Chapter 37

The Senegalese Coastal and Marine Environment

Rachid Amara*, Mamadou Diop†, Cheikh Diop†, Baghdad Ouddane‡

*Univ. Littoral Cote d'Opale, Univ. Lille, CNRS UMR 8187 LOG F62930, Wimereux, France, †Laboratoire de Toxicologie et d'Hydrologie (LTH) UCAD, Dakar, Sénégal, ‡Equipe Physico-Chimie de l'Environnement, LASIR UMR CNRS 8516, Université de Lille, Villeneuve d'Ascq Cedex, France

37.1 THE DEFINED REGION

Senegal, the westernmost country in Africa, extends between 12°N and 17°N and lies along the North Atlantic Ocean, surrounding the Gambia and sharing borders with Mauritania, Mali, Guinea, and Guinea-Bissau. The country owes its name to the Senegal River that marks its eastern and northern borders (Fig. 37.1). It covers 196,722 km^2, which is mostly flat without any pronounced relief. Senegal is generally characterized by a Sudano-Sahelian climate and quarter of its territory is arid. It has two distinct seasons: a dry season that lasts from November to May which is influenced by the Harmattan and trade winds, and a wet season from June to October in the south and from July to September in the north, as the Inter-Tropical Convergence Zone moves northward. Total annual rainfall in Senegal increases from north to south, with 263 mm in Saint-Louis, 412 mm in Dakar, 600 mm in Joal, and more than 1200 mm in the South of the country. Senegal's temperature gradient varies inversely with its precipitation pattern, with higher temperatures occurring in the north and lower temperatures in the south. The temperature ranges from 16°C to 25°C along the coast during the cold season and 20°C to 32°C in the countryside. During the rainy season (June–October), the temperature ranges from 25°C to 40°C.

The population was estimated in 2016/17 at 14.88 million inhabitants with a relatively high annual growth rate of 3% (FAOSTAT, 2017). Thus, nearly 45% of the population is under the age of 15. More than 70% of the country's population is concentrated in coastal cities, because of commercial and industrial reasons and by the development of activities related to fishing. The Saloum Delta is one of Senegal's most populous regions with 10% of this area inhabited by around 16% of the country's total population. The coastal zone contains 67.67% of agricultural activities (Niayes), 72% of the industrial sector, 63.6% of the merchant services sector, and 73.58% of the nonmarket services sector. In all, the coastal zone contributes 67.86% to the gross domestic product (GDP) of Senegal. While the country has experienced development gains in recent years, poverty remains high, affecting 46.7% of the population. The country remains classified as a least-developed country but is one of the most stable countries in Africa (World Bank, 2017).

Senegal's economy was for a long-time dependent on groundnuts and phosphate. The main mineral resources available apart from phosphate are iron ore and marble. Offshore petroleum is available on the border with Guinea-Bissau and at Rufisque, Sangomar, and Cayar. A Senegalese-Mauritanian mega-gas field in Grand-Tortue has recently been discovered by a British company. With successive years of drought and the deterioration of trade terms following the oil crisis, fisheries became a predominant sector highly integrated with the national economy. Over the last decade, the fisheries sector has become a pillar of the Government's food security policy and contributed to about 43% of the intake of animal proteins in 2013, with a yearly consumption of 23.9 kg per person.

Fisheries contributed 1.8% to the GDP in 2015 and provided more than 53,100 direct and 540,000 indirect jobs, mainly in artisanal fishing and processing (FAO, 2017). The sector employs about 15% of the Senegalese labor force, that is, approximately 600,000 people. From 1986, fisheries became the largest exporting sector, surpassing groundnut products and phosphates combined. According to the latest data on Senegalese exports for 2015, the fisheries sector ranks first with 193.5 billion CFA francs, or 20.87% of exports. Exported products are fish (86.60%), cephalopods (6.15%), crustaceans (4.67%), and gastropods (2.56%). Fishing is facilitated by Senegal's 731-km-long coastline and favorable environmental conditions and upwelling.

Senegalese agriculture is largely dominated by very small family farms which constitute almost all the agricultural activities of the village. Agriculture continues to employ most of the rural population (70%) although it represented only 15.6% of the country's GDP. It is based both on cash crops (groundnuts, cotton, horticultural products) and food crops

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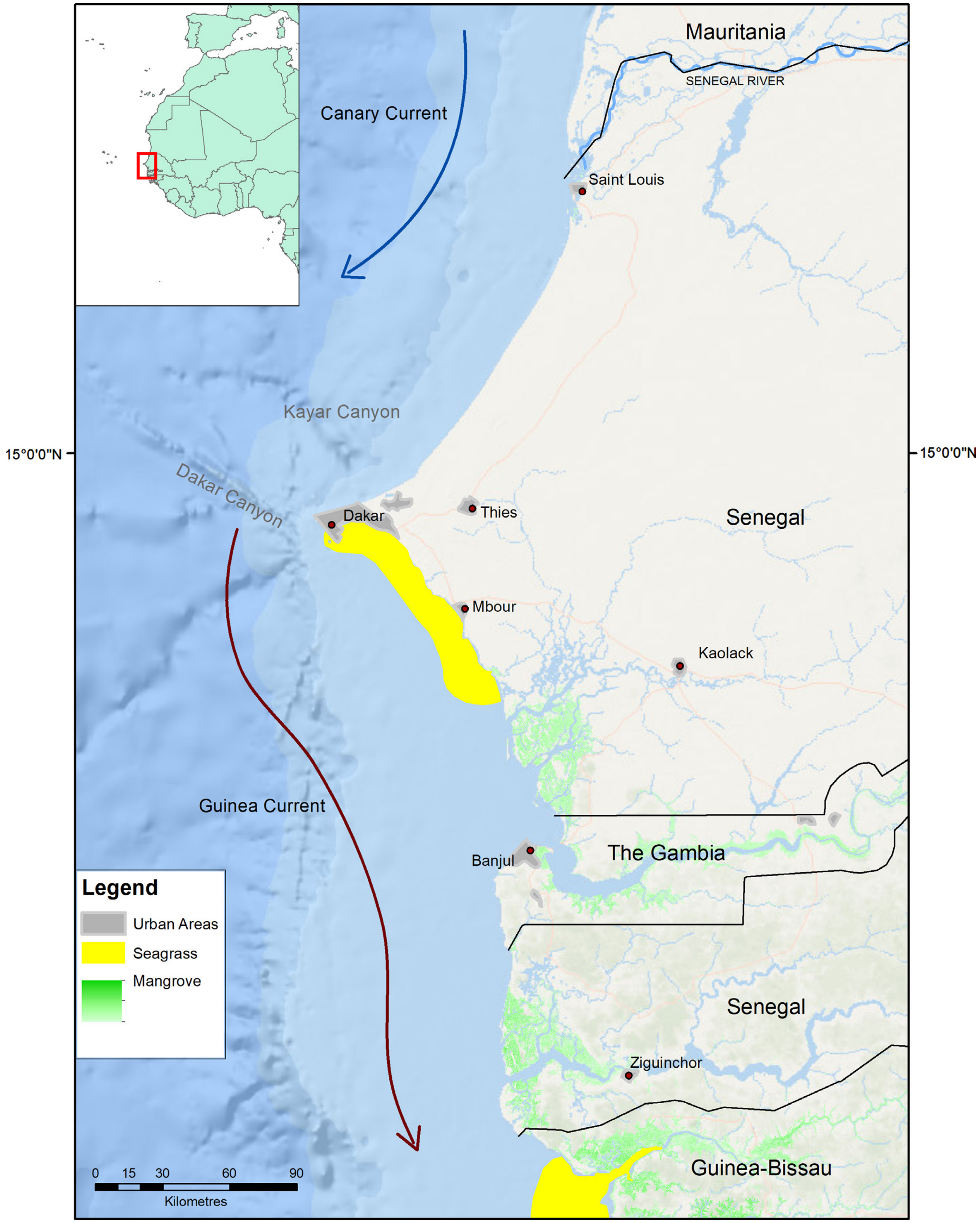

FIG. 37.1 Map of Senegal shows the main urban areas and areas of seagrass and mangroves.

(mainly cereals). Variations in the amounts and timing of annual rainfall cause fluctuations in the productivity of the agricultural, livestock, and forestry sectors and make food security an issue for most rural dwellers.

Coastal tourism is a major source of income, and Saint-Louis, Dakar, Gorée, Mbour, Saloum, and Cap Skirring are the main tourist zones. In the Dakar region, there is a pink lake which is a tourist attraction, with salt extraction activities as an additional source of income for the local population. The coast attracts over 90% of tourists visiting Senegal.

Senegal has a large deep-water port, the autonomous port of Dakar (PAD), a nerve center for foreign trade and intra-regional transit and a river transport network. Marine transport accounts for 95% of Senegal's international trade (imports and exports). There are also small ports in Kaolack, Saint-Louis, and Ziguinchor.

37.2 COASTAL AND MARINE HABITATS

Senegal extends along 731 km of coastline and contains a wide variety of habitats. The main coastal habitats are as follows:

- Floodplain depressions and salt flats in the deltas of the three major rivers (the Senegal, the Saloum, and the Casamance) that flow into the Atlantic Ocean.
- The Niayes, a series of small depressions located among the coastal sand dunes found along the northern coast (from Dakar to Saint-Louis) over 135 km long. They occupy a surface area of about 2000 km^2 and are home to about 419 plant species representing nearly 20% of the Senegalese flora.
- Large expanses of mangrove forests found at the mouth of the Saloum and Casamance Rivers. Small patches of mangrove exist at the mouth of the Senegal River and on the edges of the coastal lagoons south of Dakar.
- Sandy beaches, particularly in the north of Senegal where they extend from the large Mauritanian beaches.
- The Cap Vert peninsula, a volcanic outcrop that stands out along the otherwise sandy coastline, subdivides the Senegalese coast into two distinct regions: the Grande-Côte (large coast) in the north with large sandy beaches and where the continental shelf is quite narrow (<20 miles), and in the south, the Petite-Côte (small coast), a sandy coast segmented by small rocky outcrops and small bays forming a ragged coastline.

The continental shelf, limited by the 200 m isobath, covers 28,700 km^2. In the southern part, the continental shelf is broad and shallow where depths are shallower than 30 m across a third to half of the shelf area. Near Dakar, a large depression (the Pit Kayar) crosses the continental shelf over its entire width.

Water resources are relatively abundant in Senegal, which has a potential of about 35 billion cubic meters per year. The interior of the country is watered by the large Senegal and Gambia Rivers and small rivers such as Casamance, Kayanga, Falémé, Anambé, and Sine-Saloum flowing into the Atlantic Ocean. The peripheries of these rivers are densely populated and very rich in biodiversity, including migratory marine species. Freshwater inflows are recorded in the rainy season from July to September. The Senegal River is about 1800 km long and is the second longest river in West Africa after the Niger. The river flows into the Atlantic through an elongated estuary near the city of Saint-Louis and is the most important water resource in the country. The river's discharge has been particularly affected by Sahelian droughts since the 1970s. The mean annual water discharge at Bakel, the reference station for the Senegal River, situated 557 km upstream of Saint-Louis, is 676 $m^3 s^{-1}$, and varies from a mean low dry season value of 10 $m^3 s^{-1}$ in May, to a mean maximum flood value of 3320 $m^3 s^{-1}$ in September at the height of the rainy season. In 1985, the Diama dam was built in the lower river valley, 23 km upstream from Saint-Louis. The dam was commissioned with the twin aims of preventing saltwater intrusion, which, hitherto, penetrated up to 350 km upstream in the lower Senegal valley, and regulating the river's rainy season discharge to improve irrigation of agricultural lands. The lower Senegal delta is characterized by high biological productivity, important fishing activities, and by rich agriculture, providing 8% of the arable land of Senegal. The Sine-Saloum estuary is located 100 km southeast of Dakar, drains a catchment area of 29,720 km^2, and has a water surface area of 900 km^2. It is an "inverse estuary" showing a salinity increasing from the river mouth toward inland. This salinization process is mainly driven by a net loss of freshwater due to intense evaporation. The Lower Casamance and Saloum Delta coastal wetlands are made up of a multitude of mangrove-fringed channels and flats subjected to the tides. Mangroves play a predominant role in all subtropical and tropical areas around the world, providing a wide range of ecological and social services. Senegal has some 185,000 ha of mangroves mainly in Casamance and Sine-Saloum regions. These ecosystems contain a rich and varied fauna composed of migratory species and sedentary species (mammals, fish, shrimps, crabs, oysters, shellfish) and are nursery areas for many marine species.

37.3 COASTAL AND MARINE ENVIRONMENT

The area has a semidiurnal tide. In Senegal, the mean spring tide ranges are small: 1.2 m at Saint-Louis and 1.3 m at Dakar. Water mass circulation and hydrology in West Africa are strongly controlled by the displacements of the intertropical convergence zone (ITCZ). During the monsoon season (July–October), weak westerly winds are dominant and the region

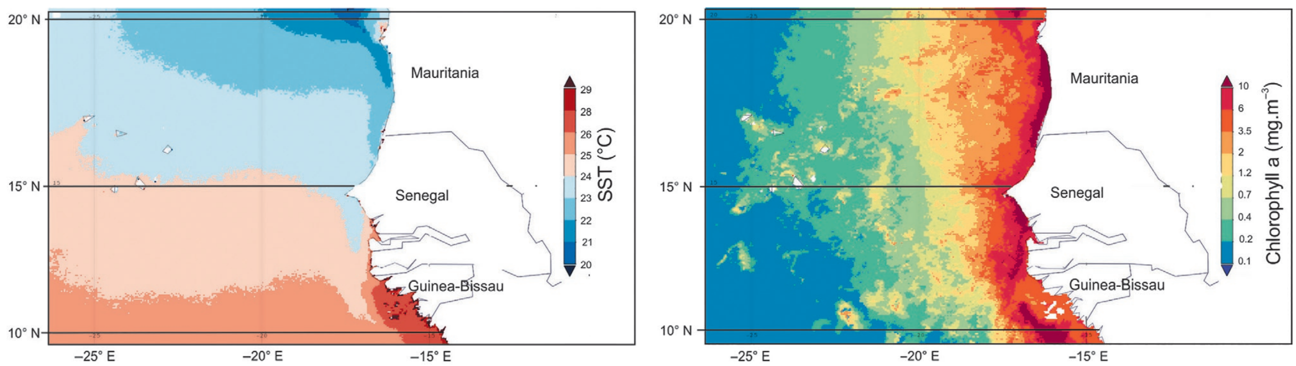

FIG. 37.2 Monthly average sea surface temperature (SST, °C) and Chlorophyll *a* concentration ($mg\,m^{-3}$) for the period 2006–2016.*(Data from Modis-Aqua Modisa produced with the Giovanni online data system, developed and maintained by the NASA GES DISC.)*

receives its main annual precipitation. From November to May, the ITCZ is located to the south and upwelling-favorable trade winds dominate (Capet et al., 2017).

The northeasterly winds along Northwest Africa cause offshore surface water transport which leads to the upwelling of subsurface denser waters and brings nutrient-rich subsurface waters to the euphotic zone, giving rise to a coastal band of enhanced primary productivity. The Canary upwelling ecosystem (CUE) situated off northwest (NW) Africa (10–35°N) is one of the four major eastern boundary upwelling systems in the world ocean (Carr, 2001). Comparative studies have shown that the CUE, with a value of $0.33\,GtC\,yr^{-1}$, would appear to be the second most productive system after the Benguela current ($0.37\,GtC\,yr^{-1}$) (Carr, 2001). The Senegalese coastal upwelling region is the southern part of the CUE. The meridional orientation of the Senegalese coast favors coastal upwelling when equatorward trade winds start to blow in early winter. This dynamic drives the productivity which has a mean annual value for chlorophyll of $1.31\,mg.chla.m^{-3}$. This productivity supports abundant fish stocks dominated by small pelagic fish.

Marine environmental conditions off the Senegalese region show a strong seasonality and spatial variability (Figs. 37.2 and 37.3). The mean sea surface temperature (SST) is higher along the southern coast (24.55 ± 3.06°C) than the northern coast (23.41 ± 2.85°C). The concentration of Chlorophyll *a* is higher near the coast than the offshore. In the coastal area, the mean Chlorophyll *a* concentration was about $2\text{–}6\,mg\,m^{-3}$.

There is strong seasonal variation in SST with lower temperatures during the cold season from January to May and higher temperatures during the hot season from June to December (Fig. 37.3). The amplitude of the seasonal temperature cycle is 8.8°C. This seasonal variation depends first on the seasonality of the heat exchanges with the atmosphere, and second on the intensity of the upwelling itself, which also varies seasonally. The Chlorophyll *a* concentration also showed seasonal variation with higher concentrations from January to June. Off Senegal, upwelling occurs in winter and late spring. During summer, weak southerly winds prevail and warm tropical waters extend over the whole shelf, creating a relatively stable and stratified environment. A recent study has shown that upwelling in South Senegal is relatively low in intensity and mainly restricted to a limited area (Capet et al., 2017). Paradoxically, the limited power of this upwelling is very beneficial for species living near the coast. Indeed, if the enrichment remains moderate, the coastal retention of upwelling waters over the shelf is enhanced. This may be favorable for fisheries since the southern Senegal upwelling sector is a well-known spawning and nursery area for several small pelagic fish species.

37.4 COASTAL AND MARINE BIODIVERSITY

The Niayes are wetlands with a high biodiversity potential that are home to 419 plant species, or 20% of the Senegalese flora, even if the densities are low. Senegal's mangrove system supports a vast range of migratory and sedentary species such as monkeys, hyenas, flamingos, pelicans, terns, herons, and several types of birds which nest in trees. Six species of mangrove have been identified, such as *Rhizophora racemosa*, Rhizophora mangle, *Rhizophora harrisonii*, Avicennia germinans, Conocarpus erectus, and Laguncularia racemosa (Ndour, Dieng, & Fall, 2012).

Senegalese marine waters contain a great diversity of macrophyte algae. At present, 242 species are listed in northern Senegal (Harper & Garbary, 1997). The presence of a rocky coastline, that makes algae attachment possible, could explain the high diversity. Seagrass beds of *Cymodocea nodosa* and *Halodule wrightii* were observed in sandy areas of some protected bays of Dakar, around Sarene (14°16′18″N, 16°54′17″W), Joal Fadiouth (14°09′08″N, 16°50′03″W), and the Bamboung-Sourou area (13°50′08″N, 16°33′09″W) (Cunha & Araújo, 2009) (Fig. 37.1). The seagrass beds ranged from small patches (1 m in diameter) to large meadows along beaches (more than 20 km long). In the bays around Dakar, serious

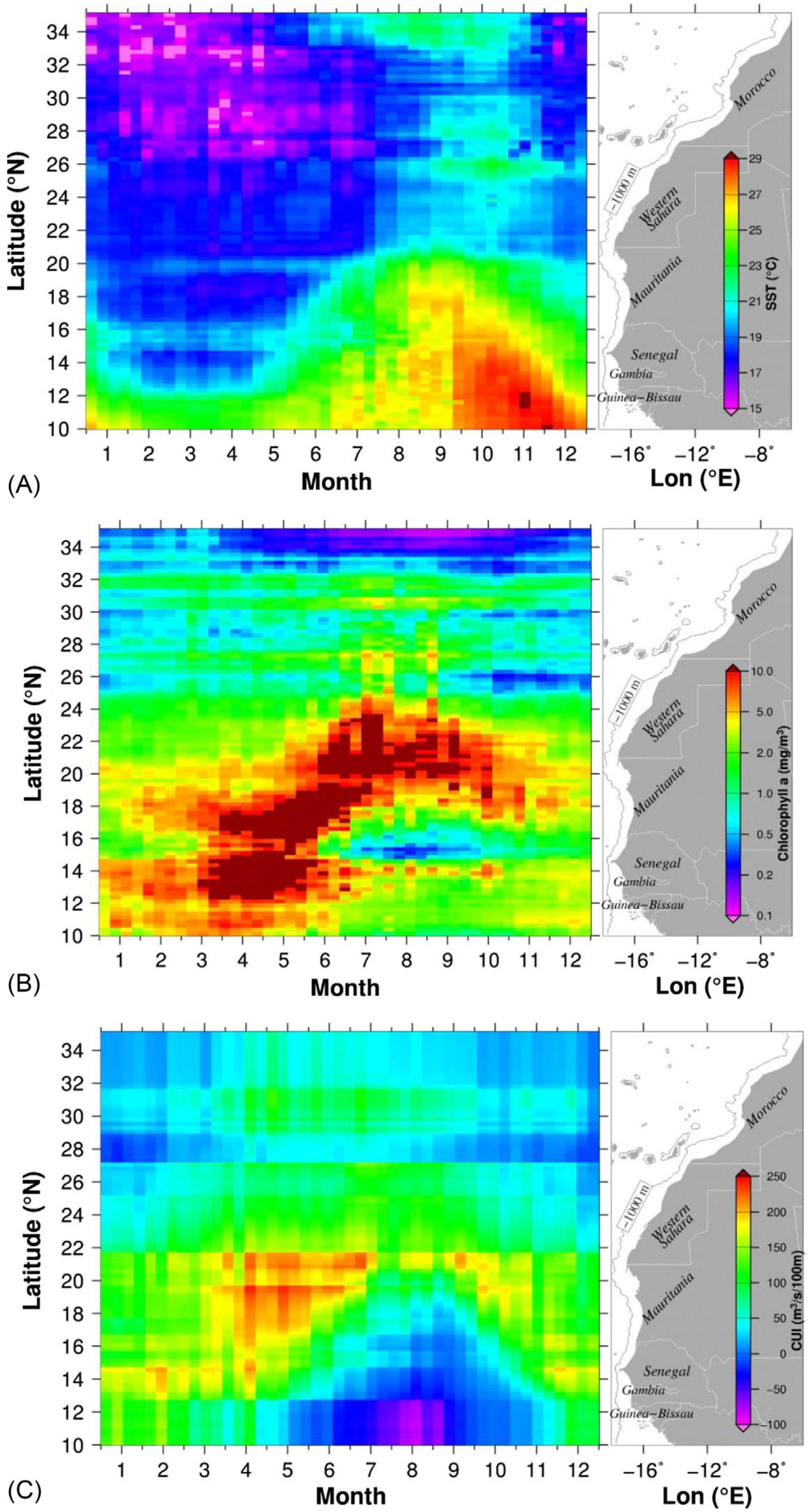

FIG. 37.3 Seasonal and latitudinal evolution of (A) sea surface temperature (SST, °C), (B) Chlorophyll *a* concentration ($mg\,m^{-3}$), and (C) the upwelling index CUI ($m^3 s^{-1}$ $100\,m^{-1}$) from 2002 to 2011. The SST is obtained from the advanced very high-resolution radiometer sensor (AVHRR) and Chl *a* concentrations were computed from MERIS sensor's data.

damage to *C. nodosa* was observed due to boat anchoring. The South of Dakar and near fishing villages, large amounts of freshly cut material (leaves and rhizomes) were observed on the beaches due to coastal net-fishing activities.

In upwelling systems, where diatoms are dominant because of their competitive advantages in exploiting turbulent waters, they are responsible for approximately 40% of net primary productivity (NPP) and up to 50% of the organic carbon exported to the ocean interior (Dugdale & Wilkerson, 1998). In Senegal, diatoms represent 93% of the biomass of all phytoplankton species. Five dominant species are present in most locations during the upwelling season (Thalassionema nitzschioides, *Pleurosigna elongatum*, Hemiaulus sinensis, Chaetoceros decipiens, and Rhizosolenia hyalina) and five other species mostly during the onset of the upwelling season, in December (Nitzschia seriata, *Chaetoceros affine*, *Chaetoceros curvisetum*, Rhizosolenia stolterfothii, and Skeletonema costatum) (Dia, 1986).

Although upwelling systems are susceptible to harmful algal blooms (HABs) because they are highly productive, nutrient-rich environments prone to high-biomass blooms, there have been no studies on HABs in the Senegalese upwelling system.

Copepod species are dominant and make up the bulk of the mesozooplankton biomass (Berraho, Somoue, Hernandez-Léon, & Valdés, 2015). The abundance of zooplankton populations is determined by the seasonality and the upwelling regime. Zooplankton is abundant throughout the year (abundances >2000 ind. m^{-3}) with peaks of both biomass and abundance (in the order of 15,000 ind. m^{-3}) from November to January and secondary peaks (5000–10,000 ind. m^{-3}) from May to August.

Senegal has around 799 fish species, including 672 marine species and 146 freshwater species (FishBase, 2017). Only 142 of these fish species are of commercial interest. In the estuaries, some 125 species have been identified (111 species in the Senegal estuary, 123 in the Sine-Saloum estuary, and 86 in the Casamance estuary) (Baran, 2000). In Senegalese hypersaline inverse estuaries (Casamance, Sine-Saloum), catfishes and croakers are dominant at the mouth; they are replaced by clupeids and mullets in the middle zone, and upstream, where salinity reaches 110% ppt, tilapias proliferate.

Coastal pelagic fishes such as sardinella (Sardinella aurita and Sardinella maderensis) are the most important marine resource, accounting for about 64% of annual catches. The main coastal demersal species are Epinephelus aeneus, Pagellus bellottii, Sparus caeruleostictus, Galeoides decadactylus, Pseudupeneus prayensis, and Farfantepenaeus notialis, representing 15% of total landings.

Many groups of marine invertebrates are still rarely inventoried, such as sponges, sea cucumbers, sea urchins, starfish, molluscs, various coelenterates, etc. The molluscs, with 400 species, belong to nearly 40 families among which there are about 100 species of bivalves, gastropods, and cephalopods. The crustaceans include some 50 species of lobsters, shrimps, crabs, and stomatopods. Among them, the Southern pink shrimp P*enaeus* notialis is the most important commercial species in Senegal (Garcia-Isarch & Munoz, 2015). Octopus vulgaris and Sepia officinalis are currently the main cephalopod species exploited by artisanal and industrial fisheries.

The marine mammals inventoried in the Senegalese Exclusive Economic Zone are whales (Balaenoptera physalus and Balaenoptera edeni), dolphins (with the genera Delphinus, Tursiops, Stenella), and manatees (Trichechus senegalensis). Other species of mammals have also been reported, such as porpoises, sperm whales, orca whales, and monk seals. Populations of common bottlenose dolphins Tursiops truncatus are common in Senegal's coastal waters. Resident or semi-resident communities inhabit year-round the Casamance River (upriver to Ziguinchor) and the Sine-Saloum Delta, but strandings and sightings indicate the species' presence along the entire coastline (Djiba, Bamy, Samba Ould Bilal, & Van Waerebeek, 2015). Due to their wide coastal distribution, the common dolphins Delphinus delphis, Tursiops truncatus, and the harbor porpoise *Phocaena phocoena* are the small cetacean species most commonly falling victim to net entanglements (Mullié et al., 2013).

The region of West Africa supports globally important nesting and foraging populations of green turtles, leatherbacks, and loggerheads, as well as smaller populations of ridleys, and hawksbills. The impact of fisheries bycatch on sea turtle populations in West Africa is suspected to be high and studies are underway in several countries to evaluate and address the impact of artisanal fisheries on sea turtles. The intentional capture of sea turtles for consumption by fishermen commonly occurs in Senegal.

Abundant marine resources off Senegal attract marine predators, and the area is a wintering ground for numerous European seabird species and a migratory corridor for others moving further into the South Atlantic. Small pelagic fish, especially sardinella, are the main food resource for seabirds wintering off West Africa and are presumably their primary motivation for visiting this area. The presence of numerous wetlands makes Senegal one of the main areas for water birds in West Africa. Senegal has five sites of international importance for water birds (Ramsar sites). These sites are the National Park of Djoudj (PNOD), the Gueumbeul Wildlife Reserve (RSFG), the Ndiaël Special Reserve (RSAN), the Saloum Delta National Park (PNDS), and the Tocc Tocc Nature Reserve. The PNOD receives nearly 3,000,000 individuals, belonging to 365 species. The Saloum Delta Biosphere Reserve is home to the third largest water bird population in West Africa (100,000–120,000 individuals with 80–95 species). More than 120,000 seabirds belonging to more than 300 species have been identified in the Saloum mangrove and 50% of the royal terns breed on the bird island in the Saloum delta (Wetland International, 2010). The PNDS is the world's largest royal tern breeding site.

Despite the Government's efforts, Senegal's marine and coastal biodiversity is under severe pressure. The major threats to biodiversity have been identified in Senegal's National Biodiversity Strategy and Action Plan (Ministry of Environment and Sustainable Development, 2014) and include natural causes (drought, water and soil degradation and salinization, wind, and water erosion) and human causes (overexploitation of biological resources, land clearing, hydroagricultural works, fragmentation and destruction of habitats, marine sand extraction, pollution and demographic, urban and industrial growth). For example, due to the construction of dams (Diama in Senegal and Manatali in Mali—for agricultural and electricity purposes), the Senegal River has lost biodiversity, with a resultant decrease in fish landings.

The insufficient in-country capacity to survey, monitor, plan, and manage coastal biodiversity constitutes a major risk for its maintenance. This concerns as follows:

– Inadequate consideration of the protection of biodiversity in the regulation of development activities
– Failure to apply and/or misapplication of the regulations concerning access to certain biological resources
– Rigid status of protected areas
– Insufficient harmonization in regulations for shared resources
– Inadequate technical, financial, and human resources
– Low level of education and training of populations
– Gaps in scientific and technical knowledge

37.5 FISHERIES RESOURCES

37.5.1 Fisheries Exploitation

Sociocultural drivers maintain the historical ties of Senegal with its fisheries, along with the role of fish in the Senegalese national dish, the Thie Bou Dien.

Senegal is located at the edge of two of the most productive fishing zones in the world, such as the Canary Current Large Marine Ecosystem and the Gulf of Guinea Large Marine Ecosystem. In the Senegalese maritime zone, four types of fishery resources are exploited, such as offshore pelagic resources, coastal pelagic resources, coastal demersal resources, and deep demersal resources. Offshore pelagic resources (tropical and small coastal tuna) and coastal pelagic resources (mainly sardinella, horse mackerel, mackerel) make up more than 70% of catches in the Senegalese exclusive economic zone, mainly through artisanal fisheries. Small pelagic fishes, such as sardinella (Sardinella aurita and Sardinella maderensis), have long been known to play a key role in the food supply for local communities and represent nearly 75% of the total quantity of fish consumed in Senegal. Coastal demersal resources (coastal shrimp, lobster, crab, sole, red mullet, grouper, sea bream, octopus) with high market value for export are exploited by industrial trawlers and artisanal fishing canoes. Finally, deep demersal resources (deep shrimp, hake) are almost exclusively caught by trawlers. Capture production was 30,000 tonnes of freshwater fish and 395,400 tonnes of marine fish in 2015. More than 304,000 tonnes of the catch were made up of small pelagic fish, of which 86% were sardinella (FAO, 2017) (Fig. 37.4). Most pelagic fish species are migratory, and hence the stocks of these fish are shared by several coastal states. The stocks of small pelagic fish exhibit high natural variations because the recruitment and migration of these species is strongly influenced by environmental variations.

Senegalese waters have suffered from years of overfishing by large, foreign commercial fishing boats and unsustainable fishing practices. All demersal stocks have declined drastically, while the small pelagic species, which now contribute to

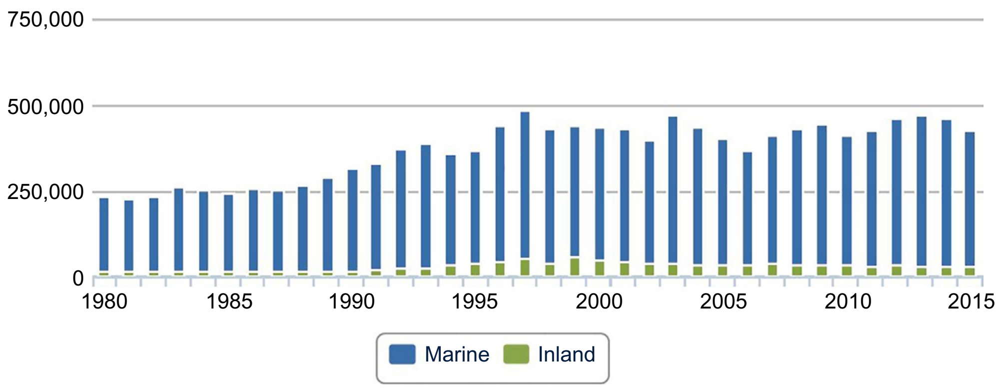

FIG. 37.4 Senegalese capture production by inland and marine waters (in tonnes). *(FAO FishStat (http://www.fao.org/fishery/facp/SEN/en).)*

the bulk of the fish consumption of the local population, are overexploited. The commercial small-scale fishing fleet rose from 13,000 boats in 2009 to 19,000 in 2015. This increase in the number of boats without proper monitoring and control combined with increasing illegal and unregulated industrial fishing activities have continued to negatively impact the country's already overexploited resources (Belhabib, Koutob, Sall, Lam, & Pauly, 2014).

The fisheries in Senegal operate under the umbrella of the Ministry of Fisheries and Maritime Economy. Fisheries resources in Senegalese waters are exploited through artisanal (maritime and continental), semi-industrial and industrial fisheries. Artisanal fishing is the predominant subsector in terms of landings: it accounts for 90% of all landings (SRFC, 2017). Traditionally, fishing in Senegal is reserved for the *wolofs* of *Guet-Ndar* (Saint-Louis), the *Lébous* of Cap-Vert and the Petite Côte, and the *Nyominkas* Sérères of Saloum.

Artisanal fishing is practiced by several fishing communities using about 20 different fishing techniques based on strategies which vary depending on biological and socioeconomic factors. The Senegalese fleet of fishing boats is by far the largest in the subregion. The most recent national survey conducted in 2015 identified 19,009 fishing units of which 90% were motorized. Some artisanal fisherman known as "migrant fishers" fish in the EEZs of neighboring countries and land their catches in Senegal.

Senegalese industrial fishing vessels can be divided into two main categories: trawlers and tuna boats. In 2015, there were 104 trawlers and 8 tuna boats. Semi-industrial fishing focuses on a single component, that is, sardine fishing. Varying between 3 and 5 units, each fleet is composed of 15- to 28 m-long seine boats with limited autonomy, which make daily trips. Industrial fishing vessels are based in Dakar's industrial port where catch is unloaded and where company offices are located.

Senegal is one of the most popular recreational and sports fishing destinations in the world. This sporting activity attracts more and more enthusiasts, especially in Casamance, one of the richest fishing areas.

37.5.2 Aquaculture

Aquaculture was introduced in the early 1980s but has shown slow growth since then. The annual production was less than 100 tonnes until 2010. Following the establishment of the National Aquaculture Agency in 2010, production increased and reached 1200 tonnes in 2015 mainly due to the expansion of tilapia farming, which was acknowledged (FAO, 2017) (Fig. 37.5). As an example, in the Mbodiène bay, some 700 tonnes of tilapia (*Sarotherodon melanotheron heudelotii*) and 60 tonnes of prawns (*Panulirus ornatus*) are produced per year.

37.5.3 Access to Fishery Resources

In Senegal, artisanal fishing units pay an annual fee to access the resources. Industrial fishing in maritime waters under Senegalese jurisdiction is subject to the possession of a valid fishing license issued by the Ministry in charge of Maritime Fishing. Fishing activities are regulated by the Ministry, which imposes restrictions on the use of certain fishing equipment and establishes where and when boats are permitted to fish. All industrial vessels registered to fish in Senegal are required to hold a fishing license and to carry a GPS tracking device allowing the government to monitor their whereabouts, that is, to ensure they do not enter the artisanal zone (a vessel monitoring system (VMS) has been in place since 2000) (ANSD, 2008).

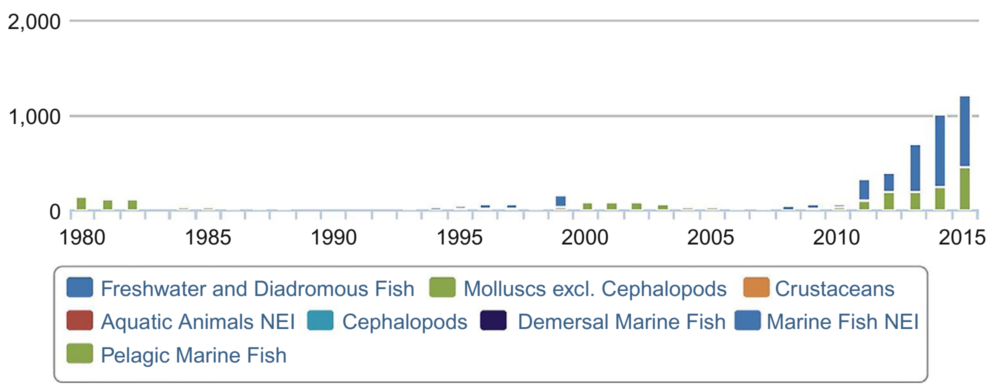

FIG. 37.5 Senegalese aquaculture production by culture environment (in tonnes). *(FAO FishStat (http://www.fao.org/fishery/facp/SEN/en).)*

A bilateral fishing agreement with Mauritania allows approximately 300 Senegalese canoes to fish in Mauritanian waters, mainly for small pelagics within a quota of 50,000 tonnes. This agreement is subject to the condition that 6% of catches are landed in Mauritania. Senegal has also signed bilateral access agreements with other countries in the subregion, in particular with Guinea-Bissau and a reciprocity agreement with Cabo Verde. The country signed a fishing agreement with the European Union (EU) in 1979 and this agreement has been renewed 17 times. In 2014, Senegal signed a fisheries partnership agreement with the EU relating to tuna and hake for a period of 5 years.

37.6 CLIMATE CHANGE

Climate change in Senegal is predicted to manifest as a decrease in the amount of rainfall, increased temperatures, and a sea-level rise (Zamudio & Terton, 2016). The economy of Senegal remains largely dependent on climate-sensitive sectors, particularly agriculture, livestock, and fisheries. The main problems facing the Senegalese coasts are linked more or less directly to climatic factors, the most important of which are flooding, coastal erosion, salinization of soils, degradation of mangroves, and changes in fishing regimes.

The mean annual temperature has increased by 0.9°C since 1960, that is, an average rate of 0.20°C per decade and is projected to increase by 1.1–3.1°C by the 2060s. As in all West African countries, Senegal's rainfall is marked by a sharp decline since the 1970s and by a great variability both intermonthly and intraseasonally. This situation has led to a water deficit and the migration of people toward the coastline and Dakar. The lack of rainfall has impacted heavily on the availability and quality of water resources and has also caused the expansion of saline soils and degradation of plant cover with the most affected component being mangrove stands (Ndour et al., 2012).

Floods have severely affected and continue to affect Senegal. The sea-level rise will lead to greater inundation of low-lying coastal areas, including those within urban centers. Senegal is ranked as the eighth most at-risk country in the world in terms of the sea-level rise. A rise in sea level by around 40 cm is projected to occur along Africa's Atlantic Ocean coastline by shortly after 2050, which could put 0.5 million people at risk of flooding in Senegal (Zamudio & Terton, 2016). Economic activities such as fishing, tourism, and agriculture may be adversely affected by the sea-level rise.

The long-term variability of marine environmental conditions along the Northwest African coast was recently reviewed by Valdés and Déniz-González (2015). Trends in open ocean temperature were analyzed using the high-resolution SST satellite that covers the whole Northwest African region. The SST for the 32 years in the period 1982–2013 showed a warming trend, with a mean increase of 0.28°C decade^{-1}. This warming may affect, as suggested by Bakun (1990), the upwelling intensity, thereby cooling the upper ocean waters. Upwelling-favorable wind intensification could benefit marine populations by increasing the nutrient supply to the euphotic layer; however, it could also have a negative impact by transporting plankton out of the shelf or disrupting trophic interactions (Valdés & Déniz-González, 2015).

In a recent study, Barton, Field, and Roy (2013) did not find evidence of intensification in upwelling-favorable winds. Moreover, they found a significant increase in SST at all latitudes in the region. Contrarily, Cropper, Hanna, and Bigg (2014), using a variety of upwelling indices for the period 1981–2010, concluded that there was compelling evidence in favor of Bakun's hypothesis, with an increase in upwelling-favorable winds north of 20°N, and an increase in downwelling-favorable winds south of 20°N. More recently, Benazzouz, Demarcq, González-Nuevo, and de Vigo (2015) found that the wind has intensified but this relative strengthening is not accompanied by a significant cooling, instead it displays a clear warming effect.

Trends in primary productivity derived from satellite Chlorophyll *a* data, a common proxy for phytoplankton biomass, from 1998 to 2014 showed that despite global warming the coastal upwelling region is relatively stable in terms of primary productivity (Demarcq & Benazzouz, 2015).

Although climate change and its consequences on the marine environment are still uncertain, some studies suggested that West African countries were among the world's most vulnerable to the impacts of climate change on marine capture fisheries (Allison et al., 2009)—a result of their exposure to predicted warming, heavy reliance on fisheries production, and low societal capacity to adapt.

37.7 HUMAN POPULATION AFFECTING THE COASTAL AND MARINE ECOSYSTEMS AND BIODIVERSITY

Senegal's coasts are affected by a number of environmental problems, including coastal erosion, coastal flooding, soil and water salinization, pollution, mangrove degradation, and a reduction in fish stocks.

37.7.1 Coastal Erosion, Coastal Flooding, Soil and Water Salinization

Coastal erosion, which results in a shrinkage of the coastline, is estimated on average at between 0.5 and 2 m per year. In the worst-affected areas, the coastline is retreating at an average rate of 2 m per year (Ndour et al., 2017). The areas most affected by coastal erosion are, from north to south, the Saint-Louis area, Mbao-Bargny, and stretches of coast between Petite Côte and Ndangane Dijiffere. Although the drivers of this phenomenon are in part of human origin (e.g., beach sand mining, coastal development), combined with natural problems (e.g., sediment deficit, slope instability, and surface runoff), their effects are expected to be exacerbated by climate change. This is one of the national priorities in addressing the effects of climate change.

Floods are a recurring phenomenon in the main cities of Senegal. They are recognized as an urban problem and occur at the low points of urban areas and during the rainy season, while in Saint-Louis estuary they are also associated with river floods.

In Senegal, soil salinization affects all regions and constitutes a major threat to irrigated agriculture. Hypersalinity occurs upstream in tidal estuaries with the salinization of groundwater in shallow aquifers up to 200 km inland. A recent study conducted by the National Institute of Pedology estimated the total land area affected by salinization at almost 1 million ha. Studies on several aquifers (Senegal River Delta system, Saloum Delta, and Casamance Delta) have revealed high sensitivities to climate variability and climate change (Gning et al., 2017).

37.7.2 Marine Pollution

The Senegalese coasts have serious environmental problems related to the densification of the population and concentration of industrial activities in the coastal cities. About 7.8 million people (60% of the total population) in Senegal representing 68% of GDP live in coastal areas (531 km) causing the release of huge quantities of solid waste. In Dakar, there are 475,000 tonnes of solid waste products per year with 13.5% being industrial waste, chemicals, and hospital waste (Cabral et al., 2015). These are liable to impact the coastal environment by producing polluting components which may enter into the human food chain (Fig. 37.6A). This phenomenon is particularly marked in the Dakar and Saint-Louis regions. Dakar, the capital city with 3.13 million inhabitants (23.2% of the Senegalese population) and more than 80% of its industries, has only one wastewater treatment plant with a flow rate of 19,200 $m^3 day^{-1}$, representing 13% of the volume of wastewater produced. Across the country, most of the domestic wastewater is drained through open channels that flow directly into the sea (Fig. 37.6B).

Other sources of pollution such as phosphate mining discharge to the northeast of Dakar, the proven reserves of the Taiba and Lam Lam phosphate deposits are 154 million tons with a high Cd content, averaging 87 $mg\,kg^{-1}$. In addition, agricultural runoff in the Niayes area where crops are grown during all seasons with use of various pesticides, contributes to marine pollution.

Recent studies have been conducted to investigate pollution along the Senegalese coast and to evaluate the level of pollutants (heavy metals, organic components) in marine waters and sediments, their spatial distribution and their accumulation in aquatic organisms.

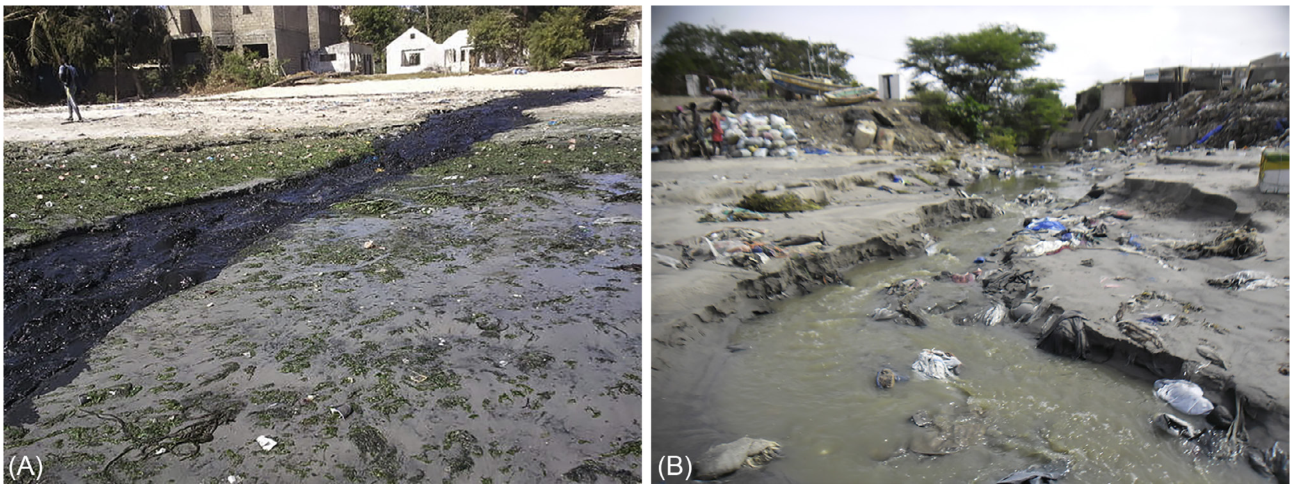

FIG. 37.6 (A) Solid waste and (B) urban wastewater directly released on the Dakar coast.

Table 37.1 shows the average concentrations of total trace metals at different sites along the Dakar coast and Saint-Louis estuary (Diop et al., 2014). High concentrations of Cd (0.27 $\mu g L^{-1}$) were observed along the Dakar coast compared with the Saint-Louis estuary (mean value of 0.11 $\mu g L^{-1}$). Phosphate mining discharge and the cement factory to the northeast of Dakar may be responsible for the high cadmium concentrations along the Dakar coast.

The coastal waters of Dakar have a higher trace metal concentration than other coasts around the world (Table 37.2) and thus constitute a higher environmental and health risk (Diop et al., 2014).

The mean values of the concentrations of trace metals (Cd, Co, Cr, Cu, Mn, Ni, Pb, and Zn) measured in surface sediment samples along the Senegalese coast are given in Table 37.3 (Diop, Dewaelé, Cazier, Diouf, & Ouddane, 2015).

In the Dakar region, the Soumbedioune, Rufisque, and Hann sites showed the highest trace metal concentrations in comparison with Camberene. This can be explained by discharges of urban wastewater in Soumbedioune and domestic and industrial wastewater in Rufisque and Hann. The low concentrations found in Camberene may be due to wastewater treatment. In general, all the metal concentrations were higher in the estuary sediments than in coastal sediments. These results are comparable to those described in the literature, that is, inland aquatic sediments are generally more polluted than coastal sediments (Biney et al., 1994). The comparison of trace metal concentrations on the Senegalese coast with those found in previous studies in other African countries shows that the concentrations of most trace metals are significantly higher than

TABLE 37.1 Average and SD ($\mu g L^{-1}$) of Three Sampling Campaigns for Each Site for the Total Metal Concentrations in Surface Water

Area	Dakar Coast				Saint-Louis Estuary			
Pollution source	Urban		Urban and Industrial		Urban and Agricultural			No Source
Location	Soumbe	Camberene	Rufisque	Hann	Laybar	Sore	Guet Ndar	Hydrobase
Total Cd	0.24 ± 0.06	0.43 ± 0.26	0.20 ± 0.14	0.22 ± 0.18	0.06 ± 0.03	0.16 ± 0.09	0.08 ± 0.04	0.13 ± 0.04
Total Co	0.30 ± 0.14	0.26 ± 0.12	0.13 ± 0.13	0.23 ± 0.12	0.24 ± 0.07	0.38 ± 0.23	0.39 ± 0.20	0.42 ± 0.19
Total Cr	4.56 ± 2.46	2.63 ± 0.41	1.42 ± 0.83	3.06 ± 1.18	2.73 ± 1.41	4.50 ± 0.56	3.47 ± 0.38	3.75 ± 1.76
Total Cu	7.29 ± 2.42	3.53 ± 1.84	2.13 ± 0.43	4.38 ± 2.49	4.86 ± 2.43	4.61 ± 1.42	3.06 ± 0.72	3.40 ± 1.66
Total Mn	11.19 ± 1.65	2.15 ± 0.86	1.17 ± 0.06	12.13 ± 5.01	6.81 ± 2.76	7.69 ± 3.01	11.13 ± 4.63	6.57 ± 3.66
Total Ni	3.06 ± 1.23	1.33 ± 0.97	1.03 ± 0.64	1.49 ± 1.05	1.44 ± 0.95	2.61 ± 1.23	2.92 ± 1.90	2.08 ± 1.23
Total Pb	1.61 ± 0.71	0.87 ± 0.54	0.47 ± 0.31	1.24 ± 0.85	0.57 ± 0.14	1.59 ± 1.49	3.87 ± 2.01	0.84 ± 0.34
Total Zn	46.74 ± 5.48	12.61 ± 9.73	15.54 ± 10.25	29.39 ± 20.99	57.01 ± 8.04	30.97 ± 7.56	26.11 ± 5.41	18.48 ± 8.28

(Data from Diop et al., 2014.)

TABLE 37.2 Comparison of Dissolved Metal Concentrations (Mean Values in $\mu g L^{-1}$) on the Dakar Coast With Those of Some Other Coasts Around the World

Area	Cd	Co	Cr	Cu	Ni	Pb	Zn	References
Dakar coast	0.23	0.12	0.45	1.93	1.28	0.48	21.29	Diop et al. (2014)
North Moroccan coast	0.06	–	–	0.04	–	–	6.05	Basraoui et al. (2010)
Congo coast	0.15	–	–	–	–	0.09	–	Mbomba, Ntumba, and Ngoy (2007)
Mediterranean coast	0.03	–	–	1.55	–	3.14	–	Rossi and Jamet (2008)
North French coast	0.04	–	–	0.61	0.32	0.08	0.72	Abbasse, Ouddane, and Fischer (2002)
Background value of natural surface seawater	0.01	–	–	0.1	–	0.015	0.01	Wu and Zeng (1983)

TABLE 37.3 Metal Concentrations (Mean 3 Sampling ± Standard Deviation) in Surface Sediments Along the Senegalese Coast ($mg\,kg^{-1}$)

	Coast				Estuary					
	Soumbe	Camberene	Rufisque	Hann	Laybar	Sore	Guet Ndar	Hydrobase	ERL	ERM
Cd	0.59 ± 0.06	0.18 ± 0.01	0.38 ± 0.07	0.33 ± 0.05	1.63 ± 0.56[a]	0.66 ± 0.16	1.35 ± 0.19[a]	0.34 ± 0.20	1.20	9.60
Co	2.80 ± 0.81	0.84 ± 0.26	2.49 ± 1.08	1.25 ± 0.28	10.58 ± 1.05	3.07 ± 1.17	7.05 ± 3.68	0.94 ± 0.47		
Cr	81.33 ± 25.55[a]	58.88 ± 19.74	62.07 ± 8.98	45.48 ± 29.43	105.69 ± 32.43[a]	64.74 ± 11.32	75.41 ± 0.97	47.83 ± 16.92	81	370
Cu	52.69 ± 6.62[a]	12.94 ± 3.79	17.67 ± 3.02	16.09 ± 7.23	121.51 ± 43.17[a]	47.61 ± 2.88[a]	82.55 ± 1.41[a]	21.85 ± 13.62	34	270
Mn	54.59 ± 27.13	7.10 ± 1.10	33.26 ± 10.79	20.62 ± 1.79	122.25 ± 33.04	53.19 ± 14.66	140.07 ± 64.17	14.94 ± 9.95		
Ni	7.79 ± 1.50	2.24 ± 2.37	3.13 ± 2.21	1.16 ± 0.49	27.65 ± 8.06[a]	8.246 ± 4.597	10.19 ± 1.42	2.62 ± 1.45	20.9	51.6
Pb	43.06 ± 53.62	2.83 ± 2.12	11.31 ± 1.68	6.63 ± 4.62	63.91 ± 22.61[a]	406.1 ± 105.2[b]	1308 ± 90[b]	26.01 ± 4.37	46.7	218
Zn	28.85 ± 7.45	7.14 ± 1.53	20.57 ± 7.57	24.09 ± 1.36	35.85 ± 9.87	32.57 ± 10.78	88.57 ± 14.43	8.98 ± 3.39	150	410

[a] *Concentrations that exceed the ERL (effects range-low).*
[b] *Concentrations that exceed the ERM (effects range-median).*

those measured in Nigeria and in the same range as those found in other African regions, such as Morocco, Ivory Coast, and South Africa (see Diop et al., 2015 for references).

The potential impacts of this pollution are an accumulation of these pollutants in aquatic resources, resulting in negative consequences for aquatic fauna and flora and for the population heavily dependent on these aquatic resources.

The concentration of trace elements and organic pollutants such as PAHs, Me-PAHs, and PCBs was measured in five marine species from different trophic levels of a food web (algae, mussel, shrimp, and fish) all representative of shallow Senegalese coastal waters (Diop et al., 2016; Diop et al., 2016; Diop & Amara, 2016). Species were sampled at five sites that differed in terms of anthropogenic pressure representative of the coastal and estuarine environments of Senegal and in both dry and wet seasons. There was no clear seasonal pattern in the concentration of elements, though intersite differences were observed with the highest concentrations of biota, which found at sites located close to areas of anthropogenic pressure such as Dakar.

The concentrations of different heavy metals (Cd, Pb, and Hg) in the edible portion of mussels, shrimps, and fish are given in Table 37.4. With the exception of Cd, element concentrations were generally of the same order of magnitude as those reported in other studies in other African countries and more generally in coastal marine areas. For most species studied, the pollutant concentrations (Cd, Pb, Hg, $\sum$PAHs, or $\sum$PCBis) were well below the European maximum level for human consumption and pose no threat to public health (Diop et al., 2017). However, at the polluted sites near Dakar (Soumbedioune and Rufisque), 50% of the mussels presented values above the limit for Cd ($1\,mg\,kg^{-1}$, ww) and 33.3% of sardinella had PAH concentrations above the guideline ($0.030\,mg.kg^{-1}$, ww) (Diop et al., 2017).

High levels of cadmium have been found in different fish species and in molluscs from West African coastal areas such as the Mauritanian waters (Sidoumou, Gnassia-Barelli, Siau, Morton, & Romeo, 2006) and the Senegalese coast (Bodin et al., 2013). The main anthropogenic source of cadmium in marine ecosystems is the phosphate industry, as cadmium is one of the trace elements highly enriched in phosphate rock. Phosphate mining (particularly to the north of Dakar) may be one of the causes of the high Cd concentrations found in marine coastal organisms (Diop, Howsam, Diop, Goossens, et al., 2016).

Due to the ever-increasing environmental pressure on the Senegalese coastal ecosystem, such as the growing phosphate mining industry, where production is expected to triple in the coming years (Senegalese Ministry of Industry and Mining, http://www.dirmingeol.sn), regular monitoring of element levels in marine biota is necessary to assess any further environmental deterioration. Such monitoring will be of major importance to resource managers and public health officials.

37.7.3 Mangrove Degradation

Mangrove forests are one of the world's richest ecosystems. The trees and shrubs which usually grow in salty waters are home to a variety of flora and fauna. Besides their important contribution to global biodiversity, mangroves provide many services such as they prevent soil from being washed away and provide nursery grounds for juvenile fish and oyster colonies. The mangrove tree also provides a stock of medicinal plants used by local populations and a significant source of income for the women who farm shellfish.

Nevertheless, due to an increase in human activities and to climate change, mangroves have been heavily degraded. A quarter of the total surface area, that is, approximately 45,000 ha, of Senegal's mangroves has already been lost since the 1970s due to cycles of droughts, as well as to the deforestation of mangroves for timber, and the blockage of waterways by road construction. This is the case of the Sine-Saloum Delta where mangroves have been reduced by 30% since 1950 (Cormier-Salem & Panfili, 2016).

37.7.4 Impacts of Fisheries

As in many other regions of the world, fisheries and overharvesting are the biggest threats to marine biodiversity. Fisheries kill seabirds by collision with towing lines or drowning on the baited hooks of long lines (Gremillet, Peron, Provost, & Lescroel, 2015). Few studies have evaluated fishing impacts on marine biodiversity. A recent study (Ndour et al., 2014) showed that fishing pressure is affecting the trophic structure and the composition of catches, off the Senegalese coast. As fishing pressure has increased over the last decade, a high impact on marine biodiversity can be expected.

37.8 MANAGEMENT REGIMES

Senegal signed and ratified the Convention on Biological Diversity in 1994 and has developed a formal framework to support, formalize, and harmonize its strategy and policy for the conservation and management of natural resources (Ministère de l'Environnement et du Développement Durable (MEDD), 2014).

TABLE 37.4 Mean ± SD Concentration (mg kg^{-1} dw) of Lead Pb, Cadmium Cd, Mercury Hg, Polycyclic Aromatic Hydrocarbons PAHs, Polychlorinated Biphenyls PCBi, and dl-PCB in the Edible Part of Some Marine Organisms

Species		Cd	Pb	Hg	PAHs	PCBi	dl-PCB
Mussels Perna perna	Min; max	0.019; 2.120	0.023; 0.842	0.004; 0.022	0.003; 0.020	0.001; 0.012	<LOQ; 0.020
	Mean ± SD	0.394 ± 0.634	0.185 ± 0.213	0.011 ± 0.006	0.008	0.006	0.017 ± 0.036
Crustaceans Penaeus kerathurus	Min; max	0.01; 0.25	<LOQ; 0.012	0.003; 0.032	0.008; 0.012	<LOQ	0
	Mean ± SD	0.03 ± 0.05	0.003 ± 0.003	0.012 ± 0.008	0.010	<LOQ	0
Round sardinella Sardinella aurita	Min; max	0.006; 0.03	0.005; 0.014	0.008; 0.032	0.008; 0.034	<LOQ	0
	Mean ± SD	0.014 ± 0.005	0.007 ± 0.002	0.015 ± 0.006	0.019	<LOQ	0
Senegalese sole Solea senegalensis	Min; max	<LOQ; 0.010	<LOQ; 0.004	0.005; 0.021	0.0002; 0.0043	<LOQ; 0.012	<LOQ; 0.004
	Mean ± SD	0.007 ± 0.003	0.004 ± 0.001	0.012 ± 0.005	0.001	0.005	0.003 ± 0.004
Flathead mullet Mugil cephalus	Min; max	NA	NA	0.002; 0.015	0.0018; 0.0032	<LOQ; 0.027	<LOQ; 0.003
	Mean ± SD	NA	NA	0.006 ± 0.004	0.003	0.006	0.00165 ± 0.0008
Tilapia *Saratherondon melanotheron*	Min; max	NA	NA	0.002; 0.064	0.0032; 0.018	0.007; 0.010	<LOQ; 0.010
	Mean ± SD	NA	NA	0.019 ± 0.014	0.010	0.0085	0.010 ± 0.017

LOQ, limits of quantification; NA, not analyzed.

Senegal produced a National Adaptation Program of Action (NAPA) in 2006, which details the country's priority adaptation responses. Coastal and marine actions include restoration of mangrove swamps, biological stabilization of sand dunes, physical protection against beach erosion and saline intrusion, water conservation methods, and improved education on adaptation. The Government of Senegal has also created a string of protected areas to preserve coastal biodiversity. These include the Djoudj National Park, the Ndiaël Nature Reserve, the Gueumbeul Nature Reserve, the Langue de Barbarie National Park, the Îles de la Madeleine National Park, the Popenguine Nature Reserve, the Saloum Delta National Park, the Kalissaye Bird Reserve, and the Basse Casamance National Park. Three of these areas are Ramsar sites (Djoudj, Ndiaël, and Saloum). Moreover, the Saloum Delta National Park is also a Biosphere Reserve.

Marine protected areas (MPAs) are one of the sustainable management strategies for marine environments and their biodiversity. The Decree No. 2004–1408 establishes five new MPAs which cover a total area of 198,920 ha, or 1% of the Senegalese maritime area such as Saint-Louis, Bamboung, Joal-Fadiouth, Kayar, and Abéné (see Fig. 37.7, Table 37.5). The creation of these MPAs was mainly driven by nonprofit organizations such as Oceanium and WWF and by the international context through the World Summit on Sustainable Development, the World Congress on National Parks, and the World Congress on Marine Protected Areas. In 2012, by Decree 2012-543, the Senegalese authorities created the Community Marine Protection Area Department (DAMCP) whose mission is to implement the State's policy on the creation and management of a coherent network of MPAs according to international standards.

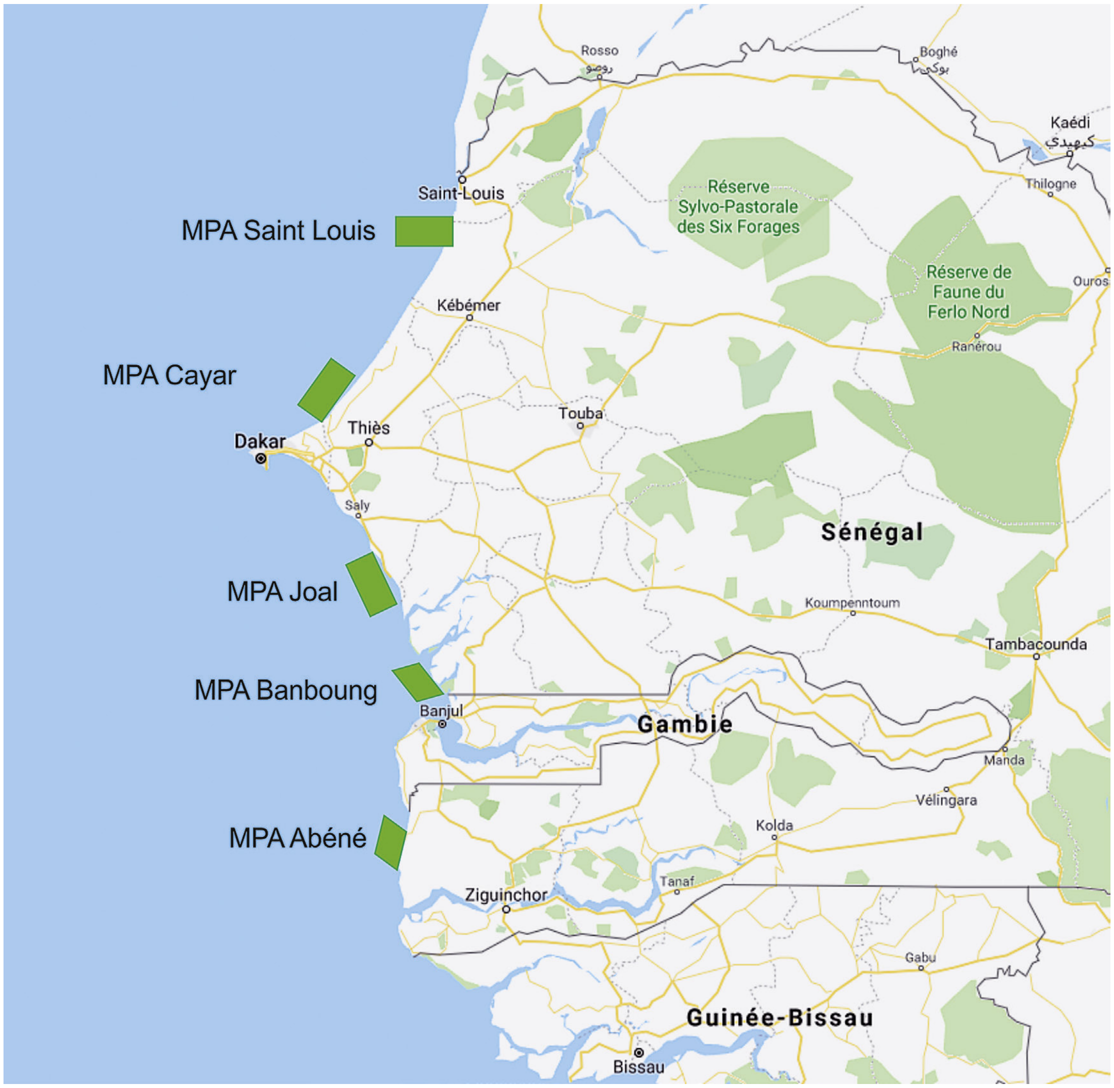

FIG. 37.7 Marine-protected areas (MPAs) in Senegal.

TABLE 37.5 Overview of the Senegalese Marine-Protected Areas Network

MPAs	Surface Area	Interest From Biodiversity Perspective
Saint-Louis Marine-Protected Area, created in 2004	49,600 ha	Repopulate the seabeds alongside one of the country's main fishing grounds and to keep foreign trawlers away. Sustainable protection and conservation of fisheries
Cayar Marine-Protected Area, created in 2004	17,100 ha	Protection of sites of special interest for maintaining and renewing fishery stocks. Most of the emblematic and endangered species noted in the Senegalese waters are present in this area
Joal Fadiouth Marine-Protected Area, created in 2004	17,400 ha	Spawning ground and reproduction site for sea turtles
Bamboung Community-Managed Marine Protected Area, created in 2004	7000 ha	Mainly composed of mangroves and bolongs, which are places of reproduction, growth, and refuge for coastal and marine species
Abéné Marine-Protected Area, created in 2004	11,900 ha	Home to several species, notably sea turtles, dolphins, manatees and several fish, and bird species. Sustainable protection and conservation of fisheries

(RAMPAO—Réseau Régional d'Aires Marines Protégées en Afrique de l'ouest—website: http://www.rampao.org.)

Other initiatives for the creation of MPAs are underway. These include Gandoul, Sangomar, and Laga in the Fatick region and Loumpoul in the Louga region. In 2013, a national strategy for Senegalese MPAs has been developed (Ministère de l'Environnement et du Développement Durable (MEDD), 2013).

Senegal has some 185,000 ha of mangrove estuaries in the regions of Casamance and Sine-Saloum, but they are disappearing at an alarming rate. The UN estimates that Senegal has lost about 40% of its mangrove forests since the 1970s. The first reforestation actions started in Senegal in the 1980s because local communities were very sensitive to mangrove degradation in some areas (Cormier Salem, 1992).

Since the 2000s, a more favorable rainfall regime together with better governance and large-scale reforestation campaigns, such as Oceanium which has expanded mangrove forest areas in certain regions, were conducted by the government and nonprofit associations. Between 2006 and 2013, 14,000 ha of mangrove forest were replanted (10% in the Saloum Delta and 90% in Lower Casamance) (Cormier-Salem & Panfili, 2016) (Fig. 37.8). With 79 million mangroves already replanted, it is the world's largest mangrove reforestation project. While natural mangrove forests are usually made up of several different species adapted to varying levels of salinity, rainfall, and tidal movement, the man-made forests include just one species, chosen for its ease of planting.

The Sine-Saloum Delta lies in the heart of Senegal and was designated in 2011 as a UNESCO World Heritage Site.

To reduce human and industrial pressure on the Senegalese coast, government authorities have established standards and regulations (environmental code, sanitation code, Senegalese standard on wastewater) but their application is a problem particularly for industrial discharges. Indeed, the laboratories do not have the technical and analytical capacity to control these discharges, which are not generally treated. Over long periods, the absence of investment to build new wastewater treatment plants, the lack of laboratory equipment and discharge control authorities, noncompliance with environmental standards by industry, increasing urbanization linked to a massive rural exodus have all been factors that have contributed to chemical pollution of the coastal environment in Senegal.

Since 1998, fishing has been regulated by a Maritime Fishing Code, which establishes the criteria for access to fisheries resources by Senegalese operators. The main new features of the Code are the creation of consultation bodies, the introduction of a biological rest period (1 month during November), and the possibility of terminating exploitation of an endangered species.

Senegal has recently adopted a series of national strategy documents that acknowledge the key role of fisheries for poverty reduction and economic growth (e.g., "Document de stratégie pour la réduction de la pauvreté" and "Stratégie nationale de Croissance Accélerée") and emphasize the need to promote the sustainable use of fisheries resources (Ferraro, Brans, Dème, & Failler, 2011). Given the extent of illegal fishing and uncontrolled industrial fishing activities, there is also an urgent need in Senegal to enhance the enforcement of fishery laws and regulations. Thanks to the new Maritime Code of 2015, the regulations to combat illegal fishing have been strengthened and a marine environment protection process has been affirmed by the Senegalese authorities. The open access regime to artisanal fisheries has contributed to the depletion of marine resources and the increase of fish prices. The overexploited fish stocks have pushed Senegalese fishermen to

FIG. 37.8 Mangrove forest replantating in the Casamance *(Photo courtesy Naziha Mestaoui).*

extend their navigation range, and therefore fish further offshore, often in the neighboring countries of Guinea-Bissau and Mauritania (World Bank, 2017). Senegal recently launched a campaign to emboss or place identification plates on 19,009 registered artisanal boats. This allows the overall capacity of the artisanal fleet to be monitored and is a first step toward a better governance of the fisheries sector.

Decreases in mean trophic level, the biomass of high trophic level species and indices of species diversity between 1990 and 2009 were observed in the artisanal commercial fisheries catches (Ndour et al., 2014). These decreases were then related to changes in fishing pressure, fishing strategy, and the combined effects of fishing and environmental factors. A better integration of artisanal fisheries pressure on the degradation of fishery resources is an important consideration for fisheries management.

Conflicts between artisanal and industrial fishermen occur in response to changes in marine resource abundance and management. Unfortunately, however, formal systems in place to mediate at-sea conflicts are ineffective and seldom used by artisanal fishermen (DuBois & Zografos, 2012).

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