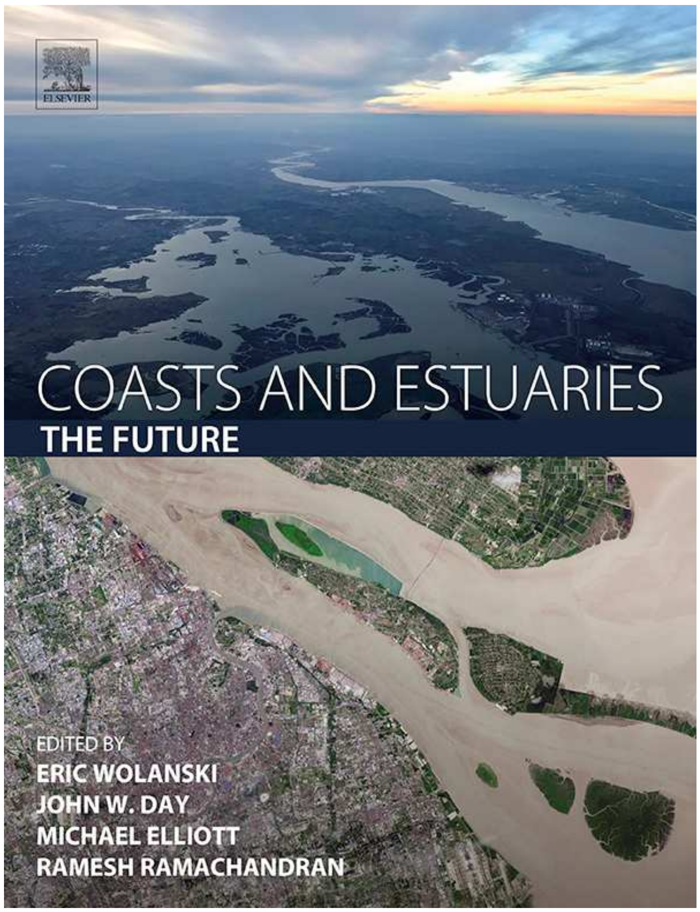

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Chapter 3

Río de la Plata: A Neotropical Estuarine System

Javier García-Alonso[*], **Diego Lercari**[†], **Omar Defeo**[†]
[*]*Departament of Ecology, CURE, University of the Republic, Maldonado, Uruguay,* [†]*UNDECIMAR, Faculty of Sciences, University of the Republic, Montevideo, Uruguay, Montevideo, Uruguay*

1 GENERAL INTRODUCTION

1.1 Geographical and Morphological Features

South America, the Neotropical continent, includes very large basins draining water into the Atlantic Ocean, notably the equatorial Amazonia and the tropical and subtropical Río de la Plata (RdlP) basin, with a very wide estuary that ends at the Atlantic Ocean. The RdlP estuary (35°S) is a highly productive area with subtropical climate, sustaining valuable fisheries for Uruguay and Argentina (Acha et al., 2008). The inner part is the source of drinking water for the city of Buenos Aires but it also receives the discharge of industrial, agriculture, and urbanized areas. The basin covers a huge area of 3,100,000 km^2 (17% of South America), involving entirely Paraguay, most of Uruguay (88%), and part of Brazil and Argentina (Fig. 1). Approximately 150 million people inhabit the basin, with almost 60 cities inhabited by more than 100,000 residents, including the capitals Buenos Aires, Brasilia, Asunción, and Montevideo (Achkar et al., 2016). The RdlP basin comprises a huge area with the Parana and Uruguay rivers as the main tributaries, and it includes 10 different ecological areas or biomes with multiple land uses, mainly agriculture (grain and fruits) and livestock. Other activities include intensive forestry, petroleum extraction, refineries, pulp mills, natural gas extraction and transport, and fruit production (Box 1). More than 20 million inhabitants have access to drinking water from the internal part of the RdlP estuary (AQUASTAT-FAO, 2016).

The main natural forces in the RdlP can be divided into topographic, oceanographic (astronomical and meteorological tides), hydrological (catchment discharge), and meteorological conditions (winds) in the estuary itself. At the western coast of the South Atlantic Ocean, where the RdlP estuary ends, converges the warm and salty Brazil current and the cold and less dense Malvinas current with the presence of a strong and dynamic frontal region (Piedra-Cueva and Fossati, 2007; Simionato et al., 2009). The El Niño Southern Oscillation phenomenon (ENSO) also affects the mixohaline conditions of the RdlP (Nagy, 2006).

In the estuarine region, maximum concentrations of inorganic suspended material occur at the Argentinean (Southwest) coast of RdlP, associated with the higher discharge of sediments from the Paraná River (PNUD-GEF, 2007). Higher turbidity occurs in winter, associated with the main discharge of tributaries and higher wind speeds causing resuspension. The amount of suspended particulate matter declines to a high degree with distance downstream, where the depth of the estuary greatly increases, acting as a barrier for the saline front. Flocculation and precipitation of suspended matter generated by the increase of salinity regulates the turbidity (PNUD-GEF, 2007). This is the natural limit of the inner (continental) part of the RdlP and the start of the brackish (mixture) water (Fig. 2). The external political limit is set by an imaginary line from Punta del Este (Uruguay) to Punta Rasa (Argentina, Brazeiro et al., 2003) although the influence of the freshwater discharge of the RdlP reaches hundreds of kilometers over the continental platform (Simionato et al., 2009).

The RdlP seabed is mainly composed of soft sediments. Sandy silt dominates at the head, silt in the intermediate estuary, and sand at the mouth, following a gradual arrangement of textures (Moreira et al., 2016). Sediment sorting and organic matter content increase toward the estuary mouth, relating to the morphology and hydrodynamics of the estuary. The topology and differential distribution of sediment types at both margins reflect estuarine coastal landscapes, with mudflats on the west coast (Argentina) and sandy beaches at the east (Uruguay) (Psuty and Mizobe, 2006).

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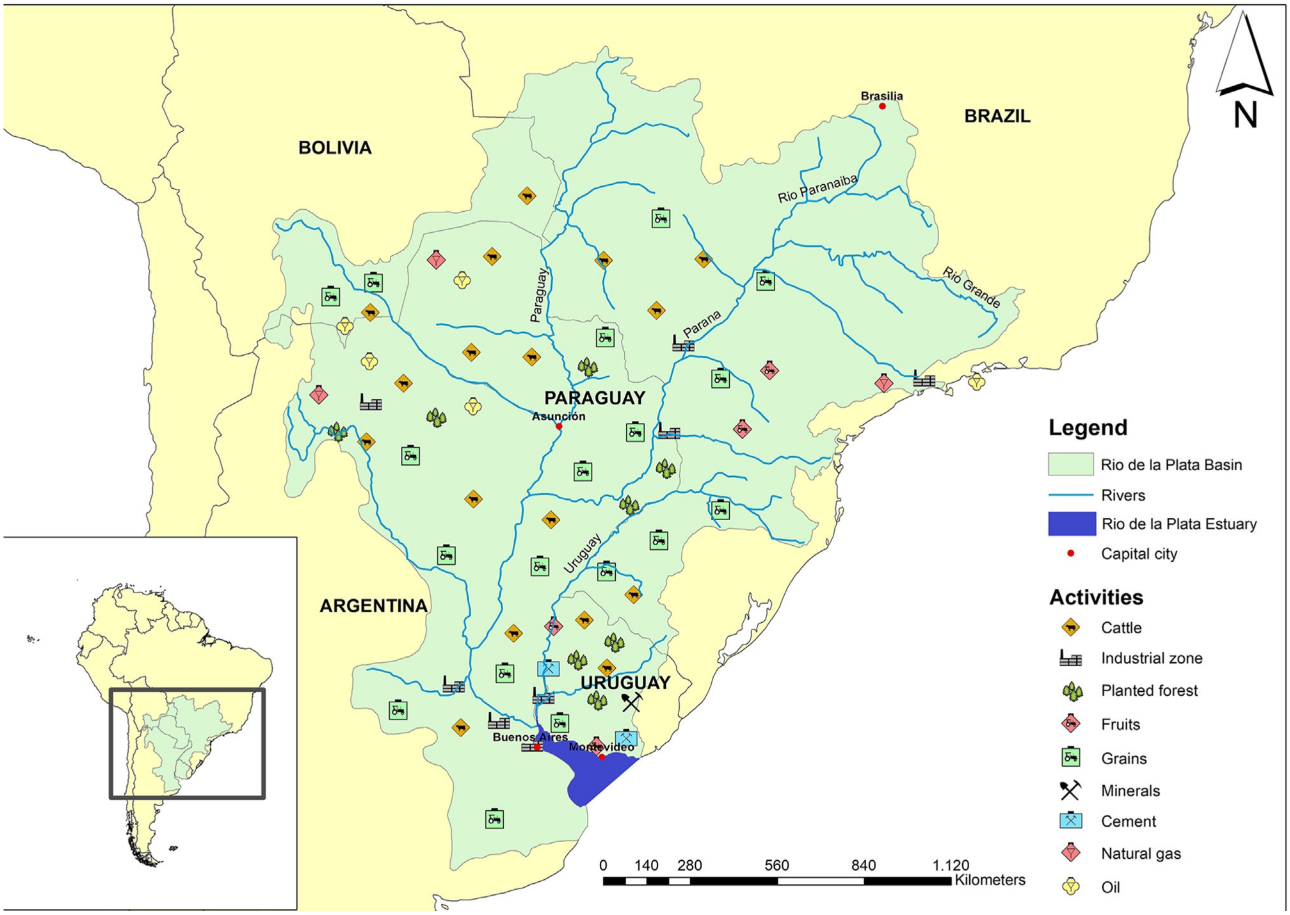

FIG. 1 Map of Río de la Plata basin showing the main tributaries, capitals, and main land uses in the catchment area. *(Modified from Achkar M, Díaz I, Domínguez A, Pesce F: Uruguay, Naturaleza, Sociedad, Economía, Ediciones de la Banda Oriental, 2016, Una visión desde la geografía, 369pp., ISBN 978-9974-1-0980-3.)*

BOX 1

The Río de la Plata (RdlP) estuary receives the water from a basin of 3,100,000 km^2 (17% of South America), the second in South America after Amazonia. There are two main tributaries, the Paraná and the Uruguay rivers. Five countries administer the basin area: Argentina, Bolivia, Brazil, Paraguay and Uruguay. Several important cities, including capitals, are in the basin such as Sao Paulo, Asuncion, Rosario, Buenos Aires, La Plata, and Montevideo. Agriculture, forestry, and animal farms are the most relevant human drivers at the basin level, with several dams for electricity supply. Several human activities occur in the region, notably marine traffic, fisheries, and coastal urbanization (including tourism expansion and pollution). The RdlP offers direct ecosystem services such as the main drinking-water source for the city of Buenos Aires, and sandy beaches uses for recreation, leisure and tourism (Sathicq et al., 2014). A binational commission from Argentina and Uruguay administers most aspects related to this transitional water system. However, coastal degradation, diffuse, and point-source contamination from agriculture and urban areas (nutrient enrichment, inorganic, and organic chemical pollutants) and overexploited fisheries are threatening the system (CTMFM, 2017). Future scenarios of concern given by global change predictions may increase the risks of environmental and human health deterioration. Continued assessment of the effects of global (including climate) change should be given a high priority in conservation and management planning.

1.2 Biodiversity

Environmental conditions, including nutrient supply from the basin and upwelling events at the external part of the estuary (Simionato et al., 2009), lead to a high primary production and biodiversity at the RdlP. This Neotropical estuary is a sensitive area, containing at the coastline an UNESCO Man and the Biosphere Reserve and a Ramsar site. In addition, the economic and ecological significance of the saline front has resulted in many species of commercial interest.

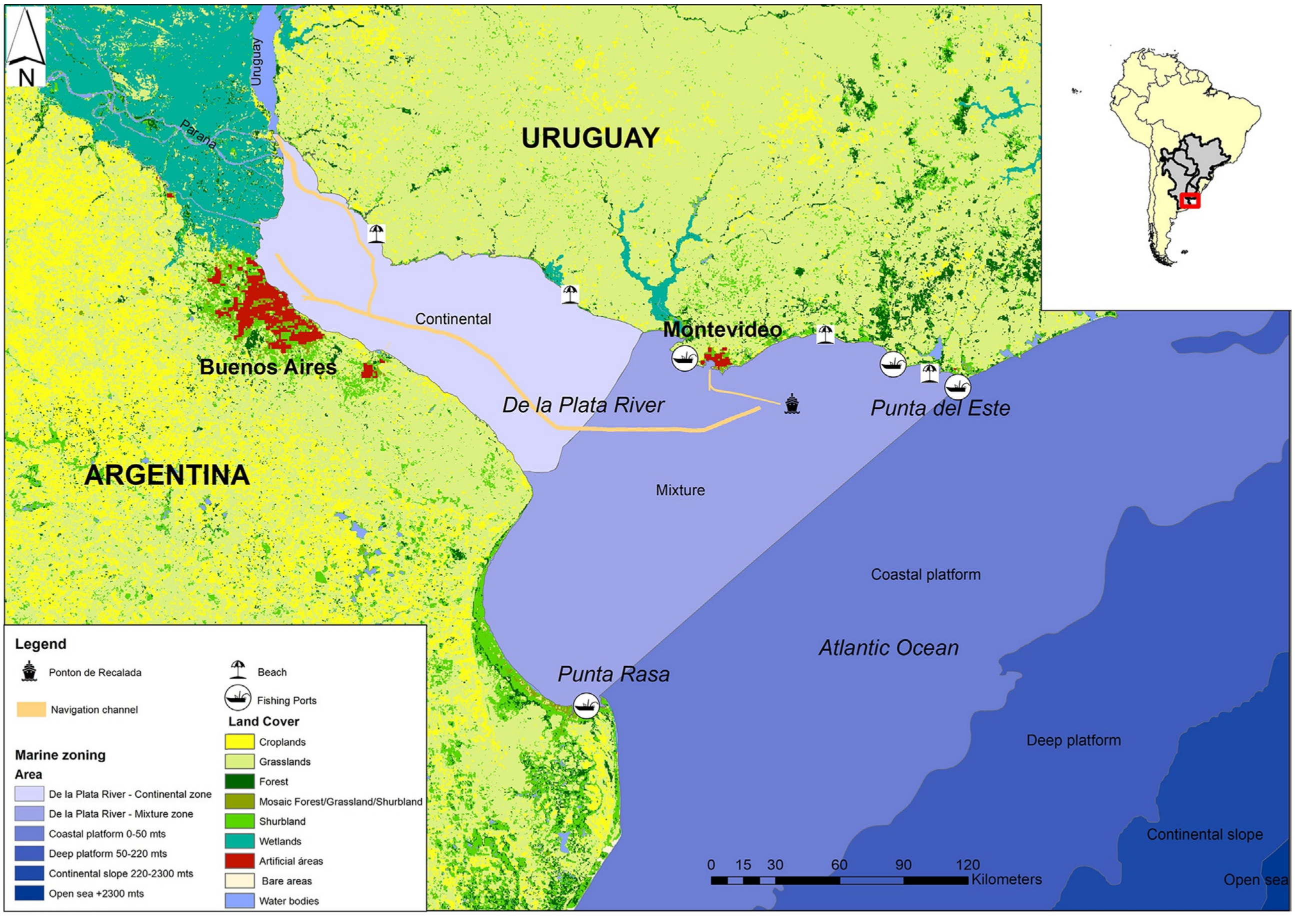

FIG. 2 Map of the Río de la Plata estuary and its main drivers and land uses in surrounding areas. Yellow lines at the estuary indicate navigation channels. Estuary limits are based on Brazeiro et al. (2003).

The biota encompasses environmental seasonal variations at different temporal scales. At the RdlP, phytoplankton blooms, including toxic Cyanobacteria are clearly associated with natural events (Sathicq et al., 2015). The benthic soft bottom communities of the RdlP estuary are composed of more than 350 taxa, mainly polychaetes, molluscs, and crustaceans. Nematodes and bivalves dominate the community in reaching more than 60% of the total abundance, while the community biomass is highly dominated by the bivalves, particularly *Mactra isabelliana* (reported as the main food resource for the fish the white-mouth croaker *Micropogonias furnieri*) (Cortelezzi et al., 2007). The density and biomass of two introduced and alien mollusc species is especially notable. The bivalve *Corbicula fluminea* is very common in soft sediments all along the estuary, while the gastropod *Rapana venosa* is more common on hard bottoms at the external area of the estuary. The macrobenthic abundance and biomass is higher in the intermediate estuarine region, followed by the outer zone (Cortelezzi et al., 2007). Trophic studies (Lercari and Bergamino, 2011) on the role of these two species in the food web of the RdlP suggest several negative effects concerning ecological and conservation issues, but also socioeconomic concerns.

Approximately 90 marine and freshwater species belonging to 81 genera and 54 families comprise the fish community along the RdlP estuary, which is structured in three assemblages: riverine, estuarine, and shelf although an additional group may be recognized outside the estuary on the continental slope. These assemblages differ spatially in their species composition: the inner zone is slightly dominated by the catfish *Paraloricaria vetula*, the estuarine area by the sciaenid *M. furnieri* and the shelf by the carangid *Trachurus lathami*. Bottom salinity and temperature are the main environmental drivers of the assemblage structure. Changes in assemblage structure between areas are gradual, with no sharp boundaries (Jaureguizar et al., 2016).

1.3 Management

In 1969, Argentina, Bolivia, Brazil, Paraguay, and Uruguay signed the first treat aiming to manage the region as a Whole Basin System for regional integration and harmonic development (CIC, 2016). In 1973, Argentina and Uruguay signed the treaty of the RdlP and its maritime front (TRPyFM) aiming for a sustainable management of aquatic resources and environmental conservation. A binational administrative commission (Comisión Administradora del RdlP, CARP) was created to regulate almost all activities in the estuary (CARP, 2012), together with the Joint Technical Commission for the Maritime Front (CTMFM). The TRPyFM aimed to overcome the controversial situation regarding the jurisdiction over the river's waters and also regulated navigation, fishing, bed and subsoil exploration-exploitation and use, pollution prevention, and other issues. Some binational initiatives are now being undertaken to pilot monitoring programs and to gather information about the basic features of the water and sediment status (FREPLATA, 2014). Under the TRPyFM, each country has exclusivity in the use of coastal areas (2 km in the inner region and 7 km in the outer estuary).

2 MAJOR ANTHROPOGENIC DRIVING FORCES AT RDLP

Various and extensive ecosystem services are provided by the RdlP basin, including production services (i.e., agriculture, livestock, and fisheries), regulating services (i.e., energy source, bioremediation of waste by wetlands and floodplains), and cultural services (i.e., leisure and recreation at the beaches). Because of this, the region is threatened by several drivers and associated pressures at different spatial and temporal scales, including expanding coastal urbanization, fisheries, intensive agriculture, livestock, and industries, including the construction of dams for electricity generation. In addition, human driving forces of these pressures increase maritime transport and propagate other pressures (e.g., dredging, invasive species). These pressures could be categorized either as exogenic unmanaged pressures (ExUPs) from a strictly estuarine perspective, or endogenic managed pressures (EMPs) from a whole system integrated perspective (Elliott, 2011; Elliott and Whitfield, 2011).

2.1 Food Supply

2.1.1 Agriculture and Livestock

As the region shows rich soils and the estuary ends in a confluence of two marine currents (the Brazil and Malvinas currents), the catchment lands and the estuary itself have been exploited for food. The catchment area covers different land uses, even though agriculture and animal husbandry dominate the area (Fig. 1). Specifically for land areas near the estuary, Argentina and Uruguay have more than 160,000,000 ha, most of them belonging to the catchment area, with almost 60% for livestock, 20% for grain, 6% for forestry, and few areas for rice and milk production (AQUASTAT-FAO, 2016). Historically, the main activity was extensive animal husbandry for export although currently soybeans have become the main export product of the region.

One of the main pressures associated with several drivers is the release of nutrients to the environment with the subsequent eutrophication processes along the basin and subestuaries of the RdlP. Red tides and cyanobacteria blooms are increasingly documented (Bonilla et al., 2015), with serious risks to environmental and human health (Vidal et al., 2017). The recent exponential increase of intensive agriculture, with soybean as the main product (https://atlas.media.mit.edu/en/profile/country/arg/; http://www.uruguayxxi.gub.uy), was not supported by scientific studies directed to assess environmental impacts in the catchment areas. However, preliminary evidence suggests that almost all the RdlP basin and coastal areas of the estuary are experiencing the adverse consequences of eutrophication.

At the basin level, land denudation and erosion have been increasing in recent decades in relation to land uses such as intensive agriculture (Bonachea et al., 2010). Several pesticides have been detected (De Gerónimo et al., 2014), such as endosulfan, chlorpyrifos, and cypermethrin, particularly along the Paraná subbasin (Etchegoyen et al., 2017). Pollution by agrochemicals and associated with eutrophication processes have also been detected (Nagy, 2006). An intensive culture of grain and oilseeds occurs, mainly maize, wheat, and soybeans (Leguizamón, 2014; Achkar et al., 2016). The compounds used to control pests are mainly herbicides (e.g., glyphosate, dicamba, atrazine) and insecticides (e.g., chlorpyrifos, cypermethrin). Insecticides released into creeks in peri-urban horticultural areas of Buenos Aires have been found at sublethal and lethal concentrations for benthic fauna (Mac Loughlin et al., 2017). Not only do emergent pollutants occur in the system, but also the earlier banned DDT and endosulfan, an insecticide banned in Uruguay in 2012 that occurs at relatively high concentrations near the mouth of the Uruguay river (Williman et al., 2017). Few management actions have been taken to counteract this effect.

2.1.2 Fishing

Fish consumption in Uruguay and Argentina has been historically below 10 kg per year per person (half the per capita fish world consumption, FAO, 2012). Fisheries production by both countries is mainly channeled to foreign markets (mainly to Brazil, the United States and Nigeria) and the remaining is sufficient to meet the local demand.

Fish catches in the estuary are mainly focused on four or five species. The white croaker (*Micropogonias furnieri*) (approx. 40,000 t/yr), striped weakfish (*Cynoscion guatucupa*) (approx. 12000 t/yr), and sharks (50 t/yr) represent more than 90% of catches in the estuary. Other commercially important fish species include: tope shark (*Galeorhinus galeus*), Argentine angelshark (*Squatina argentina*), leatherjack (*Parona signata*), Argentine croaker (*Umbrina canosai*), southern kingfish (*Menticirrhus americanus*), plaice (*Paralichthys* spp.), Brazilian codling (*Urophycis brasiliensis*), white sea catfish (*Netuma barba*), black croaker (*Pogonias cromis*), king weakfish (*Macrodon ancylodon*), and Brazilian menhaden (*Brevoortia aurea*). Freshwater species such as dorado (*Salminus brasiliensis*) are also fished along the estuary, particularly during occasional events of very large freshwater discharge from the catchment basin. The mussel (*Mytilus edulis*) is the most important invertebrate species exploited for human consumption on the Uruguayan coast of the RdlP.

Different fishing boat types and gear types are employed, and both countries (Argentina and Uruguay) have different fleet categorizations. The industrial fleet is composed of almost 30 Uruguayan vessels with a capacity higher than 10 gross register tonnage (GRT) with 30 m length and a fishing autonomy of no more than 7 days. This fleet uses bottom trawls, most of them operating by pair trawling. Argentinean industrial vessels operating in the estuary are categorized in two types: (1) the smaller boats called "Rada" or "Ría" with lengths between 7 and 17 m and up to 350 HP, mostly operated by pair trawling (75 boats in 2015), and (2) "Costeros," with a length close to 17 m and 350 HP, usually using standard bottom trawls (>50 boats in 2015) (CTMFM, 2017).

Artisanal fisheries also operate up to 5.5 km offshore, both in Uruguay (Defeo et al., 2011) and Argentina (Lasta et al., 2001). The Uruguayan fleet is composed of more than 500 small boats (mainly made of wood or fiberglass) of less than 10 GRT with outboard motors and one day autonomy. The Argentinean artisanal fleet operating in the RdlP is estimated as 370 boats (Errazti et al., 2009). This fleet targets the same stocks as the industrial fleet, thereby producing a high spatial overlap and producing negative externalities to the artisanal fleets (Horta and Defeo, 2012). Along the Uruguayan coast, the fleets follow migrations of *M. furnieri* to coastal spawning areas (Defeo et al., 2011) which are associated with the inner salinity front (Jaureguizar et al., 2008). Both fleets employ almost 2000 (artisanal) and 1400 (industrial) fishers in Uruguay (Defeo et al., 2011).

Ecological pressures by fishing activities are affecting fish populations and ecosystems. Time-series analysis of the main fishery indicators for the RdlP and contiguous oceanic zone showed that fishing effort for both fleet types has remained constant or even declined slightly (CTMFM, 2017). However, catches for the two most important species (*C. guatucupa* and *M. furnieri*) have declined (Fig. 3), reaching in Uruguay their lowest values for the last 35 years, concurrently with decreasing export volumes (Gianelli and Defeo, 2017).

Biomass population models showed a pronounced decrease in the total biomass of *M. furnieri* and a slight decrease in biomass *C. guatucupa*. In the former, the decline in total biomass might be associated with an increase in fishing mortality (CTMFM, 2017). Total biomass values are below the biomass at maximum sustainable yield (B_{MSY}). For *C. guatucupa*, total biomass (about 182,000 t) is greater than the B_{MSY} (154,000 t: CTMFM, 2017). Similar decreasing trends were observed for chondrichthyes, including *Mustelus schmitti* (De Wysiecki et al., 2017).

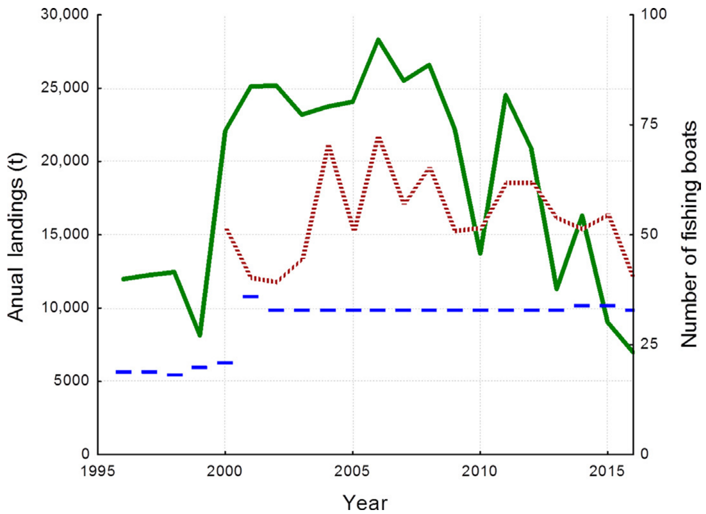

FIG. 3 Variations in fishing effort (right axis, dashed line) and annual landings (left axis) of the main two exploited species in the RdlP estuary, *M. Furnieri* (solid line) and *C. guatucupa* (dotted line). (Modified from CTMFM: El recurso corvina (Micropogonias furnieri) en el área del Tratado del Río de la Plata y su Frente Marítimo, Montevideo, 2017, Diagnóstico poblacional. Documento conjunto DINARA-INIDEP-SSPyA.)

Potential fishing impacts include bycatch, discards, and habitat degradation (e.g., the destruction of the benthic community). Bycatch and discards are also poorly assessed and understood at the level of the RdlP fisheries, and no systematic monitoring exists. A recent work reconstructing fisheries statistics for Uruguay (Lorenzo et al., 2015) has estimated a discard rate of 14% for the period 1960–2000, whereas this rate was set at 9% for 2001–2010. Industrial discards are mainly composed of small organisms of the main target species (*C. guatucupa* and *M. furnieri*), sharks and rajids (Paesch et al., 2014). Of special concern is the entanglement of the estuarine dolphin (franciscana) *Pontoporia blainvillei* by artisanal gear, which has been categorized as a vulnerable species by IUCN. This species has been incidentally caught by gillnet fisheries since the early 1940s (Secchi et al., 2001). A recent study reported that more than 300 franciscana (*P. blainvillei*) were incidentally caught annually by the artisanal Uruguayan fleet (Franco-Trecu et al., 2009). The green turtle *Chelonia mydas* (Endangered) is also incidentally caught. In one particular fishing area (Bajos del Solis) an annual incidental catch of 500–1500 turtles by artisanal fisheries has been estimated (Lezama et al., 2013). The South American sea lion (*Otaria flavescens*) also frequently interacts with Uruguayan artisanal fisheries by preying upon entangled fish such as sciaenids (Szteren and Páez, 2002). Although this interaction is viewed as a major problem to the economic sustainability of artisanal fisheries, recent studies showed only a small percentage of sea lion predation, which therefore should not be considered responsible for the low artisanal landings (De María et al., 2014). Effects of bottom trawling by the industrial fleets damaging the seafloor (Hiddink et al., 2017) may be expected as one of the most important pressures in the RdlP, although scientific evidence is lacking.

2.2 Marine Traffic

The estuary of the RdlP has a fluvial connection with Paraguay-Paraná, Rivers, a multinational fluvial transport system with a total length of 3302 km. This fluvial-maritime system is a principal way to transport products from Argentina, Bolivia, Paraguay, and a part of Brazil to export goods worldwide. This has led to intensive marine traffic and the development of port infrastructure. La Plata-Buenos Aires (Argentina) and Montevideo (Uruguay) are the biggest ports in the RdlP basin, moving jointly almost 20,000 *t* of cargo and 550,000 passengers. The Montevideo port recorded more than 4000 vessel arrivals during 2016 and Buenos Aires almost 1000 arrivals.

Most Uruguayan primary products of agriculture, such as wood, grain, meat, and dairy, are exported from the Montevideo port, which also acts as a regional cargo hub, having a 50% of its containers in transit to/from Argentina, Paraguay, and Bolivia. Most cargo moved from/to the Buenos Aires port is composed by manufactured goods, followed by chemical products, meat, fruits, textiles, fuels, lubricants, and cars. Transport of passengers (by ferries and cruises) is also important for both ports. In 2016, Buenos Aires handled more than 1.5 million passengers and Montevideo more than 700,000.

Traffic can generate environmental impacts through different mechanisms such as space reclamation and dredging together with chemical pollution. The Buenos Aires port is composed of six docks protected by two breakwaters (2500 and 950 m long), reaching more than 7000 m of piers and occupying 92 ha. Most of the space occupied by the Buenos Aires port was land-claimed from the estuary when constructed in 1928 (www.worldportsource.com). The Montevideo port is placed in a deeper natural embayment, enclosed by two breakwaters of 1300 and 900 m. The port is divided into three docks and a refinery terminal reaching a total of 4500 m of piers and a terrestrial area of 110 ha. More than 135 ha had been claimed from the estuary (Gautreau, 2006) to develop additional piers for containers, fishing, and agricultural forestry products (www.worldportsource.com). Both ports need continuous dredging to be fully operative. In addition, the channels in the RdlP are dredged in order to provide access to the Paraná and Uruguay rivers, and then to the entire estuary basin.

The RdlP estuary is freely navigable for ultramarine ships in the external region (>10 m). However, artificial channels are maintained to reach the ports of Buenos Aires and Montevideo and associated ports at the Parana and Uruguay River basins (Fig. 4). The entrance channel (Punta Indio) extends 120 km along the estuary from Montevideo to La Plata where the canal bifurcates into a northern branch (Martín García) and a southern branch (Emilio Mitre—Buenos Aires port access).

The official statistics of maritime shipping in the RdlP estuary shows a rather constant trend. Montevideo has a greater amount of ship movements (arriving plus departing) than Buenos Aires, possibly related to a major activity of fishing fleets. Despite this, there is a decreasing temporal trend in the number of ships in both ports. In terms of containers, Montevideo showed a constant increase, and Buenos Aires a slight decreasing trend (Fig. 5).

Pressures of marine traffic on the RdlP ecosystems are produced by port operations and those particularly exerted by the ships, impacting directly the water body or, indirectly, air, and terrestrial areas. At present, the most common environmental concerns of shipping refer to chemical discharges (oil, wastewater, antifouling paint, ballast water, and marine litter) and physical pollution (underwater noise, ports, fairways and channels, dredging, and shipwrecks).

Dredging is a frequent activity in the estuary. Montevideo dredges more than 60 km of canals including the docks, reaching a total sediment volume of more than 17 million m^3 in a 5-year period. In addition, more than 24 million m^3 were

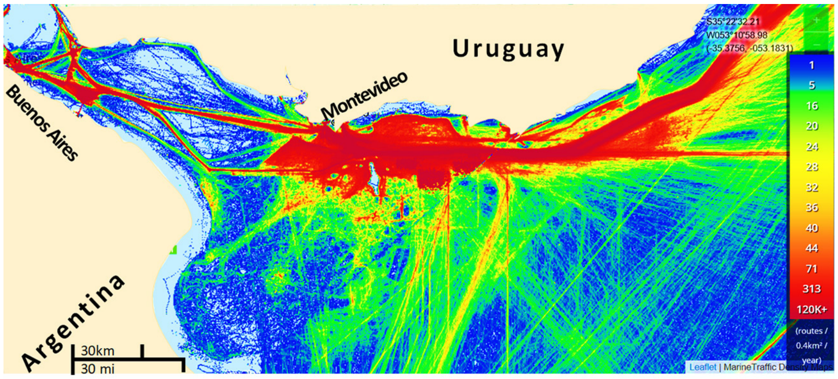

FIG. 4 Marine traffic density map for the Rio de la Plata estuary. A clear canalized pattern is observed with huge activity near Montevideo city. (https://www.marinetraffic.com/en/ais/home/centerx:-55.6/centery:-35.3/zoom:8) Publicly display content with proper attribution online allowed.

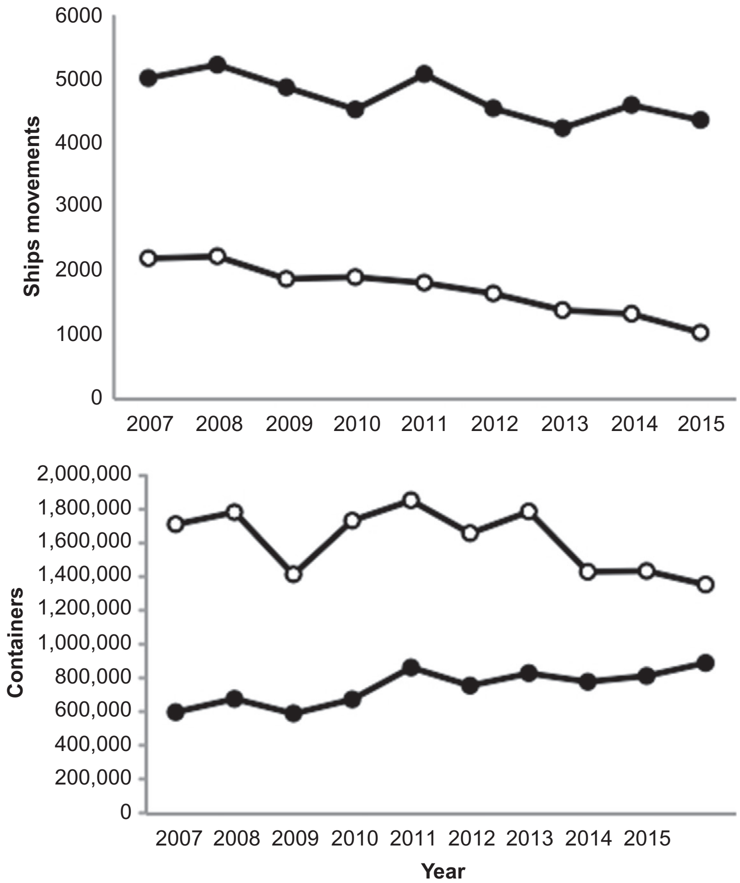

FIG. 5 Indicators of main traffic state in the Río de la Plata estuary main ports (2007-Present). Buenos Aires (Plain circle) and Montevideo (Shaded circle). From official statistics.

recently dredged to construct an access channel and port infrastructure for a re-gasification plant. The Buenos Aires port is artificial, placed in terrain claimed from the estuary. In the 1980s, 30 million m^3 of sediments were dredged, and the sediment removed was used to claim more than 4 km^2 from the estuary. At present, this area is included in a reserve and park along the city coast. Buenos Aires dredges more than 2 million m^3 per year, including main docks and access channels. The dredged sediment is disposed in the RdlP at few kilometers from both ports. There have been no specific studies focused on the impacts of dredging.

Chemical and biological pollution is generated by traffic. The Montevideo Bay was described as highly polluted (Danulat et al., 2002). Sediments in the RdlP have been affected by high PAHs (polynuclear aromatic hydrocarbons) concentrations since at least 1989, particularly in the main ports. In Buenos Aires, La Plata, and Montevideo, a range of 2.5–555 µg/g were reported (Colombo et al., 1989; Muniz et al., 2004). The mean PAHs concentration is very high (29.5 ± 63.4 µg/g), exceeding by several orders of magnitude Canadian guidelines for individual PAHs (5.9–111 ng/g for 13 PAHs; sum = 468 ng/g). Disentangling the sources of diverse PAHs in RdlP estuary may be challenging since data are scarce. The main sources of aliphatic and polycyclic aromatic hydrocarbons are petroleum inputs and combustion (Venturini et al., 2015) due to oil transport and refining (Fig. 2), maritime activities, and vehicular emissions. The release of these harmful substances into the estuary is not regulated. Total aliphatic hydrocarbons and PAH levels are in the same range as those determined in heavily polluted areas worldwide. Metals are released into the environment by leaking combustible materials from ships. Lead, a metal associated with fuels, is present even at moderated toxic levels on some beaches of Montevideo city (García-Alonso et al., 2017), although the multiple sources of pollution prevent the determination of the main source. Although now banned under International Maritime Organization (IMO) regulations, tri-butyl-tin (TBT) has been used as an antifouling in ship paints to prevent settlement of sessile organisms that affect passage and navigation. Although TBT concentrations in the RdlP are unknown, imposex in female mollusks was detected, suggesting potential deleterious effects of TBT (Bigatti et al., 2009). Marine debris in the RdlP includes packaging objects, plastics, and fishing gears (Acha et al., 2003). The salinity front of the estuary acts as a barrier accumulating debris, particularly in the inner estuary, where important ecological areas (e.g., spawning and nursery areas) occur (Acha et al., 2003).

Argentina and Uruguay have signed UN treaties and conventions, such as the International Convention for the Prevention of Pollution from Ships (1973) and the Protocol of 1978 (MARPOL 73/78). The 1973 TRPyFM agrees about the common use of the space in the estuary and assigns rights and responsibilities about navigation and infrastructure in the common zone, excluding a 7-mile coastal fringe of national exclusive jurisdiction. The binational commission CARP manages and controls the activities at the estuary, such as navigation (del Castillo-Laborde, 2008). Despite its wide remit and competence, most resolutions of this Commission focus on navigation infrastructure (e.g., dredging of new channels), and there are no apparent resolutions concerning impacts and pressures of the activities.

Uruguayan and Argentine navies are responsible for enforcing international treaties related to maritime traffic and pollution, including protocols for environmental protection and security, and implementing monitoring, control, and surveillance of national and international regulations. This is achieved by long-term strategies (e.g., by planning and training) but also rapid responses to contingencies (e.g., oils spills). Both port administrations are committed to the reduction of environmental impacts, delineating diverse policies toward this direction. National and international rules and certification programs are followed to manage waste, transport of dangerous materials, and to develop environmental impact assessments for new developments. For instance, the port of Buenos Aires is following the Environmental Ship Index strategy, offering discounts in the services for ships with a good environmental score (http://www.environmentalshipindex.org).

3 MINOR DRIVERS: INDUSTRY, URBANIZATION, AND TOURISM

Several industries are located along the coast of the RdlP, particularly near Buenos Aires and Montevideo. In Uruguay, there are pulp mill factories at the inner estuary, while petro-chemicals, cloro-alkali plants, tanneries, refineries, pulp mills, chemical industries, and bitumen producers are found near Montevideo (Danulat et al., 2002; SADI, 2013). In Argentina, several industries are located in the inner RdlP. The subbasins of Riachuelo and Reconquista rivers are the most polluted watercourses in Argentina, receiving untreated disposal points from urban, agricultural, cattle farming and industrial effluents. Approximately 90% of industrial waste produced in the Reconquista river subbasin is discharged directly into watercourses (Salibián, 2006). Since permissive environmental laws exist on industrial discharge and chemical importation in comparison to the EU REACH legislation, toxic chemicals are still used and released by industries to the environment without treatment. For example, carcinogenic surfactants alkylphenols polyethoxylated with endocrine disrupting properties are freely commercialized in the region.

Polluted areas have been detected aling both banks of the estuary using different markers of pollutants such as toxicities (Basílico et al., 2017), metal traces (Tatone et al., 2012, García-Alonso et al., 2017), macrophyte assemblages (Feijoó and Lombardo, 2007), biofilm coating, and metagenomics (Bauer et al., 2007; Piccini and García-Alonso 2015). The population increase and the tourist demand for accommodation have induced the construction of housing and related infrastructure with a lack of sewage treatment, thereby negatively impacting coastal streams and beaches (Arreghini et al., 2007; Basílico et al., 2017; Rigacci et al., 2013). At Buenos Aires, tourism is more than half of the Argentinean tourist GDP (gross domestic product), reaching 11.1 billion US$ (WTTC-Report, 2017). In Uruguay, sandy beaches attract tourists for recreation, with tourism reaching 7% of the country GDP, with the number of visitors (particularly in summer) being the same as the local permanent residents (Achkar et al., 2016). In addition, almost 200 cruise liners arrived at Punta del Este and Montevideo in summer 2014–15 (Achkar et al., 2016), reaching 13% of total tourists (Ministerio de Turismo del Uruguay, MINTUR, 2016). Montevideo is the Uruguayan port where more tourists disembarked (Bellani et al., 2017).

Urbanized coasts are inducing heavy pressures on the environment. Discharges of untreated effluents into the RdlP estuary are a major concern, since this produces a conflict with water for human consumption and recreation. Unknown amounts of biological and chemical pollutants are released into the estuary from the main Buenos Aires sewer at Berazategui (2 million m^3 per day: Cirelli and Ojeda, 2008) and from the sewage discharge at Punta Carretas in Montevideo city (Nagy et al., 2014). At Montevideo, only the presence of fecal coliforms is monitored in beaches used for recreation to reduce health risk by posting sanitary flags when fecal Coliforms exceed 1000 UFC per 100 mL (www.montevideo.guv.uy/ciudadania/desarrollo-ambiental/playas). Chemical pollutants are not routinely measured, including cyanotoxins, although polycyclic chlorinated biphenyls (PCBs) and polybrominated diethyl ethers (PBDEs) were detected in suspended organic matter near the sewage discharge of Buenos Aires. These chemicals bioaccumulate almost 40 times more than organic matter in the streaked prochilod fish *Prochilodus lineatus* (Cappelletti et al., 2015). These pollutants acting additively with other industrial and domestic chemicals (as endocrine disrupting compounds: EDCs) interfere in the normal functioning of hormones. The effects of EDCs with estrogenic properties have been detected in the estuary itself (Valdés et al., 2015) or in tributaries such as the Santa Lucía River (Griffero et al., 2018). Urban beaches of the RdlP accumulate anthropogenic marker elements such as phosphorous, lead, copper, chromium, zinc, and mercury, with an unknown potential health impact in humans and ecosystems (García-Alonso et al., 2017).

Eutrophication processes originating from different pressures are one of the most important environmental impacts. Point source (domestic sewage and industrial discharge) and diffuse (agriculture activities) sources throughout the whole basin and the RdlP estuary increase the concentration of nutrients, mainly near the coast. A lack of basic knowledge on the system and poor monitoring programs do not allow predicting the carrying capacity of the RdlP to cope with the nutrient enrichment by environmental homeostasis.

4 THE FUTURE OF THE RDLP ESTUARY

Estuaries are complex systems where several natural stressors occurring simultaneously may interfere in environmental monitoring programs (Elliott and Quintino, 2007; Elliott and Whitfield, 2011). For instance, integrating the whole pollution-toxicity relationship in estuarine systems is needed for estuaries, since the homeostatic properties are specific for each region (García-Alonso et al., 2011).

Natural climatic factors and external unmanaged pressures from anthropogenic activities at the basin level (e.g., dams, irrigation, intensive agriculture) together with main drivers inside the estuary may affect the status of the RdlP estuary both in the short and long terms. The relatively scarce monitoring, control, and surveillance programs of pressures and impacts in a basin administered by five countries, and the lack of historical data makes it difficult to determine the current potential level of impact and to predict the impact of human activities at the basin level. At the level of the RdlP estuary and associated ecosystems (wetlands and floodplains), there is a substantial lack of environmental management and conservation plans. Since long-term management strategies are lacking, predictions of potential scenarios in the future are unreliable.

Even though several fishery management measures have been proposed by CTMFM and CARP to improve stock conditions (e.g., restrictions in fishing effort, minimum landing sizes, protected areas and time closures, total allowable catches and quotas per year), commercial fish populations are declining, and more efforts are needed in order to maintain sustainable stocks (CTMFM, 2017).

It is expected that maritime traffic will increase in the RdlP in the near future. For example, the port of Montevideo is experiencing a significant capacity increase. New and planned infrastructure includes a multipurpose dock, a new terminal for forest products and bulk solids, and a new fisheries terminal. These developments will result in more than 600 m of docks, and dozens of hectares have been claimed from the estuary. In addition, there are plans to extend port activities (in Montevideo bay) by constructing a new passenger terminal and a new logistic hub with an industrial zone and port (Puntas de Sayago). The port of Buenos Aires is also expanding its capacity. The historic docks will be land filled to attain deeper waters, allowing larger vessels to enter (such as the New Panamax type). This cargo would be operated by two terminals instead of three, as at present, requiring an investment of 850 million US$.

Different drivers and pressures exert impacts that interact with other drivers and ecosystems services of the RdlP. For instance, exogenic unmanaged pressures (ExUPs) from agriculture and domestic sewage generate eutrophication that affects the quality of drinking water at its source or recreation areas. Without an effective and increased regulation of fertilizers, phosphorous-based biocides and sewage treatments, an increase in cyanobacteria and harmful algal blooms may be expected to occur at the basin and coastal areas of the RdlP (Martínez et al., 2017). In addition, urbanization and industrialization may threaten the environmental quality in spawning and nursery areas, exerting unknown negative effects on fisheries. In fact, most sciaenid species spawn in the sub-estuarine systems of the Uruguayan coast. Nutrient enrichment associated with eutrophication of RdlP may have a detrimental impact in some ecosystem services of the estuary (drinking-water source, food supply, and recreation) if the markers become above the managed environmental homeostasis level (Elliott and Quintino, 2007).

Hundreds of sandy beaches at the RdlP are used for human welfare, where recreational activities occur. Monitoring programs of environmental quality need to be updated to actual international standards for marine and transitional waters, such as the reduction of the maximum allowable concentration of fecal coliforms, quantification of *Enterococci* and chemical pollutants, and analyzes for metal pollution (WHO, 2003).

Several binational projects have been developed in the inner part of the RdlP, including the use of water for human consumption, and at brackish areas with sandy beaches for recreational leisure (Sathicq et al., 2014). In addition, international projects are being executed aiming to improve the environmental management of the RdlP and its maritime front (e.g., ECOPLATA and FREPLATA: www.freplata.org). However, the lack of basic studies and monitoring programs precludes estimating basic reference points for assessing ecosystem health status (García-Alonso et al., 2017). Therefore, there is a need to identify and assess drivers and pressures in order to reach sustainable development in these complex social-ecological systems (Norgaard et al., 2009).

Finally, global change (climate change and environmental pollution) is likely to increase eutrophication and toxicity within the RdlP. Eutrophication-like processes are expected under climate change scenarios and are likely to deeply impact the already eutrophic estuaries in South America (Kopprio et al., 2015). Assessment of impacts and attributing causes to global change pressures are challenges for all estuaries (Little et al., 2017), in particular in low-industrialized regions such as the RdlP estuary, where more baseline studies are needed to develop long-term sustainable management programs.

In summary, we have described the main social and ecological issues of the RdlP estuary, with special emphasis on the main drivers and pressures affecting the system, highlighting information gaps, and the lack of long-term management policies and comprehensive plans that should consider the RdlP as a social-ecological system. The inclusion of multisectoral goals and the reinforcement of comprehensive long-term monitoring programs to assess ecosystem status are needed to attain a sustainable use of the RdlP estuary.

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