7 GONAKIER FORESTS OF SENEGAL RIVER FLOODPLAIN, SENEGAL AND MAURITANIA

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CLASSIFICATION

National: Acacia nilotica (Gonakier) forest was recognised as a distinctive vegetation type (Unit F4) by Stancioff et al. (1985) and is recognised in subsequent biodiversity surveys (CSE 2005). It is an important component within the Senegal River valley (Vallee du Fleuve Senegal) ecoregion (Tappan et al. 2004), which also includes shrub steppes and wetlands.
IUCN Habitats Classification Scheme (Version 3.0): 1. Forests / 1.5 Subtropical/Tropical Dry Forest.

ECOSYSTEM DESCRIPTION

Characteristic native biota

This unique forest ecosystem is dominated by *Acacia nilotica* (Gonakier) with *A. raddiana* and *A. seyal* (Fig. A.1). Other woody species are uncommon but include *Acacia albida, Adenololobus rufescens* (syn. *Piliostigma rufescens*), *Balanites aegyptiaca*, *Mitragyna inermis* and *Ziziphus mauritiana*. The understorey is generally sparse and grassy, with *Chloris plieurii, Dactyloctenium aegyptium* and forbs *Alysicarpus ovalifolius* and *Zornia glochidiata* (Stancioff et al. 1985). Gaps, created naturally or anthropogenically, are colonised by *Panicum anabatistum, Borreia verticellata* and *Vetiveria nigritana* (Stancioff et al. 1985). Due to regular inundation, the forest provides critical habitat for fish and migrating birds (Tappan et al. 2004). The diversit y of woody species is comparatively low and the groundlayer flora is sparse and poorly documented (Fig. A.1). However, the structure, fluvial function and composition of the ecosystem is unique in the region and contrasts markedly with surrounding steppe and bare-earth ecosystems within the Senegal River valley ecoregion. Although *A. nilotica* does occur in other ecosystems, it is a less common member of more floristically diverse savannas and shrub steppes, and does not form a forest canopy.

Figure A7.1. Gonakier forests of the Senegal River floodplain showing dominance of *Acacia nilotica* with sparse understorey (left) and aerial view of forest structure with Senegal River in foreground (right). Photos: Gray Tappan.

Abiotic environment

The ecosystem is restricted to a broad alluvial valley along the Senegal River comprising levees, flats and depressions subject to annual flooding (Tappan et al. 2004). The valley includes a mosaic of forest, savanna and steppe that is determined largely by the hydrological and pedological conditions of the floodplain. The soils supporting Gonakier forest are hydromorphic and vertic sandy clay loams and

clays and are inundated annually between July and November (Fig. A8.1). The Sahelian tropical climate has a seasonal rainfall pattern, with wet summers in June-August and dry winters. Mean annual rainfall in the 1990s varied from 150 to 600 mm along the riverine corridor (Tappan et al. 2004).

Distribution

Gonakier forests of the Senegal River floodplain are restricted to the riparian zone of the Senegal River from Dagana to Bakel, This area includes the border regions of northern Senegal, southern Mauritania and southeastern Mali (Fig. A8.4, A8.5).

Key processes and interactions

Gonakier forests of the Senegal River floodplain are typically inundated annually by wet season floods between July and November. Periodic floods are vital for sustaining forest structure and water-dependent biota in the arid and semi-arid landscapes through which the river flows (Fig. A8.2). The trees are able to tolerate periods of inundation of up to several months. Stancioff et al. (1985) describe the forest as a pseudo-climax community because it occurs at the end of a post-disturbance succession, although a change in flood regime will likely result in a new formation. Overbank flows also redistribute resources and disperse propagules of plants and aquatic biota. The precise mechanisms and dependencies of the ecosystem on flood regimes are uncertain, however Stancioff et al. (1985) noted drought induced declines in tree density during the 1970s and 1980s, when an absence of flooding in some stands lead to the highest tree mortality rates observed within the wooded vegetation formations of Senegal (Fig A8.2). In some cases, the forest has been replaced by steppe.

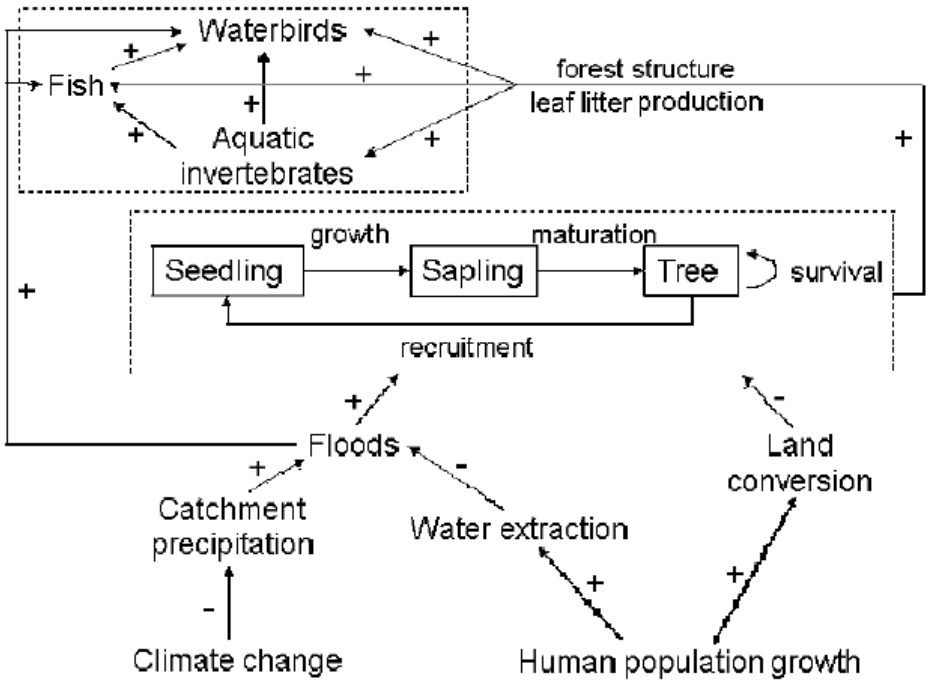

Figure A7.2. Cause-effect model of ecosystem dynamics for Gonakier Forests of Senegal River floodplain showing positive (+) and negative (-) environmental and anthropogenic infleunces on ecosystem processes and components.

The sparse structure of groundlayer suggests that grazing is not an important process in the ecosystem. The role of fire is poorly known, but the intact forests are unlikely to carry fire due to sparse ground fuels and annual inundation.

Threatening Processes

Change in land use (conversion of forest to agriculture) and changes to river flow regimes are the major current threats to Gonakier forests of the Senegal River floodplain (Fig. A8.2). Land clearing was initially associated with traditional subsistence agriculture, which increased gradually over several centuries (Fig. A8.3). Historically, clearing of the forest was carried out to make it more suitable for grazing by promoting development of the groundlayer with incursion of shrubs and grasses from the surrounding steppe (Stancioff et al. 1985). More recently, the land occupied by Gonakier forests has become an important resource for flood recession agriculture. In recent decades, extensive hydro- agricultural projects, designed to increase domestic food production and export production of rice and sugarcane, have resulted in more rapid transformation (Tappan et al. 2004). Cutting of wood for charcoal production, a major source of energy for local communities, exacerbates the trends driven primarily by expansion of irrigated agriculture (Tappan et al. 2004). These processes have resulted in a contraction of the distribution of the ecosystem, which may be considered to have collapsed when its area falls to zero. Twenty-eight patches of forest were designated as forest reserves by 1974 (Giffard, 1974), however, declines in distribution occurred despite these protected areas.

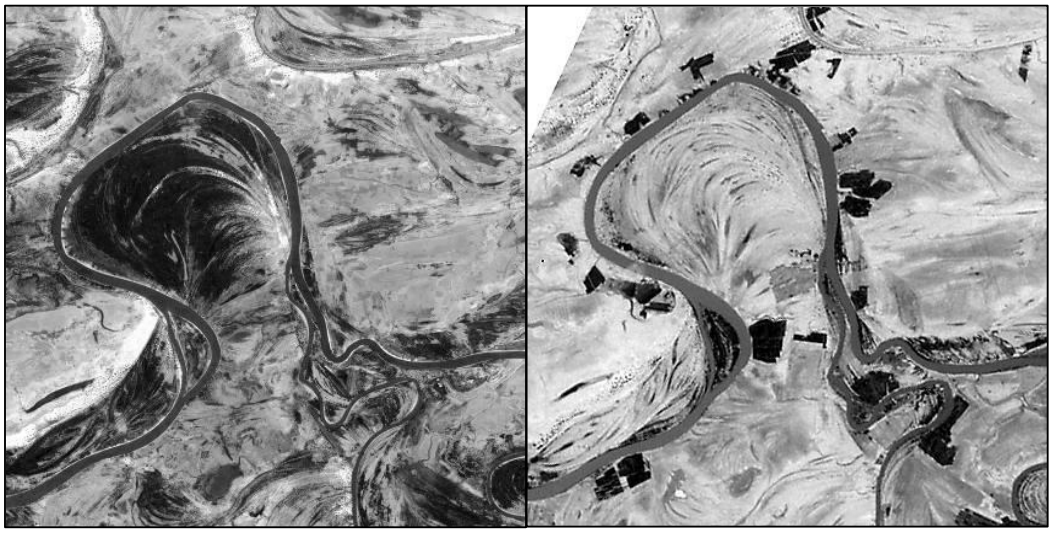

Figure A7.3. Conversion of Gonakier Forests of Senegal River floodplain to agricultural land use over the period from 1965 (left) to 1992 (right). Source: Tappan et al. (2004).

Changes in the flow regime of the Senegal River have occurred, both as a consequence of regional climate change and the construction of river regulation infrastructure (Fig. A8.2). The West African Sahel has experienced the most substantial and sustained decline in rainfall recorded in the world since rain gauge measurements began in the late 1800s (Nicholson 2000). This region includes the catchment of the Senegal River, which originates in Guinea and southern Mal (Fig. A.4), where mean annual precipitation exceeds 1400 mm (Hollis 1990), and flows through drier parts of Mali, Senegal and Mauritania, where precipitation is less than 250 mm.

Figure A7.4. Catchment of the Senegal River. The major source of river water are forested areas in the south of the basin (Guinea and southern Mali), and the river flows through semi-arid and arid environments in the northwest (Senegal and Mauritania).

The entire catchment experienced declines in precipitation in the order of 10-50% during the twentieth century, with the greatest declines occurring in Senegal (Gonzalez et al. 2010; 2012). Inter-annual variation in Senegal's precipitation is closely (inversely) related to Sea Surface Temperatures in the Southern Atlantic Ocean (Fall et al. 2006a). Large and long cyclical variations in precipitation make trends difficult to detect over decadal time scales (Fall et al. 2006b). Although four extended regional droughts during the twentieth century were within extremes inferred from lake sediments spanning the past 2500 years (Shanahan et al. 2009), directional changes over the past 100 years in both precipitation and temperatures have been attributed to anthropogenic climate change (Held et al. 2005; Zhang et al. 2007; Gonzalez et al. 2012). In addition to climate change, Senegal's population has grown tenfold since 1900, increasing pressure on its limited arable land and water resources (Tappan et al. 2004; Fig. A8.2). Construction of the Manantali dam upstream in Mali in 1988 accelerated diversion of water for agriculture and reduction of flood volumes. Hollis (1990) estimated that 14.37 $km^3.year^{-1}$ of water would need to be extracted from the Senegal River and its tributaries for the region to achieve full irrigation potential, an area of 420,000 ha.

The relationship between flood occurrence and maximum river flows allows the conditions for ecosystem collapse to be estimated, given the dependence of Gonakier forest on flooding. It may be assumed that collapse was underway when extensive forest dieback was observed by Stancioff et al. (1985), and that this can be measured bythe concurrent maximum river flows. For example, at Bakel the river height was continually below 800 cm between 1976 and 1986 when extreme rates of tree mortality were observed, whereas river height had fallen below that level once in the preceding 70 years (Fig. A8.6).

Ecosystem collapse

For assessment of criteria A and B, collapse was assumed to occur when the mapped distribution or projected suitable habitat declines to zero. Because this is a floodplain ecosystem threatened by water interception and climate change, we identified maximum river height as a proxy for overbank inundation to assess the relative severit y of environmental degradation under criterion C. Conservatively, we assumed that the ecosystem will collapse when maximum river height falls to 0-10% of unregulated levels.

ASSESSMENT

Summary

Criterion	A	B	C	D	E	overall
subcriterion 1	CR	VU	VU	DD	DD	CR
subcriterion 2	DD	LC	DD	DD		
subcriterion 3	CR(EN-CR)	VU	DD	DD		

Criterion A

Current decline: Gonakier forests of Senegal River floodplain have a distinctive remote sensing signature (Fig. A8.3) that makes them readily distinguishable from the surrounding shrub steppe and other land cover types. Three independent temporal analyses of the distribution of Gonakier forests have been carried out for time periods during the past 50 years (Table A8.1). The first was a comparison of Corona and Landsat images captured in 1965 and 1992, respectively (Fig. A8.5), showing a 77% decline in mapped area (Tappan et al. 2004). The second was a comparison of two Landsat images captured in 1975 and 2000 showed a 72% decline in area (Tappan, unpubl. analysis). The annualised rates of decline from these studies are remarkably similar (Table A8.1), suggesting that rates of decline were roughly constant at 5% per year over a 35-year period 1965-2000 and that area estimates were insensitive to mapping methods and source of imagery. Assuming that rates of decline remained roughly constant for a 50-year period, extrapolation produces an estimate of 92-93% decline in distribution over the past 50 years (Table A8.1).

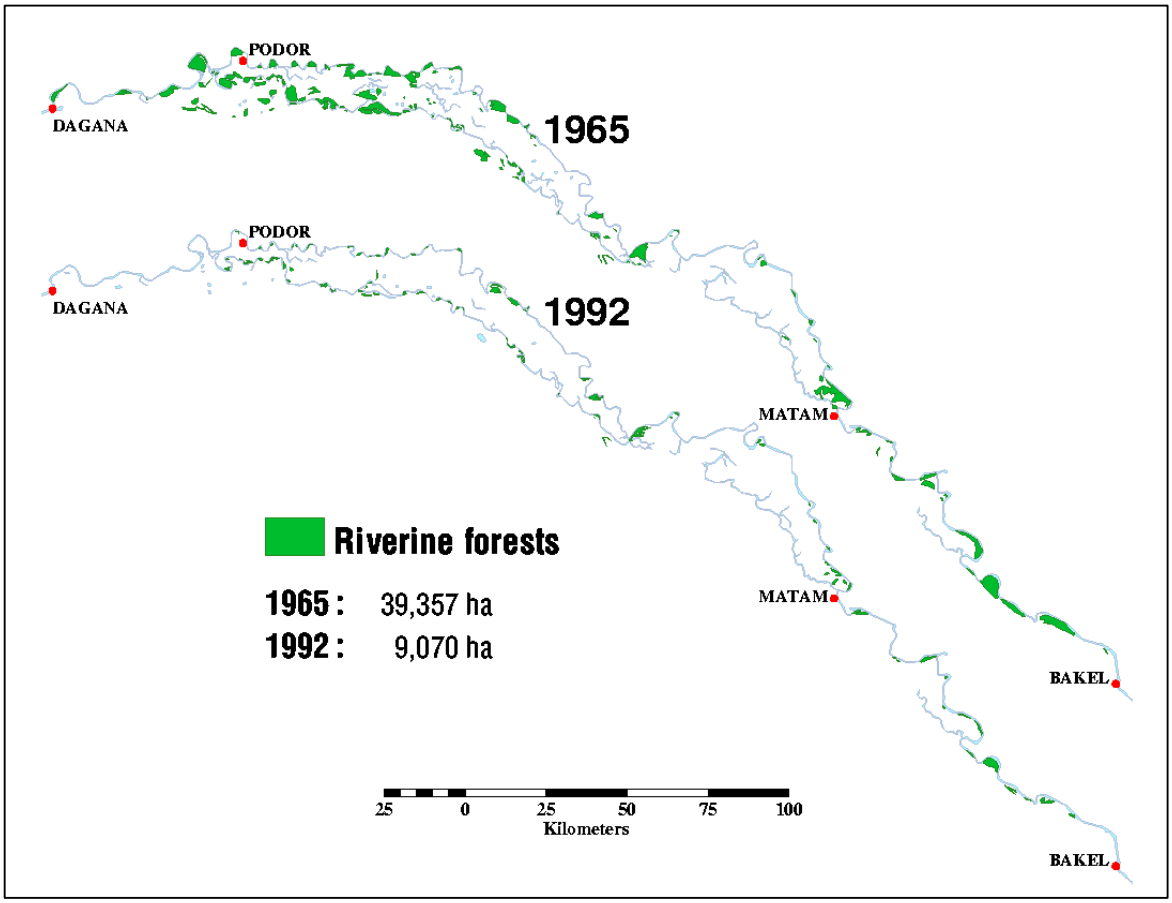

Figure A7.5. Change in distribution of Gonakier forest mapped from Corona imagery captured in 1965 and Lasndsat imagery captured in 1992 (adapted from Tappan et al. 2004).

Table A7.1. Estimated declines in distribution in distribution of Gonakier forests of Senegal River floodplain.

Year	Area (km^2)	% decline	Time frame (yrs)	Annual decay rate	Annual decline	Extrapolated decline over 50 years	Domain	Source
1965 1992	393.57 90.7	77.0%	27	-0.0544	5.29%	93%	National (Senegal only)	Tappan et al. (2004)
1975 2000	116 32	72.4%	25	-0.0515	5.02%	92%	National (Senegal only)	Tappan (unpubl. data)
1984 2003	1071.73 526.02	50.9%	19	-0.0375	3.68%	85%	Global (Senegal & Mauritania)	CSE (2005)

For both of these analysis, the spatial data were limited to the Senegal side of the border. A third analysis has been carried out on the global distribution of Gonakier forests encompassing both Senegal and Mauritania (CSE 2005). This comparison of Landsat images captured in 1984 and 2003 shows a decline in Gonakier forest area of 51% (Table 1). Although the time frame of comparison was slightly shorter, the annualised rate for decline was estimated to be 3.7%, suggesting slightly slower rates of loss on the Mauritania side of the river than in Senegal. Assuming the rate of decline was roughly constant in Mauritania, as it appears to be in Senegal (Tappan et al. 2004 cf. Tappan unpubl. analysis), extrapolation produces an estimated decline of 85% over the past 50 years. Based on a bounded estimate of 85-93% decline in distribution over the past 50 years, the status of Gonakier forests of Senegal River floodplain under criterion A1 is Critically Endangered.

Future decline: No projections are available for the future distribution of Gonakier forests of Senegal River floodplain. If declines continue at the current rate, the distribution may be expected to contract by a further 85 - 93%, however, this assumption may not hold true if protected areas prevent conversion of forests to agriculture. The status of the ecosystem is therefore Data Deficient under criterion A2.

Historic decline: The historic declines in Gonakier forests are likely to be greater than those estimated for the past 50 years. There is anecdotal evidence that agricultural expansion took place in Senegal at an increasing rate during the twentieth century. The national population increased tenfold during that period (Tappan et el. 2004) and continues to increase at 1 - 3 % per year (Gonzalez et al. 2012). Tappan et al. (2000) noted that eastern Senegal had been inhabited by people practicing subsistence agriculture for centuries and that most of the present day villages had been established bythe 1930s when colonial agriculture was expanding at an increasing rate. In northwestern Senegal Gonzalez (2001) documented declines in forest species richness and tree density from 1945 to 1993. However, little of the historical information is specific to Gonakier forests of Senegal River floodplain, so it is difficult to estimate how much of the decline in the distribution of these forests took place prior to 1965, the earliest date of imagery used in published mapping studies (Tappan et al. 2004). Although further work is needed to map the historic distribution of Gonakier forests of Senegal River floodplain, the available evidence (Table S.1) suggests that the magnitude of in area decline must be at least 85-93%. The status of the ecosystem under criterion A3 is therefore at least Endangered and likely to be Critically Endangered.

Criterion B

Extent of occurrence: A minimum convex polygon enclosing all occurrences mapped by CSE (2005) from imagery captured in 2003 has an area of 22,307 km^2. There are continuing declines in distribution (see criterion A) and in a measure of environmental quality (see criterion C) of the ecosystem due to
reduced flows of the Senegal River, and there may be as few as two locations (see below). The status of the ecosystem is therefore Vulnerable under criterion B1.

Area of occupancy: Gonakier forests mapped from 2003 imagery occupied 151 10 x 10 km grid cells. Of these, 93 cells contained more than 1 km^2 Gonakier forest (i.e. more than 1% of their area). The status of the ecosystem is therefore Least Concern under criterion B2.

Number of Locations: Gonakier forests of Senegal River floodplain do not have a highly restricted area of occurrence (see above). The most severe plausible threat to Gonakier forest is currently land conversion. Senegal and Mauritania represent different socio-economic communities and apparently exhibit different rates of forest clearing (see criterion A). If rates of clearing are similar between village communities, there may be as few as two locations of the ecosystem. The ecosystem is prone to severe threats, such as clearing and drought, such that is may become, or may already be Critically Endangered. It therefore meets criterion B3 for Vulnerable status.

Criterion C

Current decline: Flooding is a key ecological process that sustains this ecosystem (Fig. A6.2). As floods occur only during the wet season months, the maximum annual river heights were assumed to be indicative of the river's capacity to flood each year. River height data were available for 100 years from 1904 to 2003 from four gauging stations within the distribution of Gonakier forests of Senegal River floodplain: Bakel; Matam; Podor; and Dagana (Fig. A6.5 for locations). To assess criterion C, we assumed that the mean annual maximum river height across these four gauging stations was a suitable proxy for environmental degradation. River flows declined sharply, reaching a minimum during the late 970s and 1980s. Hollis (1990) estimated that floods of 2500 m3/s needed for floodplain inundation would be very unlikely to occur based on river flows observed during 1986 -1989. Stancioff et al. (1985) observed extreme rates of tree mortality between the mid 1970s and the mid 1980s, corresponding to the lowest maximum river heights (473±-27 cm) observed during the 100 years of records (Fig. A6.6).

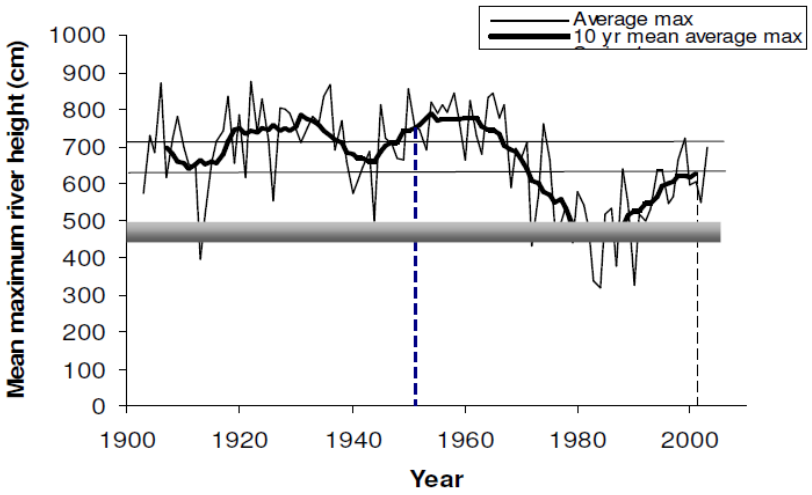

Figure A7.6. Trends in annual maximum river height averaged across four river gauge stations at Bakel, Matam. Podor and Dagana. Vertical broken lines show the past 50 years. Upper horizontal line shows mean maximum river height for 1904 - 1953, lower horizontal line shows mean maximum river height for 1954 - 2003, and horizontal grey bar shows assumed 50-year mean maximum flow that would cause ecosystem collapse based on observed flows during 1976 - 1985. Data from Centre de Suive Ecologique, Dakar.

We therefore assumed that the ecosystem would collapse (due to extensive tree mortality) when the mean maximum river height for a 50 year period fell below 450 - 500 cm. To calculate the relative severity of hydrological decline, we first calculated the difference between mean maximum river height between the periods 1904 - 1953 and 1954 - 2003. We then divided this by the difference between mean maximum river height during 1904 - 1953 and the assumed mean height assumed at collapse. Relative severity of hydrological decline over the past 50 years was therefore between 100×(712-619)/(712-450) = 35% and 100×(712-619)/(712-500) = 44%. The status of the ecosystem was therefore
Vulnerable under criterion C1.

Future decline: The are currently no future projections of flows of the Senegal River. The status of the ecosystem under criterion C2 is therefore Data Deficient.

Historic decline: Available historic data suggest regional declines in precipitation have been ongoing since records began in the late 1800s (Nicholson 2000). For example mean annual precipitation at St Louis at the mouth of Senegal River declined from 450 mm in 1855 to 240 mm in 2009, while twentieth century declines in precipitation were estimated to vary between 10 and 50% across the Senegal River catchment (Gonzalez et al. 2012). The impact of these changes on flows in the Senegal River are uncertain. For example, maximum river height showed no obvious trend between 1904 and the mid-1950s (Fig. A8.6) when precipitation was declining. As data on river flows are lacking over a longer historic time frame, the status of the ecosystem is Data Deficient under criterion C3.

Criterion D

Tree dieback and mortality is one of the biological outcomes of the degradation processes described above and in Fig. A.2. Changes in tree density of cover would therefore be suitable proxy variables for biotic degradation. Gonzalez e al. (2012) found that tree density declined significantly from 1954 to 2002 in the western Sahel at Njóobéen Mbataar and Fété Olé, in northern Senegal and that tree species richness declined significantly from 1960 to 2000 across the Sahel in a sample of 14 village areas in Mauritania, Mali, Burkina Faso, Niger, and Chad. They attributed tree decline to two forms of climate variability: increasing temperature and decreasing precipitation, which were jointly attributable to global

climate change (Gonzalez et al. 2012). There is also independent evidence of declines in tree density and species richness across the northern and central Senegal savannas. Unfortunately, there are insufficient data available specifically for Gonakier forests of Senegal River floodplain to draw reliable inferences about changes in tree density and species richness within that ecosystem. The status of the ecosystem under criterion D is therefore Data Deficient.

Criterion E

No quantitative analysis has been carried out to assess the risk of ecosystem collapse for Gonakier forests of Senegal River floodplain. The status of the ecosystem is therefore Data Deficient under criterion E.

REFERENCES

CSE (2005) Projet Biodiversité Mauritanie-Sénagal: caractérisation de la zone et des sites du projet, 230p. Projet-RAF/98/G31. Centre de Suive Ecologique, Dakar.

Fall S, Semazzi FHM, Niyogi DDS, Anyah RO, Bowden J. (2006a) The spatiotemporal climate variability over Senegal and its relationship to global climate. International Journal of Climatology 26: 2057-2076

Fall S, Niyogi DDS, Semazzi FHM (2006b) Analysis of Mean Climate Conditions in Senegal (1971–98). Earth Interactions 10: 1-40. (doi:http://dx.doi.org/10.1175/EI158.1)]. Giffard P. (1974) L'Arbre dans le paysage senegalais, Dakar.

Gonzalez P. (2001) Desertification and a shift of forest species in the West African Sahel. Climate Research 17: 217-228.

Gonzalez P, Neilson RP, Lenihan JM, Drapek RJ. (2010) Global patterns in the vulnerability of ecosystems to vegetation shifts due to climate change. Global Ecology and Biogeography 19:755-768.

Gonzalez P, Tucker CJ, Sy H. (2012) Tree density and species decline in the African Sahel attributable to climate. Journal of Arid Environments 78: 55-64.

Held IM, Delworth TL, Lu J, Findell KL, Knutson TR. (2005) Simulation of Sahel drought in the 20th and 21st centuries. Proceedings of the National Academy of Sciences of the United States of America 102, 17891-17896.

Hollis GE. (1990) Senegal River Basin Monitoring Activity. Hydrological Issues: Part II. Working Paper No. 57. Institute for Development Anthropology. Binghamton, USA.

Nicholson S. (2000) Land surface processes and Sahel climate. Reviews of Geophysics 38: 117–139.

Shanahan TM, Overpeck JT, Anchukaitis KJ, Beck JW, Cole JE, Dettman DL, Peck JA, Scholz CA, King, JW. (2009) Atlantic forcing of persistent drought in West Africa. Science 324: 377-380.

Stancioff, A. S, Staljanssens M, Tappan G. (1985) Mapping and remote sensing of the resources of the Republic of Senegal: A study of the geology, hydrology, soils, vegetation and land use potential. South Dakota State University. Brookings, USA.

Tappan GG, Hadj A, Wood EC, Lietzow RW. (2004) Use of Argon, Corona, and Landsat Imagery to Assess 30 Years of Land Resource Changes in West-Central Senegal. Photogrammetric Engineering & Remote Sensing 66: 727-735.

Tappan GG, Sall M, Wood EC, Cushing M. (2004) Ecoregions and land cover trends in Senegal. Journal of Arid Environments 59: 427–462.

Zhang X, Zwiers FW, Hegerl GC, Lambert FH, Gillett NP, Solomon S, Stott PA, Nozawa T. (2007)

Detection of human influence on twentieth-century precipitation trends. Nature 448: 461-465.