish. In Brazil, however, many of the indigenous tribes have remained somewhat isolated and intact. Other groups such as the Bakairi, Bororo, and Tereno have adopted Brazilian culture (**Figure 9**) and even some Christian traditions (**Figure 10**). There are also a significant number of descendants of German and Japanese immigrants living in the Alto Paraná region of Brazil. Today most of the population in the Río de la Plata region lives in Montevideo, Uruguay and Buenos Aires, and Argentina, and is primarily of European descent.

Figure 9. Image of Al Generated La Catrina. Photo Credit: Pixbay.

Figure 10. Church in Buenos Aires, Argentina. Photo Credit: https://www.aguiarbuenosaires.com .

3.8.2. Language

New World Encyclopedia [23] found "*Rioplatense Spanish or River Plate Spanish* (*in Spanish, castellano rioplatense*) *is a regional form of the Spanish language which is mainly spoken in the areas in and around the Río de la Plata basin, in Argentina and Uruguay. The adoption of the Spanish language in the area was due to Spanish colonization in the region. Many non-Spanish speakers confuse Rioplatense Spanish with Italian because of the similarity of its cadence. However, native Spanish speakers can understand it as another form of standard Spanish, as different from Peninsular Spanish as Mexican or Caribbean Spanish.*"

"*Until immigration to the region, the language of the Río de la Plata had virtu-*

ally no influence of other languages and varied mainly by the means of localisms. Argentina, much like the United States and Canada, though, is mostly comprised of immigrant populations, the largest being of Italian descent."

"*Due to its diverse immigrant populations, several languages influenced the criollo Spanish of the time:*

1870-1890: *mainly Spanish, Basque, Galician, and Northern Italian speakers and some from France, Germany, and other European countries.*

1910-1945: *again from Spain, Southern Italy, and in smaller numbers from across Europe; Jewish immigration, mainly from Russia and Poland from the* 1910*s until after World War II was also large*".

"*English-speakers, from Britain and Ireland, were not as great in numbers as the Italian, but were influential in the upper classes, industry, business, education, and agriculture. Indigenous languages in the area have largely been influenced, or even completely replaced, by Spanish since most Indian populations were expunged when the Spanish arrived in Argentina. However, some Indian words have entered into the Spanish of the region, with a few having been adopted into English*" [23].

4. Results and Discussion

4.1. Restoration of the Rio De La Plata Landscape to Reduce Soil Erosion and Sedimentation

A major concern has been the lack of diversity in regions with highly specialized agriculture. Questions have been raised on the sustainability of this pathway. There is renewed interest in promoting integrated crop-livestock systems (ICLS), because they are rare examples of reconciliation between environmental quality and agroecosystem intensification and because ICLS are more diverse than specialized systems. A glance at world regions that have experienced similar trends suggests that an urgent course correction is needed.

De Faccio-Carvalho *et al.* [2] discusses "*alternatives to redesign multifunctional landscapes based on ICLS. Recent data provide evidence that recoupling crop and animal production increases the resilience of nutrient cycling functions and economic indicators to external stressors, enabling these systems to face climate-market uncertainty and reconcile food production with the provision of diverse ecosystem services. Finally, these concepts are exemplified in case studies where this perspective has been successfully applied.*" The terrestrial biomes in Brazil have lost about 50 M·ha of their natural cover over the last two decades. The Pampas had the most substantial loss of all the Brazilian biomes (16.8%) [24]. The area of native grasslands decreased by 1.6 M·ha between 2000 and 2018, with 58% being converted to cropland and 19% to silviculture [24]. Several studies have identified the role of cultivated forests (mainly eucalypts; *Eucalyptus* spp.) and temporary crops (mainly soybean) driving the progressive and rapid degradation of natural landscapes [25]-[29]. Estimates of habitat loss show that only 41% of the original area of native vegetation of the Brazilian Pampa biome remained in 2002 and 36%

in 2008 [30]. In regions where soybean expansion was more important, the remaining areas of native grasslands are now less than 10% of their original area [29].

The northernmost area of the Rio de la Plata region is the Brazilian Pampas [3]. Currently, there are about 9 M·ha used for grain cropping in this region, mainly soybean (~5.9 M·ha), rice (~1 M·ha), and maize (~0.8 M·ha) in the summer [31]. In the winter only about 1.3 M·ha are used for grain crops including rye (*Secale cereale*), triticale (*Triticosecale*), barley (*Hordeum vulgare*), canola (*Brassica napus*), oat (*Avena sativa*), and wheat (*Triticum aestivum*) [31]. According to the latest census about 20% of the total agricultural land area is integrated with livestock production [32], making this the region with the largest percentage area under ICLS in Brazil. The remaining area (~66% of the total agricultural land, *i.e.*, 6 M·ha) is covered with winter service crops in no-till systems, mainly grass species such as black oat (*Avena strigosa*) and Italian ryegrass (*Lolium multiflorum*), or fallow in systems managed under multi-pass tillage practices.

Those areas represent an opportunity for the coupling of livestock and crop production to provide additional provisioning services. Service crops are planted to restore deteriorated ecosystem services and include green manures, catch crops, cover crops, and other types of crops. Although agricultural intensification (high-technology machinery, genetic modification, and increases in agrochemical inputs) has resulted in substantial yield increases, the decoupling of livestock and crop production along with landscape homogenization has led to losses of ecosystem services [6]. In Argentina, livestock production has been intensified in displaced marginal areas or feedlots [33].

The use of grains as feed in feedlots has increased in subregions dominated by native grasslands and particularly in areas with less than 60% native grassland cover, whereas stocking rates have increased. The latter have aggravated overgrazing of native grasslands with negative impacts on aboveground net primary production and meat production. Side effects include negative impacts on the diversity of plants (**Figure 11**), birds (**Figure 12**), and mammal (**Figure 13** and **Figure 14**) species, as well as on soil organic carbon content and increased soil erosion. A pathway to solving many of these problems has been proposed in the Rio de la Plata region utilizing ecological intensification of agricultural systems. These problems arise mainly from long fallow periods in addition to the decoupling of crop and livestock production and homogenization of agroecosystems with low crop diversity [34]. Including service crops during fallow periods channels the energy not intercepted by catch crops toward the restoration of deteriorated ecosystem services and increases biodiversity [35] [36].

Ecological intensification aimed at mimicking the functioning and structure of natural systems is proposed. The goal is to maintain or increase soil organic carbon and nitrogen stocks, reduce weed populations, control soil erosion, improve soil physical properties, and reduce nutrient losses, among other functions [37]-[40]. Also, some service crops produce forage biomass during the winter when forage production from native grasslands is usually insufficient. With service crops producing provisioning services such as animal protein in periods of forage scarcity in the native grasslands and there is a huge opportunity for complementarity. In addition to the opportunity for the redesign of ICLS in those agricultural areas, grazing livestock mimic the herbivory of natural systems and restore this pathway of nutrient cycling [2].

Figure 11. Diversity of fauna and flora in Rio de la Plata. Photo Credit: https://www.riodelplaneta.com.

Figure 12. Birds in Rio de la Plata. Photo Credit: https://www.riodelplaneta.com.

Figure 13. Capuchin monkeys in Rio de la Plata. Photo Credit: https://www.riosdelplaneta.com.

Figure 14. Capybara. Photo Credit: https://www.blogspot.com.

4.2. Ecology and Economy

New World Encyclopedia [23] determined "*A treaty between Argentina and Uruguay was established in* 1973 *to manage the binational estuary. On the Uruguayan side, some limited management has developed with financial and technical assistance of Canada's International Development Research Centre* (*IDRC*). *Their goal for this area is to improve environmental conditions while promoting the sustainable use of coastal resources. This experiment, referred to as ECOPLATA, calls for the combined efforts of national and local institutions.*"

"*Some of the economic and ecological challenges rest with the fact that there are approximately* 70 *percent of Uruguay's* 3.3 *million people living within* 100 *km of the coast. Unfortunately, human activities cause marine pollution and can accelerate beach and dune erosion. Mechanized agriculture* (*cultivation*) *and deforestation cause soil erosion, which then leads to sedimentation. Coastal degradation* (**Figure 15**) *is contributed by inappropriate sand mining activities as well. With all these concerns combined with the rapid depletion of fisheries, it is not surprising that the deterioration of the ecosystem is affecting both local populations and the tourism industry.*"

Figure 15. Shoreline of Buenos Aires. Photo Credit: Encyclopedia of Britannica.

"*On the Argentine side, located on the western bank* (**Figure 15**) *of the Río de la Plata estuary across from Uruguay, is the cosmopolitan gateway to South America, Buenos Aires* (**Figure 16**). *Its port, Port Alegre, is the largest in South America, handling 96 percent of the country's container traffic. The cruise ship terminal Puerto Buenos Aires opened in 2001, contributing to the congestion. With its narrow channel from the port to the Atlantic Ocean, there is a need for constant dredging to keep the heavy traffic flowing. Cleaning the waterways remains one of the city's most pressing problems.*"

Figure 16. Center Square of Buenos Aires, Argentina at night. Photo Credit: https://www.peakpx.com.

"*Just east of the port, however, there is an ecological reserve called Reserva Ecológica Constanera Sur. Built over a landfill sprawling with wetlands filled with foxtail pampas grass, there are over* 500 *species of birds and a few iguanas, thus making the area a paradise for birdwatchers and nature lovers alike*" [23].

4.3. Rio De La Plata Water Quality Threats and Future Challenges

4.3.1. Water Pollution

The concentration and pollution level of As and heavy metals in surface sediments from Montevideo coastal zone (Río de la Plata estuary) were measured in 18 sites in March 2015, from the western portion at the mouth of Santa Lucía River to the east at the mouth of Carrasco stream [41]. The study area receives a continuous discharge of untreated industrial and domestic effluents through two streams and one submarine sewage pipe. Sediments were analyzed for sediment fractions, As, and organic matter content and heavy metal concentrations (As, Cd, Sc, Al, Cr, Cu, Ni, Pb, Zn, Fe and Mn). Results showed that in the study area the contribution of sand was low, with exception of the innermost region of Montevideo Bay at the mouth of Pantanoso and Miguelete streams. Total organic matter contents were in general high (between 3.82% and 15.72%), and values are typical for low energy, estuarine, and anthropized ecosystems. Concentrations in adescending order was Zn > Cr > Cu > Pb > Ni > As > Sc > Cd. The highest concentrations were found in the innermost stations of the bay and lower in the western portion of the study area. Pearson correlation and principal component analysis suggest the similar distinctiveness of Cr, Cu, Pb and Zn. The different indices applied suggest that the study area can be considered from low to mildly polluted by metals in general. Compared with previous results, all the studied metals showed marked reductions highlighting the importance of management measures. In this sense, efforts made by industries and the government some years ago had positive results in terms of reduction/reclamation of particular metallic elements.

Muniz *et al.* [1] determined "*the current status of sediment quality in terms of heavy metals and As along the most urbanized area of Uruguay, which is affected by several anthropogenic impacts. High heavy metal concentrations were recorded in areas where there was evidence of untreated industrial and domestic sewage discharges as in the inner portion of Montevideo Bay. Conversely, the western adjacent coastal zone can be considered as the less polluted area based on metal and As concentrations*".

4.3.2. Sedimentation

The Río de la Plata is a micro-tidal estuary located in Southeast South America. With an annual mean flow of 26,500 m^3/s, it receives 160 million tons/yr of suspended sediments [42]. The high content of cohesive fine sediments in the estuary generates high turbidity levels in its intermediate and inner zones, which can be seen in color satellite images. In this work, an image-based algorithm was successfully implemented to remotely detect the turbidity front of the Río de la Plata, based on the top of the atmosphere (TOA) reflectance in the red band of MODIS-Aqua satellite. The algorithm finds the reflectance level that "best" separates two water classes: clear ocean and turbid fluvial waters. In the four-year period from 2014-2017, the front dynamic was studied by combining remotely sensed information and river discharge data, salinity, winds, and sea level time series. River discharge was identified as the main external forcing, revealing a solid general pattern of behavior. When discharge was high (low) the front tended to be in the outer (intermediate) zone of the estuary. Sea level seemed to be a secondary forcing, presenting higher correlations along the center of the estuary than near both coasts. Local winds needed to have a relatively persistent (2-day) component in each direction to affect the location of the front. Additionally, results of an already implemented numerical model of the Río de la Plata were evaluated in terms of spatio-temporal performance, considering turbidity and salinity front locations. New strengths and limitations of the model were identified, and an improvement in the parameterization of sediments' settling velocity was tested. Model results revealed the relative importance of bottom shear stress on the general location of the front and salinity on the flocculation process of cohesive sediments. Maciel *et* *al.* [42] work provided new insights for the understanding of the Río de la Plata estuarine dynamics through the combination of three complementary tools – in situ data, remote sensing, and numerical modeling, – which may be extended to other systems around the world.

Maciel *et al.* [42] found "*The main tributaries of the Río de la Plata are the Paraná and Uruguay rivers, from which it receives a mean annual inflow of 26,500* m^3*/s of water and 160 million tons/yr of suspended sediments* [43]. *The suspended sediment load is mainly the contribution of the Paraná River and it is composed of fine sand, silt, and clay. The sand fraction mostly settles close to the Paraná mouth, while the cohesive sediments are advected into the inner zone of the estuary*".

Lohaiza *et al.* [44] found "*Argentina is a Latin American country which has encountered soil degradation problems. The most productive regions have implemented conservative land practices (no-till). However, the agricultural frontier has been displaced to marginal lands with arid and semiarid climates, with the consequent disappearance in many areas of native forest and land degradation. In this work, the fallout of gamma-emitting radionuclides,* ^{137}Cs *and* ^{7}Be*, was jointly used to assess changes in soil erosion in a recently converted semiarid ecosystem into agricultural land.* ^{137}Cs *was utilized to estimate erosion over the past* 60 *years, whereas* ^{7}Be *was employed to estimate erosion after the conversion of the area to cultivated land and soil tillage. For* ^{137}Cs *the Proportional Model (PM), the Mass Balance Model II (MBMII) and the MODERN model were used, for* ^{7}Be *the Profile Distribution Model (PDM) and the MODERN model were used.* ^{137}Cs *indicates mean erosional rates of* 8.2, 10.5 *and* 6.5 $Mg \cdot ha^{-1} \cdot a^{-1}$, *using MBMII, PM and MODERN, respectively, and that a soil layer between* 0.5 *and* 0.8 *mm was annually lost by erosion. By applying a* ^{7}Be *tracer, we measured erosion rates of* 2.4 *and* 3.3 $Mg \cdot ha^{-1}$ (*with PDM and Modern, respectively*), *indicating the loss of the upper 0.2 mm of soil. This erosion can be attributed to a few heavy rainfalls that occurred within the past* 90 *days. The results suggest that current land management practices have led to an increase in soil erosion. This could be attributed to the fact that the soil remains bare after crop harvest, which may compromise its conservation and future productivity*".

4.3.3. Invasive Species

New World Encyclopedia [23] suggested "*A major threat to the Río de la Plata's estuary is the arrival of small mollusks from Asia and Africa carried in as larvae in the bilge water that ships take on in various ports to improve their stability. When the ship comes into shallow waters, like the Río de la Plata, the water is discharged, dumping the species into a new ecosystem. The adult species ride in on the ship's hull, chains, or keel. The most harmful is the golden mussel, a freshwater bivalve native to the rivers and streams of China and Southeast Asia. With no natural predators, this new intruding species can displace native species, prevent normal development of marsh plants, and change the local ecological conditions. Solutions to these problems lie in a collaborative network for the research,* *development, and implementation of an integrated plan to preserve and develop the coastal resources and ecosystems*".

Muniz *et al.* [1] determined "*Contaminants enter estuarine waters via several key routes, particularly direct pipeline discharges from coastal cities, riverine inputs, atmospheric deposition, and nonpoint source runoff from land. Urban development and the industrialization of the coastal zones have promoted a continuous increase in heavy metal contamination. This is especially true in estuarine areas, where the mixing of riverine water with seawater affects the estuarine physicochemical characteristics resulting in the formation of a turbidity front* (*flocculation area*) *that facilitates the deposition of particulate matter and their associated contaminants* [45]".

"*Bottom sediments instead of column water particularly act as a sink or a source of pollutants, depending on the prevalent physical and chemical conditions and their sedimentological characteristics. Also, sediment, which is more stable than the overlying water, is often used to monitor the environmental quality of estuarine and marine areas. Therefore, understanding the quality of marine sediment is very helpful in setting suitable management and regulation plans. The study of sediment-associated metals is relevant since heavy metals affect the ecosystem as a whole and human health through the processes of bioaccumulation and biomagnification* [46]. *Heavy metals cannot be biologically or chemically degraded; in particular, they can accumulate in aquatic organisms and are subsequently transferred to humans through the food chain, posing a threat to human health* [47]."

"*The Río de la Plata provides both very important socio-economic and environmental services for a large human population. It is a large estuary and its environmental quality is highly variable due to human pressure and natural variability at seasonal, interannual, decadal and centennial scales* [48]. *The Río de la Plata estuary is situated between Argentina and Uruguay at* 35˚ *S on the Southwest Atlantic Ocean. Its catchment area, that covers ca.* 36,000 km^2, *is the second largest basin of South America following the Amazon's basin* [49]. *The mean annual river flow that governs monthly to interannual variations is* 25,000 $m^3 \cdot s^{-1}$. *The main tributaries of the La Plata basin are Paraná River, Paraguay River, and Uruguay River. The average annual suspended sediment load from Paraná and Uruguay rivers,* 79.8 $M \cdot t \cdot yr^{-1}$, *contains 75% coarse to medium silt,* 15% *fine to very fine silt, and* 10% *clay* [50]. *Strong vertical salinity stratification and low* (<1 *m*) *tidal amplitude characterize this estuarine area, which due to its large extension and shallow water depth is very influenced by atmospheric forcing* [51]."

"*The Río de la Plata estuary is very productive and represents an area particularly relevant for the global carbon budget, acting as a* CO_2 *sink, especially during spring and summer* [52]. *In the Río de la Plata estuary a well-developed turbidity front may constrain primary production; however, at the same time in the immediate vicinity of the front photosynthesis rates may be high* [53]. *The turbidity front changes its position from west to east depending on predominant winds, tides and river discharge* [49]. *Also, unpredictable strong winds can produce in few hours partially mixed conditions, being responsible for the high variability of the* *system*" [1].

Water and sediment contamination are the main threats affecting the ecological integrity of Río de La Plata, impacting benthonic, nektonic and planktonic communities with mortality, population reductions, and disease that can ultimately affect human health through bioaccumulation [2]. Urban and coastal areas, particularly in Argentina, are heavily impacted due to land use and lack of appropriate treatment of domestic and industrial sewage effluents, affecting in turn a wide spectrum of biological communities and human health [54]. Acceptable bacteria levels only occurring 3000 m from the coast and inshore fecal bacteria levels in the water column exceed limits for safe recreational use. Harmful algal blooms based on Ciliates, Cyanophytes, and Dinoflagellates are commonly triggered by high nutrient loads, mainly in the Argentine sector.

Waters contaminated (**Figure 17**) by hydrocarbons, PCBs, PAHs, and heavy metals are found along the south coastal area of the Río de la Plata between La Plata and Buenos Aires at levels higher than those recommended for aquatic biota [55]. Only the Montevideo area is impacted by heavy metal (lead and chromium) inputs from sewage and tributaries and along the Uruguayan coast [56].

Figure 17. Waste discharge into the Rio de la Plata from urban areas. Photo Credit: https://www.elinsignia.com.

Where flocculation promotes the sinking of clay particles with adsorbed metal ions the offshore sediments, along the estuary, are only slightly contaminated, except at the turbidity front. Waves, dredging, currents, and bottom fishing tows can re-suspend and even alter sediment transport and result in bioaccumulation of pollutants by filter feeding and detritivorous species. Habitat structure and the abundance and diversity of benthic communities are also impacted by these activities. The fishing areas encompass many of the main spawning and rearing habitats. Without proper management the fisheries can be severely impacted as has been shown for *Micropogonias furnieri* [57]. On the Uruguay coast *Mustelus schmitti* and *Cynocion guatucupa* have been acknowledged as overexploited [58].

International commercial navigation can result in introductions of invasive species via adhering to the hull or transport in ballast tanks. The diversity of exotic species in de la Plata River estuary is still low although reported species show high population abundances. The bivalves *C. langilleri*, *Corbicula fluminea*, and *Limnoperna fortunei* are currently widely distributed in addition to *Cyprinus carpio* and *Oreochromis niloticus*, and have a high economic impact on water pumps and on shore structures [59]. Other exotic species such as the gastropod *Rapana venosa* has also been found [60]. Brazeiro *et al.* [61] stated that the Turbidity Front, the Ortiz Bank, and the Santa Lucía and Samborombón wetlands can be classified as the most highly critical areas because they have both support important environmental risks and functional relevance for the fluvio-marine ecosystem.

To maintain their ecosystem services coordinated management policies are required to restore the Río de la Plata's ecological integrity, particularly in wetland and coastal (**Figure 18**) areas. This will require managers to enforce appropriate water treatment for both industrial and urban effluents, develop appropriate governance institutions and processes to apply and enforce environmental laws, including sustainable fishing regulations and management policies and improve socioeconomic conditions for people inhabiting shore areas (**Figure 19** and **Figure 20**). As the Río de la Plata system represents the end point for the second largest river basin in South America. Conservation strategies should also encompass transboundary agreements and policies oriented to balance ecological requirements and socioeconomic benefits at a basin scale.

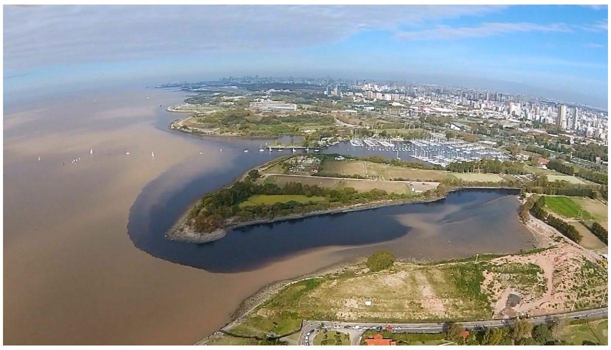

Figure 18. Coastal shoreline with sediment rich waters. Photo Credit: New World Encyclopedia.

Figure 19. Organized urban development along the coastal shoreline. Photo Credit: https://www.riosdelplaneta.com.

Figure 20. Organized tourist development. Photo Credit: https://www.riosdelplaneta.com.

5. Summary

The primary objective was to mitigate the environmental impact of invasive species, soil erosion, deforestation, cultivation, and sedimentation on declining Rio de la Plata water quality. Some of the most productive environments on the planet are estuaries which support many different ecosystem goods and services. The problem of human occupation in coastal zones is of special concern to developing countries, where population growth and coastal occupation are combined with industrial activities, representing a challenge for any sustainable development and environmental management initiative. In general, anthropic activities impacting the ecosystem are responsible for the environmental health or contamination level of the system.

Many people are dependent on the waters of the Rio de la Plata and its rivers for their domestic water consumption. However, pollution of these waters from industrial wastes and sewage, as well as pesticide and fertilizer run-offs from agricultural lands, has led to a sharp decline in the water quality. The use of mechanized agricultural practices (cultivation) and large-scale deforestation of land along the course of the Uruguay and Paraná Rivers has triggered soil erosion and sedimentation throughout the Rio de la Plata Region. Introduction of non-native species from Asia and Africa, like golden mussels, into the waters of the Rio de la Plata by ships harboring these species in their hulls, chains, and keel. These non-native species further threaten to replace the native aquatic flora of the wetland ecosystem. Such invasive species, displacing the native species of the region and their ecological role, are disturbing the food chain.

The current trajectory of agricultural intensification in the Rio de la Plata region has increased environmental side effects and increased food production per unit area of land. The latter are mainly a consequence of decoupling of crop and livestock production systems, which have replaced native grasslands and previously established crop-pasture rotations and the specialization toward low diversity cropping systems. This intensification pathway must be reconsidered. Therefore, ecological intensification based on diverse and multi-functional agricultural landscapes is the way forward. This includes integrated crop-livestock systems. Based on recent research findings, De Faccio-Carvalho *et al.* [2], argued that "*ICLS can be seen and used as an innovative concept for producing diverse ecosystem services for billions of people. Regional data provide evidence that recoupling specialized crop and grazing animal production systems improves the long-term resilience of the whole system in terms of nutrient cycling functions, economic performance, and adaptation to climatic variation. Ecological intensification aimed at mimicking the functioning and structure of natural systems is proposed to maintain or increase soil organic carbon and nitrogen stocks, improve soil physical properties, reduce weed populations, control soil erosion, and reduce nutrient losses, among other functions. This new vision of long-term resilient systems to face climate-market uncertainty is pivotal to facing climate change, so crucial to the future of the Rio de la Plata region*".

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Conflicts of Interest

The author declares that there is no conflict of interest.

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