Coastal Ecosystems of West-Africa
Biological Diversity-Resources-Conservation
(Edited by J.-J. Symoens)
Brussels (2005)
pp. 195-210

Les écosystèmes côtiers de l'Afrique de l'Ouest
Diversité biologique-Ressources-Conservation
(Edit. : J.-J. Symoens)
Bruxelles (2005)
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The restoration of the Lower Delta of the Senegal River, Mauritania (1993-2004)

La restauration du bas-delta du fleuve Sénégal, Mauritanie (1994-2003)

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Key words. — Dawling National Park ; Delta ; Flamingoes ; Floodplain ; Langue de Barbarie ; Mauritania ; Restoration ; Senegal River ; West Africa.

Mots-clés. — Afrique de l'Ouest ; Delta ; Flamants ; Fleuve Sénégal ; Langue de Barbarie ; Mauritanie ; Parc National du Dawling ; Plaine inondable ; Restauration ; West Africa.

Abstract. — The ecological functioning of the Senegal River estuary and Lower Delta was negatively affected by the construction of the Diama dam in 1986. As from 1994, managed flood releases were used to rehabilitate part of the floodplain and to create an artificial estuary. By simulating the pre-dam hydrodynamics, ecosystem functions were restored. This allowed the local inhabitants to resume their traditional livelihood activities and had positive impacts on biodiversity. The rapid flood recession, which characterised the pre-dam hydrodynamics, has been the most difficult aspect to emulate, for three main reasons : opposition from the fisherfolk who want to keep the fish in their basins, park managers who want to extend the season for waterbirds and the difficulty of evacuating water at flood recession because of the filling in of waterways by

wind-blown deposits. Still, the results of the restoration effort have been encouraging, both socio-economically and ecologically. Two new major challenges require a revision of the management plan and an expansion of its geographical extent. Firstly, to alleviate flooding of the city of Saint-Louis, a 4 m wide trench was dug through the coastal dune in October 2003. The gap expanded very quickly to a width of some 900 m. This intervention has profoundly affected the hydrodynamics downstream of the dam through a strongly increased tidal influence, a stabilisation of salinity fluctuations in the estuary and a reduced propensity for flooding. The new water management upstream of the dam means less water is available for the managed flood releases in August and September. Secondly, a vast area of sebkha north of the delta has been flooded, which has attracted huge numbers of waterbirds. There has been successful breeding of Greater Flamingo *Phoenicopterus ruber*, probable breeding of Lesser Flamingo *Phoeniconaias minor* and attempted breeding by White Pelican *Pelecanus onocrotalus*. Moreover, the protected areas of the Mauritanian and Senegalese delta will soon be integrated into a transboundary biosphere reserve, requiring more intensive coordination of the management on both sides of the border. This also creates an opportunity for stronger leverage on the dam management authority, so far mainly concerned by upstream irrigated agriculture, for appropriate flood releases from Diama to support local livelihoods and biodiversity.

RÉSUMÉ. — Le fonctionnement écologique de l'estuaire du fleuve Sénégal et de son bas-delta a été affecté défavorablement par la construction en 1986 du barrage de Diama. Depuis 1994, les gestionnaires ont exécuté des relâchements d'eau pour restaurer la plaine inondable et créer un estuaire artificiel. Par simulation de l'hydrodynamique antérieure au barrage, les fonctions de l'écosystème ont été rétablies. Ceci a permis aux habitants de la région de reprendre leurs activités de subsistance traditionnelles et a eu des impacts positifs sur la biodiversité. Le retrait rapide l'inondation qui caractérisait l'hydrodynamique antérieure au barrage a été le trait le plus difficile à imiter pour trois raisons principales : opposition des populations de pêcheurs qui veulent garder les poissons dans leur bassin, gestionnaires de réserves qui veulent allonger la saison des oiseaux d'eau et difficulté d'évacuer l'eau au moment du retrait de l'inondation en raison de l'obstruction des chenaux par des dépôts amenés par le vent. Néanmoins, les résultats des efforts de restauration ont été encourageants, à la fois du point de vue socio-économique et écologique. Deux nouveaux défis nécessitent une révision du plan de gestion et une expansion de sa couverture géographique. Premièrement, en vue de modérer l'inondation de la ville de Saint-Louis, une tranchée de 4 mètres de large a été creusée en octobre 2003 au travers de la dune côtière. La brèche s'est élargie très rapidement pour atteindre une largeur d'environ 900 m. Cette intervention a profondément affecté l'hydrodynamique à l'aval du barrage par une influence fortement accrue des marées, une stabilisation des fluctuations de la salinité dans l'estuaire et une tendance réduite des inondations. La nouvelle gestion à l'amont du barrage implique une

moindre disponibilité d'eau pour les lâchers organisés en août et septembre. En second lieu, une vaste surface de sebkha au nord du delta s'est trouvée inondée, ce qui a attiré un nombre immenses d'oiseaux d'eau. Il y a eu ainsi une reproduction réussie du Grand Flamant *Phoenicopterus ruber*, une reproduction probable du Petit Flamant *Phoeniconaias minor* et une tentative de nichée du Pélican Blanc *Pelecanus onocrotalus*. En outre, les aires protégées du delta, tant en Mauritanie qu'au Sénégal, seront prochainement intégrées dans une réserve de biosphère transfrontalière, ce qui nécessitera une coordination accrue de a gestion des deux côtés de la frontièe. Ceci fournit aussi l'occasion d'une influence accrue sur l'autorité de gestion du barrage, jusqu'ici principalement concernée par l'agriculture irriguée à l'amont, en vue de lâchers d'eau de Diama adéquats pour assurer les moyens de subsistance des populations et la biodiversité.

Introduction

In an attempt to reduce dependency of agriculture on rainfall and highly variable flooding, the Organisation pour la Mise en Valeur du Fleuve Sénégal (OMVS) founded by Mali, Senegal and Mauritania, constructed two large dams in the Senegal River basin in the 1980s (Fig. 1) : a hydropower dam at Manantali in Mali and a salt wedge dam at Diama close to the river mouth. The OMVS has 3 main objectives : the development of irrigated agriculture on 375,000 ha of the valley's floodplains, the production of hydropower and the improvement of river navigability.

In the Middle Valley and the Upper Delta, in spite of huge investments (1500 to 6500 $US per ha), the conversion to irrigated agriculture lags behind expectations and, of the 120,000 ha equipped in 20 years, only about 60 % is cultivated annually while the potential is 200 % if all land would, as planned, be under double cropping (Fraval *et al.* 2003). The unfavourable economics of irrigated rice are leading to increasing impoverishment of small-scale farmers in the valley (Koopman 2004), though the World Bank seems to have a contrary view (Alam & Dione 2004). The second sectoral objective of OMVS is to produce hydropower for the capital cities of the three member countries and, with 200 MW installed, this has been achieved in 2003. Theoretically, OMVS has the opportunity to practise managed flood releases from Manantali to allow profitable recession agriculture (Fraval *et al.* 2003), irrigation and hydropower production to coexist (Bader *et al.* 2004) but managed flood releases from Manantali are increasingly perceived as a water use in competition with the hydropower production. The third sectoral objective of OMVS, facilitation of river transport, is unlikely to become economically viable any time soon.

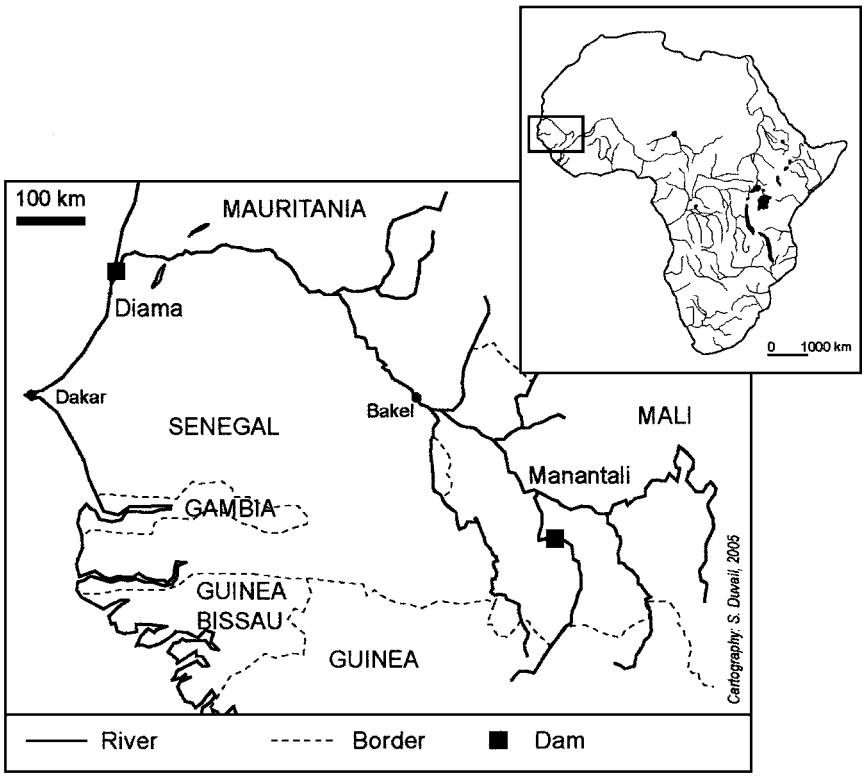

Fig. 1. — Map of the Senegal River Basin with the location of the two dams Diama (near the river mouth) and Manantali (in Mali on the main tributary coming from Guinea). Inset map of Africa with the study area.

In the Lower Delta, the highly saline soils precluded the development of irrigated agriculture and an alternative land use, favouring conservation, was proposed as the most economically effective (GANNETT FLEMING *et al.* 1980). Though this view was controversial, the creation of a protected area, partly as a compensatory measure for the biodiversity loss caused by the impact of the dams, was finally achieved in 1991 with the establishment of the Diawling National Park on 16,000 ha of the Mauritanian lower delta. In contrast to the majority of protected areas in Africa, which in those days still favoured exclusion of extractive human activities, the Diawling National Park (DNP) explicitly stated as its aims :

To preserve and ensure the sustainable use of the natural resources of a part of the lower Senegal delta ecosystem ;

To promote the continuous and harmonious development of the range of activities of the local population ;

To coordinate pastoral and fishing activities within its boundaries.

In the early 1990s most of the Mauritanian lower delta, deprived of flooding by the construction of the Diama dam, had basically turned into a saline desert (HAMERLYNCK & DUVAIL 2003). The former estuarine area was also greatly reduced by the construction of the dam. In the dry season, hypersaline conditions downstream of the dam had highly destructive effects on the natural vegetation (*Avicennia germinans* mangrove and *Sporobolus robustus* grasses). Between 1994 and 1996, embankments and sluicegates were constructed in order to simulate the pre-dam hydrodynamics on the former floodplain and to create an artificial estuary in the Ntiallakh basin. Through a participatory approach, the water requirements of different local user groups (fisherfolk, livestock keepers, gatherers), and of the DNP authority were analysed, modelled and reconciled with the imperatives of the dam management organisation OMVS. A number of flood scenarios, optimising productivity were proposed, discussed, tested and formalised in a management plan approved by all stakeholders and government institutions in 1997 (MDRE PND 1997). The effect of the managed flood releases on various components of the ecosystem was quantified and the flood scenario improved through an iterative consultative process (DUVAIL & HAMERLYNCK 2003). In practice, the application of the original management plan required considerable flexibility because of external constraints such as climatic events, damage and repairs to infrastructure, invasive aquatic plants, etc.

A recent economic evaluation has shown that the restored area produces about 65 $US of added value per ha per year, of which over 80 % is contributed directly by the extractive activities of the local communities. By stemming the rural urban drift of young men this economic revival has also contributed to an improved social equilibrium (MOULAYE ZEIN 2004).

The management plan for the Lower Delta, initially written for the period 1997-2000, needs to be revised for three main reasons :

Firstly, the Mauritanian lower delta is to become a biosphere reserve, which will incorporate the Diawling National Park and the Chat Tboul reserve, a neighbouring protected area and Ramsar site (MEASSON 2001). The management plan will therefore need extended geographical coverage. A similar biosphere reserve will be created in Senegal, which will incorporate the Djoudj National Park, the Langue de Barbarie National Park, the Guembeul and Ndiaël nature reserves (Fig. 2). Both national

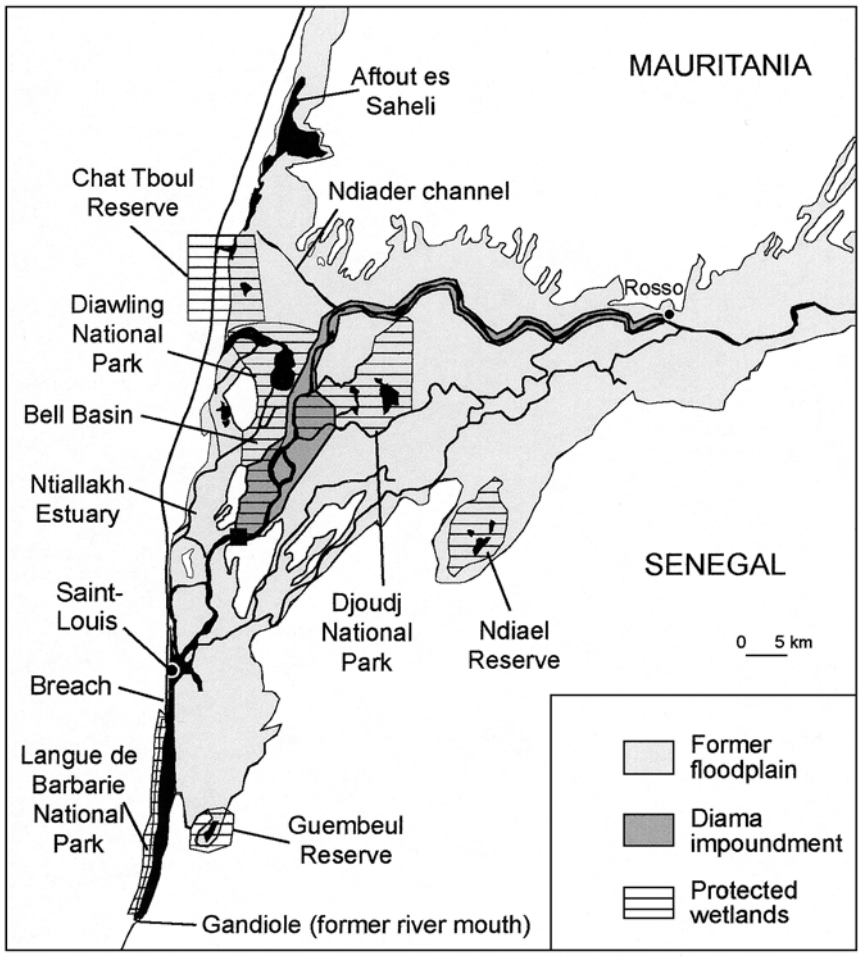

Fig. 2. — Protected areas in the Lower Delta of the Senegal River, the new breach 6 km to the South of the town of Saint-Louis and the former river mouth at Gandiole.

biosphere reserves will then be integrated into a large transboundary biosphere reserve.

Secondly, the creation of a breach in the coastal dune, some 6 km south of the city of Saint-Louis, has profoundly affected the hydrodynamics both upstream and downstream of the Diama dam and the impacts of these changes need to be taken into account in the new management plan.

Thirdly, after some intermittent and limited flooding through the

Diawling National Park in the late 1990s (HAMERLYNCK & MESSAOUD 2000), the southern part of the sebkha of the Aftout es Saheli has been permanently flooded since 2003. The Ndiader channel, an old connection with the Senegal River, was dredged to improve water supply to irrigated agriculture areas. With the breach in the Langue de Barbarie, OMVS has difficulties to discharge large amounts of water through the Diama dam, because the increased energy of releases at low tide may destabilise the dam. When OMVS needs to release water it therefore prefers filling the Aftout. This has attracted very significant concentrations of migratory and breeding waterfowl, which justify its integration into the new transboundary biosphere reserve.

Materials and methods

Between 1994 and 2004, data have been collected, at various levels of detail and continuity, on water level, water quality, vegetation structure and productivity, presence of livestock, gathering of *Sporobolus* grasses and artisanal production, fish production, abundance and distribution of waterbirds. Most of these results up to 2000 were summarised in HAMERLYNCK & DUVAIL (2003). The international waterbird counts of mid-January from 2000 to 2003 have been summarised by DODMAN & DIAGANA (2003) and the more recent counts by the Diawling National Park (PND 2003, PND 2004). In December 2004, an aerial survey allowed to evaluate the presence of flooded areas and concentrations of waterbirds, which were then counted in detail in January 2005 (BENMERGUI 2005).

Water level data in the basins of the DNP were collected systematically from 1994 to 2000. This monitoring was resumed in 2002. Only the recent 2002-2004 data set is presented here and only for the Bell basin as the local communities predominantly exert their livelihood activities there. The basin's hydrogram is compared to the recommended hydrogram of the management plan as adapted after 1999 : no dry season release to lower salinity in the estuary and with a flood peak at 1.4 m Above mean Sea Level (ASL).

Water level data are collected systematically by OMVS at the Diama dam at least once a day (usually at 07 :30 a.m.). By monthly compiling the maximum and minimum water levels downstream of the dam between November 1st of year *n* and May 31st of year *n + 1* (to avoid interference from flood releases from Diama during the wet season), tidal amplitude was compared between the pre-breach (19 monthly amplitudes between January 2001 and May 2003) and the post-breach situation

(8 monthly amplitudes between November 2003 and December 2004). Averages and 95 % confidence were calculated for both data sets.

On 6 and 7 December 2004, the conductivity of surface water was measured downstream of the Diama dam on the low and the early incoming tide at several locations during transects by boat and positions were noted using a Garmin Etrex GPS. All coordinates are in WGS84, degrees, minutes, hundreds of minutes.

Results

In December 2004, the aerial survey showed extensive flooding of the Aftout es Saheli and the Chat Tboul, estimated at 7000 ha. Subsequent groundtruthing confirmed that freshwater was flowing from the Ndiader basin into the Aftout es Saheli. The conductivity measured at the Chat Tboul (3.9 mS/cm) was low in comparison to data from 1997 and 1998 (17/12/1997 44.8 mS/cm, 02/12/1998 14.6 mS/cm) and was decreasing (2.53 mS/cm) in the northern branch, connected to the inflow from the Ndiader basin.

There were an estimated 30,500 flamingos present in the Aftout, of which approximately 10,500 were Lesser Flamingo *Phoeniconaias minor* of which a high proportion were juveniles and the rest were Greater Flamingo *Phoenicopterus ruber*. At the western edge of the Aftout, a breeding colony of Greater Flamingo *Phoenicopterus ruber* was found on a small island (a few hectares at most) at approximately 16°41.78 N, 16°23.16 W. The number of nests could not be ascertained, as the colony was in activity and disturbance had to be avoided, but it is likely to be several hundred. Further north at 16°44.45 there were 180 nests of White-breasted Cormorant *Phalacrocorax carbo lucidus* in a flooded grove of *Tamarix senegalensis* and, on a large island (approximately 25 ha) at the same latitude, an abandoned colony of White Pelican *Pelecanus onocrotalus* with 1900 eggs in approximately 800 nests.

According to local stakeholders, there is a tendency in the Bell basin of the DNP for the preferred *Sporobolus robustus* to be replaced by sedges (mainly *Bolboschoenus maritimus*), which are of much less economic value. When comparing the flood hydrogram 2002-2004 in the Bell basin with the management plan hydrogram (Fig. 3), it is clear that, in each of the 3 flood seasons monitored, the flood recession is delayed. More importantly, the duration of the flooding of the areas above 1.10 m ASL has been 78 days during the 2002 flood, 107 days during the 2003

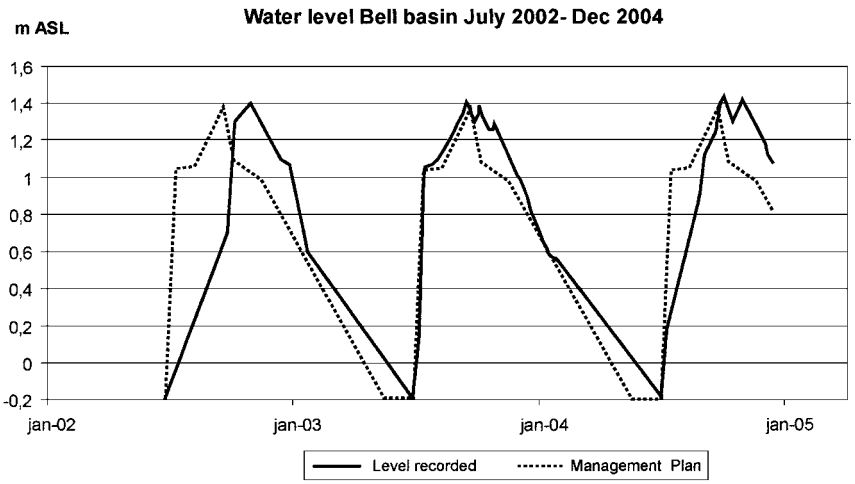

Fig. — 3. Comparison of the water level recorded in the Bell basin and the water level as recommended by the management plan between July 2002 and December 2004.

flood and 102 days during the 2004 flood while *Sporobolus robustus* prefers less than 45 days of flooding (DUVAIL 2001).

Conductivity data downstream of the Diama dam on 6 and 7 December 2004 are shown in Fig. 4. The conductivity tends to be higher in the main riverbed and lower in the shallow side branches to the west of the island of Mboyo and in the marigot de Boytet.

The lowest low water measured downstream of the Diama dam in the pre-dam situation (data from January 1995 to October 2003) was -0.41 m ASL. After the breach, the lowest level recorded so far is -0.81 m ASL. Mean monthly dry season (November to May) tidal amplitude before the creation of the breach was 0.41 m (n = 19, the 95 % confidence interval is 0.37-0.45 m). After the creation of the breach in October 2003 it increased by 0.74 m to 1.16 m (n = 8, the 95 % confidence interval is 1.01-1.30 m).

Under the hypothesis that, in an average year, the area influenced by the managed flood releases by the Park covers some 50,000 ha, the infrastructure investment costs were about 35 $US per ha. The total investment conceded between 1993 and 2004 (including staff, equipment, research, community development programmes and infrastructure) by the different donors is about 4.4 million US$, just under 100 $US per ha (Table 1).

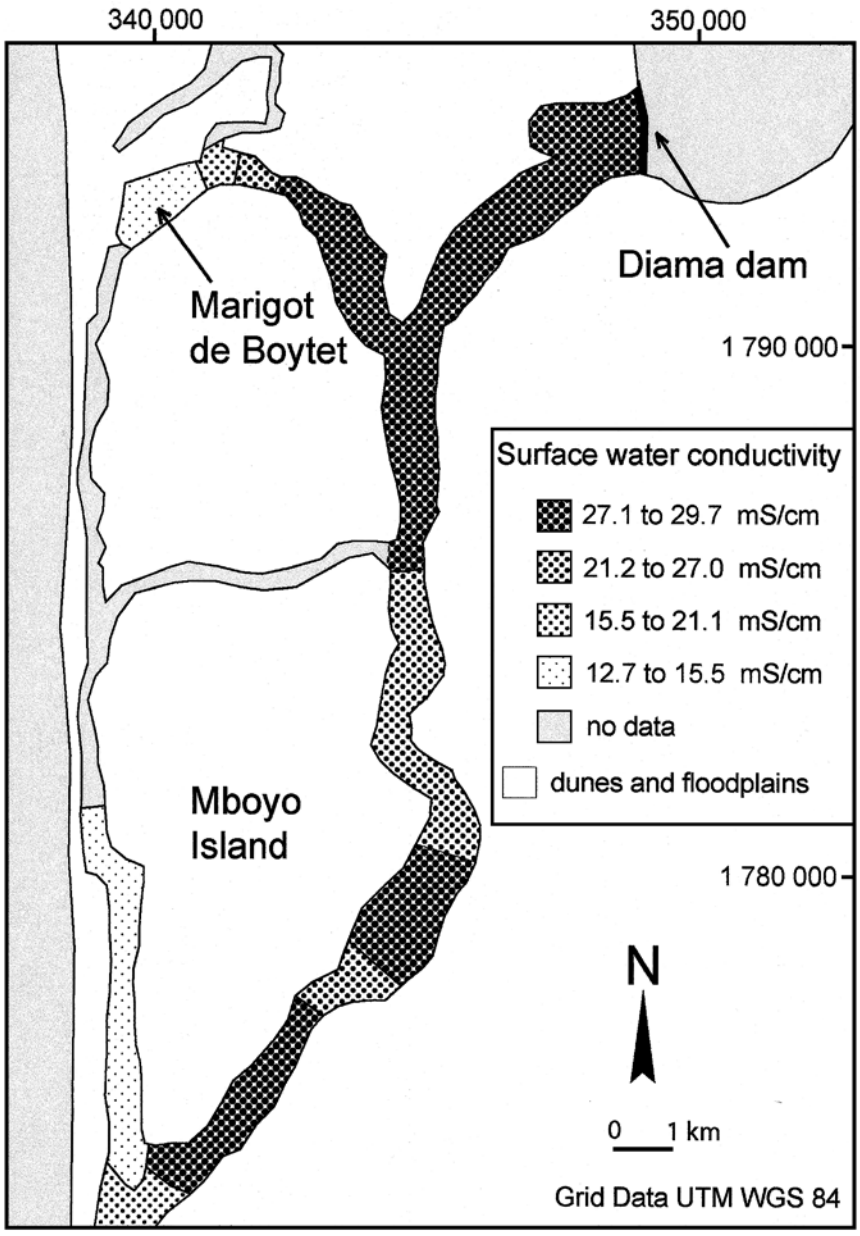

Fig. 4. — Surface water conductivity recorded downstream of the Diama dam on 6 and 7 December 2004.

Table 1

Cost of the various phases of the restoration project (1993-2004)

Cost of restoration		US$
Phase 1	1993	175,000
Phase 2	1994-1996	1,790,000
Phase 3	1997-1999	120,000
Phase 4	2000-2004	2,605,000
Total	1990-2004	4,690,000

Discussion

One of the main threats to the Diama dam is strong turbulence at its downstream side, which can scour the riverbed and eventually cause the dam, which has no solid foundations, to topple over under the hydrostatic pressure of the reservoir. The safety limit for releases from the dam is 1000 metres per second (cumecs) per meter of water level difference. Before the breach, the water level in the reservoir was kept at 1.50 m ASL during the wet season in order to reduce pumping costs for irrigated agriculture (mainly practised from July to October). At that level, in the post breach situation with the lowest low tides at -0.6 to -0.8 m ASL, that implies a 2.1 to 2.3 m water level difference, allowing the dam to safely release only a few hundred cumecs at most. This is largely insufficient to evacuate the annual peak flows of 1500 to 2000 cumecs that usually reaches the delta in September or October.

The new strategy of the dam operators is to lower the upstream level to around 1.10 m ASL in July and to release surplus water into the Aftout es Saheli instead of through Diama. The natural flood and the releases from Manantali are then used, at the end of the wet season in October, to raise the level in the Diama reservoir back to its dry season average of 2.25 m ASL. At present, the flood releases into the Aftout have no other objective than to secure the Diama dam but have had a tremendously positive impact on waterbirds.

The prolonged flooding of the *Sporobolus robustus* fields above 1.10 m ASL has led to their progressive replacement by sedges, entailing loss of income for the local communities. To maintain ecosystem structure and function would seem important that local stakeholders and DNP management agree on a rapid recession after the flood peak. A revised flood hydrogram has been proposed that would keep the water level below

1.10 m ASL until early September, reaches the flood peak of 1.40 m ASL mid October, followed by a rapid flood recession to 1.20 m ASL at the end of October and 0.9 m ASL at the end of November.

In the Ntiallakh estuary, the impacts of the breach are double sided. On the one hand, the increased tidal amplitude and the increased stratification of the estuary, as indicated by the lower conductivities in the shallow side branches, would seem to be favourable conditions for the expansion and the productivity of the mangroves and the intertidal mudflats. On the other hand, the improved outflow to the ocean and the small releases by Diama reduce the chances for beneficial flooding of the 1.2 m to 1.4 m ASL floodplain. For the local livelihoods the results are therefore mostly negative : no flooding means no groundwater recharge and therefore progressively more saline wells, problems with drinking water supply and reduced opportunities for market gardening. Also, the productivity of the *Sporobolus* and *Echinochloa* grasses in the Ntiallakh basin can be expected to decline strongly, the species appearing perhaps only in years of exceptionally high rainfall. Fisheries productivity can also be expected to decline.

To mitigate these negative impacts the Diawling National Park could, during the wet season, increase its managed flood releases into the Ntiallakh estuary. From the Bell basin these could be increased by dredging the outflow channel connecting the basin to the main channel of the Ntiallakh. Additional flows could be released from the Diawling basin through the Lekser sluice gate. These could be increased substantially by adding a sluicegate at Mohad to control the outflows to the Chat Tboul and Aftout, which are currently receiving sufficient fresh water directly from the Senegal River through the Ndiader basin. Possibly, by appropriately timing these releases from the basins of the Diawling National Park to coincide with high tidal amplitudes and with releases from Diama, flooding could be achieved to some extent in the lower lying parts of the Ntiallakh basin.

As was already proposed by DUVAIL *et al.* (2002), during the dry season the Diama dam should release sufficient amounts of water to compensate for evaporation losses and thus keep salinity within viable limits for the mangrove and other ecosystem components.

Still, the new strategy of OMVS to practise managed flood releases to the southern depressions of the Aftout es Saheli instead of through Diama can be expected to alter the equilibrium between the various forces tending to open or close the breach in the Langue de Barbarie. Effectively, a series of ‘fossil’ river mouths exists for the Senegal River (DUVAIL 2001)

depending on the equilibrium between the river floods and the longshore current (OULD ELMOUSTAPHA 2000). The Chat Tboul, navigable still in the late 18th century, extends the East-West axis of the main river valley and, before human intervention, presumably constituted the outflow to the ocean during series of successively strong floods. A few more fossil outflow channels exist further south. When floods exert less force, the North-South longshore drift tends to fill in these mouths and the main branch tends to shift southward. The present artificial mouth, situated just south of Saint-Louis Island is probably rather close to its position at the time of the foundation of the city in the 17th century. With decreasing river flows, the mouth gradually moved southward some 30 km to Gandiole. It can therefore be expected that the artificially created breach will progressively become more shallow and migrate southwards again, inversing the current trends. However, predicting the rate at which this will occur will requiring monitoring and modelling of the morphology of the breach.

Conclusion

The total cost of the restoration effort of the lower delta over the 12 years under consideration is about 100 $US per ha while the annually produced added value is about 65 $US. The restoration therefore seems to be economically viable if mechanisms can be put in place which will ensure maintenance costs can be funded internally.

The management plan for the Diawling National Park needs to be adapted to the new situation created by the breach in the Langue de Barbarie. Especially, a much higher emphasis should be put on flood releases towards the Ntiallakh estuary, preferably in conjunction with releases from Diama and during spring tides, to achieve maximal flooding at optimal salinities. Dredging of the connecting channel between the Bell basin and the Ntiallakh and the construction of an additional sluicegate at Mohad in order to regulate the outflow from the Diawling basin to the Chat Tboul and the Aftout could greatly enhance the managed flood releases towards the artificial estuary. Within the framework of the transboundary biosphere reserve, the area downstream of the Diama dam could benefit from managed flood releases targeted at improving local livelihoods and biodiversity values.

The large number of wintering waterbirds, the breeding of Greater and very probably Lesser Flamingo, the breeding attempt by several hundred pairs of White Pelican show convincingly that the flooded southern part of the Aftout es Saheli should be designated as a wetland of International

Importance and integrated into the planned transboundary biosphere reserve of the Senegal River Delta. There is a lack of data on the hydrogram of the current releases into the Ndiader basin and the resulting water levels and quality in the Aftout. It is likely that the timing and magnitude of these releases could be optimised for biodiversity and for fisheries productivity.

Acknowledgements

The authors wish to thank the Director of the Diawling National Park Dr. Bah ould Moctar Sidi and his staff for the facilitation of the field work, especially warden Moctar ould Dada and technical staff Ba Amadou, Traoré Fousseynou and Ahmed ould Chorfa. We would also like to thank Col. Cheikh ould Ahmed, Director of the Navy for access to the Chat Tboul reserve and information on the presence of waterbirds in the Aftout. The continuing financial support of the Royal Netherlands Embassy, through IUCN, the World Conservation Union and of the French Fonds pour l'Environnement Mondial to the protected areas of the Lower Delta is highly appreciated.

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