

PATTERNS OF VEGETATION CHANGE IN THE ZAMBEZI DELTA, MOZAMBIQUE



**WORKING PAPER #3
PROGRAM FOR THE SUSTAINABLE MANAGEMENT OF CAHORA BASSA DAM
AND THE LOWER ZAMBEZI VALLEY**

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1. Wattled Cranes, waterbirds, and wetland conservation in the Zambezi Delta, Mozambique (Bento and Beilfuss 2000)
2. Patterns of hydrological change in the Zambezi Delta, Mozambique (Beilfuss and dos Santos 2001)
3. Patterns of vegetation change in the Zambezi Delta, Mozambique (Beilfuss, Moore, Dutton, and Bento 2001)
4. Prescribed flooding and restoration potential in the Zambezi Delta, Mozambique (Beilfuss 2001)
5. The status and prospects of Wattled Cranes in the Marromeu Complex of the Zambezi Delta (Bento, Beilfuss, and Hockey 2002)
6. The impact of hydrological changes on subsistence production systems and socio-cultural values in the lower Zambezi Valley (Beilfuss, Chilundo, Isaacman, and Mulwafu 2002)

TABLE OF CONTENTS

Introduction and background	4
Previous studies of vegetation change in the Zambezi Delta.....	8
Methods	11
Results	14
Discussion.....	32
Conclusions.....	40
Appendix 1 History of development in the Zambezi Delta	41
Acknowledgements.....	44
References.....	45
Endnotes.....	53
Figures	55

PATTERNS OF VEGETATION CHANGE IN THE ZAMBEZI DELTA

INTRODUCTION AND BACKGROUND

Water resources development projects have substantially altered the hydrological regime of the Zambezi Delta. Prior to the construction of Kariba Dam on the middle Zambezi River, peak floods spread over a mosaic of vegetation communities in the 12,000 km² Zambezi Delta – one of the largest wetland systems in southern Africa. Floodplain grasslands were inundated with floodwaters for up to nine months of the year, and many areas were saturated throughout the dry season.

With the closing of Kariba Dam in 1959 and Cahora Bassa Dam in 1974, nearly 90% of the Zambezi catchment has become regulated and the natural flood cycles of the lower Zambezi River are now a phenomenon of the past. Flooding events in the delta, when they occur, are now dependent upon local rainfall-runoff within the lower Zambezi catchment or unplanned (possibly catastrophic) water releases from the upstream dams. These hydrological changes are further exacerbated by the construction of dikes along the lower Zambezi that prevent medium sized floods up to 13,000 m³/s from inundating the south bank floodplains. The cumulative impact of these developments is a significant shift in the magnitude, timing, duration, and frequency of flooding in the delta. The implications of these hydrological changes on vegetation communities in the delta must be considered in the context of the hydrogeomorphic conditions and disturbance processes that control vegetation distribution and abundance.

Fluvial landforms and hydrogeomorphic control of floodplain vegetation

Among the many factors that influence the distribution patterns of African floodplain vegetation, the fluvial landform with its characteristic hydrogeomorphic processes is the most important (Denny 1985a, Hupp 1988). Fluvial landforms include the main river and distributary channels with associated point bars on the active-channel shelf; natural levees bordering the channel; the broad floodplain with meander scrolls, lagoons, oxbow lakes, backwater swamps, and pans; the low-level terrace; and the high-level terrace and hillslope, with estuarine muds and raised beaches in coastal systems (Leopold *et al.* 1964, Welcomme 1979). Each landform has unique hydrological and geomorphologic properties that support characteristic vegetation associations (Denny 1985a). The vegetation in turn modifies the width, height, and stability of the fluvial landform (Hupp 1988).

As the sinuous channels of the main river and distributaries (*eupotamon*) fan out over the delta floodplain, they transport, erode, and deposit alluvial sediments (Amoros *et al.* 1987a). Depositional bars are created on the convex side of river meanders as they traverse the active-channel shelf, eroding during high flows and re-forming during dry season low flows. These unconsolidated sandbars may be colonized by a variety of annual and short-lived species, but are usually scoured free of vegetation by the annual floods (Hupp 1988).

Natural levees adjacent to the river channels result from the deposition of coarse sediments as floodwaters spread laterally overbank (Leopold *et al.* 1964). The levees are typically the highest features on the floodplain, sloping steeply towards the river and grading gradually towards the low-lying floodplain. Levees are inundated for a much shorter duration than the surrounding floodplain, and often support a variety of woodland and savanna species that can tolerate only periodic flooding such as *Acacia xanthoxylem*, *Kigelia africana*, and *Borassus* palms (Ellenbroek 1987). *Phragmites mauritanus* is typical on riverine fringes, especially in narrow bands on levees (Thompson 1985).

The broad floodplain is composed of thick alluvial sediments, with coarse sand overlain by fine-grained silts and clays (Gaudet 1992). Floodplain soils are strongly gleyed, hydromorphic vertisols, formed by alternating periods of wetting and drying of montmorillonite clays. These “black clays” support a mosaic of emergent grass and sedge species along a moisture gradient (Tinley 1977). The vertisols shrink during the dry season, leaving wide and deep cracks, and swell when wet, such that once saturated during the rainy season, the clay becomes almost impermeable to water and is frequently anaerobic. Highly expansive vertisols, deposited during prolonged periods of deep water inundation, occur in the lowest lying areas and are typically dominated by perennial, rhizome-spreading species such

as *Leersia hexandra*, *Echinochloa pyramidalis*, and *Oryza longistaminata* (Ellenbroek 1977). More weakly expansive and gleyed vertisols occur in the higher floodplain areas, supporting perennial and annual bunchgrass species that primarily spread by seed, such as *Vetiveria nigra*, *Panicum coloratum*, *Seteria spaelata*, and various *Hyparrhenia* spp. (Thompson 1985). Mesic savanna species, such as *Borassus aethiopum* and *Hyphaene coriacea* palms and certain *Acacia* species, are widely scattered among bunch grasses in the highest floodplain areas (Gaudet 1992). Towards the coast, floodplain soils become increasingly saline due to subsurface tidal influence, and support more salt-tolerant species such as *Sporobolus virginica* and *Cyperus laevigatus* (Tinley 1977).

The relatively flat floodplain surface is interrupted by meander scrolls, undulating ridges and swales of coarse stratified alluvium that occur on the convex side of abandoned river bends (Leopold *et al.* 1964). These relict features remain in areas where the river formerly traversed the floodplain. The ridges often support narrow islands of less flood-tolerant species, similar to those found on river levees, with more typical floodplain grasses in the swales (Hupp 1988).

Floodplain water bodies include lagoons, oxbow lakes, backwater swamps, and pans (Leopold *et al.* 1964). Lagoons (*parapotamon*) are dead arms of the main channel that remain connected to the river throughout the year at their downstream end. Oxbows (*paleopotamon*) are disconnected meander bends, cut-off from the mainstem river when it migrated laterally across the floodplain (Amoros *et al.* 1987a). Oxbows are often bordered on their concave banks by ridges from relict levees that may support palm and deciduous woody species. Swamps, or sloughs, are deeply flooded areas of stagnant water that form in meander scrolls and along valley walls. Shallow pans or pools are isolated, ephemeral bodies that often dry out during the dry season. These open water bodies are colonized by submerged, floating-leaf, and surface floating macrophytes, distributed according to local variation in temperature, nutrients, carbon dioxide supply, salinity, alkalinity, pH, and microclimate, as well as competition (Denny 1985b). Hydrological conditions in lagoons are dynamic, fluctuating with river levels, and support emergent species with a wide range of tolerance to changing water conditions such as *Vossia cuspidata* and *E. scabra* (Thompson 1985). Oxbows and swamps, only connected to the river during overbank flooding events, have more stable hydrological conditions. Papyrus swamps (dominated by *Cyperus papyrus*) typically occupy these deepwater zones, with reedswamps of *Phragmites australis* and *Typha latifolia* common in more drought-prone or brackish environments (Thompson 1985). There is a fairly distinct boundary between these species of deep-flooded soils and those found on more shallow-flooded vertisols (Gaudet 1992).

In coastal systems, the floodplain gives way to tidally influenced estuarine muds and raised beaches. The estuarine muds are dark, clayey alluvium of marine origin, rich in organic matter. The muds are inundated by seawater at high tides, exposed during low tides, and flooded by freshwater during the rainy season (Thom 1984). They support well-developed stands of mangrove forest in distinct zonation patterns related to hydromorphy and salinity (Smith 1992). Parallel raised beaches of aeolian sands, most extensive near the coast, occur up to 30 km inland from the present coastline. The ridges support a complex mosaic of dune thicket, woodland, and dry forest species. Deltoid clays finger into these sand ridges to form lowland, hydromorphic swales with saline grassland (Tinley 1994).

At the upper margin of the floodplain is the low-level terrace, a zone of old river alluvium under recent coarse colluvial deposits that is connected to the mainstem river only, if ever, during extreme flooding events (Leopold *et al.* 1964). The low-level terrace is occupied by a variety of dry forest, woodland, and thicket species that thrive under seasonal high water table conditions but are mostly intolerant of flooding, including various *Acacia* spp. and *Combretum* spp. (Hupp 1988). The activities of termites, particularly hill-building *Macrotermes* termites, provide a critical pathway for vegetation of the low-level terrace to invade the open floodplain. Termite mounds provide well-drained convex surfaces, extending far into the inundated floodplain, for colonization by less flood-tolerant species of woodland and thicket (Tinley 1977). The upper terrace and hillslope, above the zone of hydrological connection with the present river, support the typical dry forest and woodland vegetation of the region.

Disturbance processes and floodplain vegetation

Superimposed on the fluvial landform is a complex disturbance regime. African floodplains are dynamic, disturbance-dependent communities (*e.g.*, Denny 1985a, Gaudet 1992). Patterns of flooding, grazing, browsing, mound building, and fire exert a tremendous influence on floodplain vegetation.

Flood pulsing is fundamental to the distribution of floodplain vegetation by maintaining hydrological connectivity between the river and floodplain and by altering local hydrogeomorphic conditions (Junk *et al.* 1989, Amoros *et al.* 1987b). The frequency, magnitude, timing, and duration of flooding influences such factors as the extent of floodplain inundated by floodwaters, the amount of available soil moisture during the dry season, the depth of surface water in oxbows, pools, and backwater swamps, the degree of salt water intrusion, and the spread of flood-intolerant species from the floodplain margin. The timing of the flood pulse further influences the phenology of plant growth and the timing and spatial dynamics of seed and propagule movement and regeneration across the floodplain (Middleton 1999). These factors combine to influence the *hydrosere*, or characteristic pattern of vegetation distribution along a soil moisture gradient (Denny 1993). Similar hydroseres were observed for a number of different African floodplains, including the Kafue Flats (Ellenbroek 1987), Okavango Delta (Smith 1976), Middle Zambezi (Muller and Pope 1982), and Chambeshi floodplain (Thompson 1985) in southern Africa.

Plant growth on the floodplain is initiated during the rainy season. Deciduous floodplain trees and shrubs come into leaf shortly before or during the first rains, and most grass and sedge species break dormancy with the onset of rains (Ellenbroek 1987). As floodwaters spill overbank and inundate the floodplain, many species are triggered to grow rapidly and remain above the level of inundation (Thompson 1985). At the height of flooding, little water is visible through the dense growth of emergent plants. In many areas, especially along watercourses, plant growth is almost impenetrable even before the main flood comes. There is a succession of growth and flowering during the rainy season, with some species completing growth and setting seed before others have come into flower (Denny 1985a). As floods recede, they leave behind a dense growth of grasses and herbs. The stems of many species are weak and collapse when no longer supported by water, covering the ground with a thick mat of insulating vegetation.

In healthy floodplain systems, the processes of grazing, trampling, and fire remove most of this annual growth by the end of the dry season. Herbivory is an integral part of the succession dynamics of floodplain systems, exerting selective pressure on the delta grassland composition (Ellenbroek 1987). Many herbivores have co-evolved with plants, acting as dispersers and influencing plant regeneration patterns (Middleton 1999). Native ungulates typically move off the floodplain to the low-level terrace during peak flooding, then follow the receding floodwaters to feed on the recently exposed vegetation (*e.g.*, Sheppe and Osborne 1971). Coarse grass feeders, especially buffalo and elephant, graze down rank pastures and enhance grazing conditions for the medium to short grass feeders such as waterbuck and zebra. The mulch of grass flattened by large herds of buffalo and elephant also enables greater penetration of rain and results in better primary production of floodplain grasses (Tinley 1977).

Following the ebb line is a zone of changing width of moist soil (depending on microrelief at each water level), supporting a green flush of vegetation that gradually dries out on its upper margins. Grazing herds follow the green zone and vacate browning lands. During these annual migrations, herbivores provide opportunities for plant regeneration by removing large quantities of emergent vegetation and trampling seed into soils, while browsers remove woody growth at the floodplain periphery (Ellenbroek 1987). Other important animal disturbances include the actions of hill-building termites that provide suitable sites for woody plant invasion into seasonally flooded grasslands, and the wallowing activities of hippo that scour and maintain open channels (Tinley 1977).

Fire is also critical in maintaining the structure of the African floodplain, altering the physiognomy and boundaries of vegetation associations and contributing to the mosaic pattern of land cover (Thompson and Hamilton 1983). Historically floodplain fires may have been caused by lightning strikes during late dry season thunderstorms, but today almost all fires are human-induced and few sites escape burning (Komarek 1976). Fires in wetlands release nutrients, open the canopy and detrital layers, and increase

production and diversity (Middleton 1999). Hot dry season fires are highly destructive to shrubs and small trees at the floodplain margin, sometimes eliminating canopy components, but do not damage the seeds and underground rhizomes of the grasses (Vogl 1977; Kozlowski and Ahlgren 1974). Burning removes old vegetation growth and stimulates new growth from underground rhizomes. Many species of annual forbs flower and set seed only after fire has removed the surrounding dead vegetation (Ellenbroek 1987).

Patterns of vegetation change

In response to hydrogeomorphic conditions and disturbance dynamics, African floodplains exhibit a regular pattern of *cyclical* vegetation change, similar to the succession patterns observed in many North American (e.g., Clark and Benforado 1981), Asian (e.g., Middleton *et al.* 1991), and Australian wetland systems (e.g., Finlayson 1991). Vegetation species are constantly in flux, moving in and out of new areas as environmental conditions permit. Individual life history strategies, including life span (e.g., annual, short-lived perennial, or long-lived perennial); flood tolerance (e.g., presence of anatomical, morphological, or metabolic adaptations to flooding); reproductive strategy (seed bearing or vegetative propagation); dispersal strategy (e.g., anemochory, hydrochory, zoochory, avichory); propagule longevity (e.g., seed bank or dispersal dependent species); and propagule establishment requirements (e.g., drawdown or flooded conditions) enable different species to colonize different substrates (van der Valk and Davis 1978, Denny 1985c, Middleton 1999). Floods, droughts, fires, grazing events, and other processes, all operating at different spatial and temporal scales, alternately facilitate and counteract these shifts in distribution.

Cyclical vegetation change occurs as a function of the long-term stability of hydrogeomorphic conditions and disturbance patterns. Cycles of change may occur within a single year (e.g., an *Acacia polyacantha* seedling establishes in *Hyparrhenia rufa* grassland and is subsequently eliminated by browsing, fire, or flooding), or may correspond to medium or long-term disturbance cycles. Howard-Williams (1975) and Gaudet (1977) documented the cyclical succession of emergent vegetation on different shallow floodplain lakes in east Africa during multi-year drying and filling phases. Ellenbroek (1987) studied cyclical succession patterns in the Kafue Flats related to inter-annual variation in soil moisture status, and Smith (1976) observed similar patterns in the Okavango Delta. Some cycles occur over extended time periods. Hughes (1990) observed that forest age structure in the Tana River floodplain of Kenya is related to high-magnitude, low frequency flooding events or sets of events, occurring every 50-80 years. Furness and Breen (1980) described a similar forest structure in the Pongolo River floodplain.

Directional vegetation change, in which species successfully invade and establish in areas that they have not previously occupied or substantially increase in density in areas they currently occupy, results from temporary or permanent disruptions in the floodplain disturbance regime—most notably the hydrological regime. Examples of directional vegetation change include the establishment of savanna and thicket species in previously open floodplain areas, the displacement of flood tolerant species by more drought tolerant species, or the displacement of freshwater species by saline species. Unlike with cyclical vegetation changes, to which human and wildlife communities have adapted over time, directional vegetation shifts result in unanticipated changes that may affect the accessibility of local resources, the spread of tsetse and other diseases, the carrying capacity of floodplain grasslands for wildlife, or the availability of breeding sites (Loxton, Hunting, and Associates *et al.* 1975a&b, Tinley 1977, Anderson *et al.* 1990, Beilfuss and Bento 1997). But despite the serious implications of these changes, there are few quantitative studies of the effects of hydrological change on African floodplain systems (e.g., Hughes 1988, Dunham 1989b).

In Working Paper #2, I examined the hypothesis that water resources development projects have resulted in substantial long-term hydrological changes in the Zambezi Delta. In this working paper, I investigate long-term vegetation change in the Zambezi Delta, and examine the hypothesis that long-term hydrological changes have resulted in a shift from cyclical to directional vegetation succession patterns. I test this hypothesis through three fundamental questions:

- *How has the vegetation of the delta changed over the past century?*
- *What factors control the distribution of vegetation across the Zambezi Delta? How have these factors change over time?*
- *How are the patterns of vegetation change directly or indirectly related to hydrological changes in the delta? What other factors are contributing to vegetation change?*

In Working Paper #4, I assess the potential for reversing changes in the vegetation of the delta through improved hydrological management.

PREVIOUS STUDIES OF VEGETATION CHANGE IN THE ZAMBEZI DELTA

Historical vegetation studies

The earliest written accounts of the vegetation of the Zambezi Delta are found in the journals and letters from Portuguese missionaries, dating back to the 1600s (Liesegang and Chidiambamba 1997). Entries from this period reflect the dynamic nature of the delta, documenting the periodic loss and formation of islands and waterways through the various delta distributary channels.

The Livingston expeditions of 1858-1863, described in the travel diaries of Livingston (Wallis 1956), Kirk (Foskett 1965), Stewart (Wallis 1952), and Thornton (Tabler 1963), provide the first detailed (although qualitative) accounts of the vegetation of the lower Zambezi up to Cahora Bassa. Many of these entries also relate to changes in landform characteristics and disturbance processes. Describing the Mutu River, one of the most important north bank distributaries connecting the Zambezi with Quelimane, Livingston wrote:

“The Mutu, at the point of departure, was only 10 or 12 yards broad, shallow, and filled with aquatic plants. Trees and reeds along the bank overhang it so much that, though we had brought canoes and a boat from Tete, we were unable to enter the Mutu with them, and left them at Mazaro. During most of the year, this part of the Mutu is dry, and we were even now obliged to carry all our luggage by land for about fifteen miles. As Kilimane [sic] is called, in all the Portuguese documents, the capitol of the rivers of Senna, it seemed strange to me that the capital should be built at a point where there was no direct water conveyance to the magnificent river whose name it bore; and on inquiry I was informed that the whole of the Mutu was large in days of yore, and admitted of the free passage of great launches from Kilimane all the year round; but that now this part of the Mutu had been filled up.”

The first attempt to map vegetation cover in the Zambezi Delta was undertaken by Barbosa (1952) as part of a vegetation survey of Zambezia Province. The vegetation of the northern half of the delta was classified as “hydrophilic grassland, with or without scattered trees, and forests on alluvium.” Revisions to the vegetation map were produced for *Flora Zambesiaca* (Wild and Barbosa 1967)—which covers the entire Zambezi catchment from Zambia to Mozambique—but the delta floodplains were still broadly mapped as one unit, “Dry tree savanna-moist grassland-fringing forest-aquatic flora mosaic of big river alluviums and deltas (lowland, sublittoral).” The extensive papyrus swamps on the delta north bank were not distinguished, although smaller papyrus swamps of the lower Shire Valley in Malawi were mapped as “Sudd”. Along the coastline, “Mangrove (*Rhizophora mucronata*)” and “Littoral thicket and forest of recent dunes (*Mimusops caffra*)” units were mapped at the outlet of the major delta tributaries. Vegetation of the adjacent Cheringoma and Morrumbala Plateaus were mapped as “Mosaic of moist semi-deciduous forest with miombo woodland,” with lesser units of “Dry semi-deciduous (lowland-sublittoral) forest” and “Dry deciduous lowland forest” described but not mapped. Extensive coconut groves near Quelimane were also mapped. White (1983), in his *Vegetation Map of Africa*, simply classified the delta as being part of the East African coastal forest/grassland mosaic.

In 1973, Loxton, Hunting, and Associates in association with A.O.C. Technical Services Pty. Ltd., Hidrotécnica Portuguesa, and Empresa Técnica de Levantamentos Aereos Lda. was contracted by the Zambezi Valley Planning Authority (GPZ) to survey the natural resources of the southern region of the lower Zambezi Valley. The region was divided into three units, with two units (Blocks 10 and 11)

covering the Zambezi Delta. Block 10 covered the region from the Zambezi River south to the Mungari River and from the Inhaminga-Inhamitanga-Chupanga road in the west to the Indian Ocean in the east. Block 11 covered the entire northern half of the delta and Morrumbula escarpment. The southeast corner of the delta from the Mungari River to the Cheringoma escarpment was not mapped. The consultant team carried out detailed field investigations to describe and map the physiography and vegetation of the study area (Loxton, Hunting, and Associates *et al.* 1975e,f,g,&h).

The Quaternary Deltoid plain¹ was subdivided into six physiographic units based on soil moisture and inundation characteristics. These sub-units include: (1) Seasonally flooded areas of strongly to moderately gleyed vertisols and some humic gleys, occupying the regionally depressed Quaternary Deltoid Plain and the backslopes of levees in the western zone; (2) Tidally influenced areas occupied by mangrove swamps; (3) Seasonally flooded areas of strongly gleyed soils with tidally influenced drainage lines; (4) Elevated levee and watercourse areas, of recent alluvium with mainly sandy to medium textured alluvial soils, that are periodically flooded; (5) Broad, relatively elevated floodplains and backslopes of levees, that are only periodically flooded; and (6) Raised beaches on the coast.

The vegetation cover of the delta region was mapped as “pedo-ecological units,” based on a classification system developed by Phillips (1971) for Loxton, Hunting, and Associates. The system involves visual assessment of vegetation characteristics, including species composition, canopy cover, height, density, basal cover, and abundance. The resulting 1:100,000 land cover maps classify ten pedo-ecological units for the Zambezi Delta and surrounding escarpment (Figure 3-1). Each of these classes was further divided into sub-units based on vegetation physiognomy, geomorphology, soils, and microclimate.

During the same period, Tinley (1969, 1971, 1975, 1977) carried out extensive field research on the vegetation and landforms of the delta region, from Gorongosa National Park across the rift valley and Cheringoma plateau to the Marromeu Buffalo Reserve and coast. Tinley viewed the delta landscape as a constantly changing “kaleidoscope” of physical and biological components controlling vegetation distribution and dynamics. He emphasized soil moisture as the master variable at the ecosystem level, with soil characteristics (such as nutrient status, pH, salinity, and texture), flooding patterns, and micro-relief determining individual species composition. Tinley also described the role of different disturbance vectors, from mound-building termites to large-scale disturbance cycles, in maintaining the vegetation communities of the delta.

Tinley’s research in the delta focused on the floodplain region near the Cheringoma escarpment, complementary to the more northern area covered by the Loxton, Hunting, and Associates *et al.* reports. In particular, Tinley stressed the importance of the perennial streams draining the escarpment for the maintenance of the southern delta floodplains. Tinley described four major landforms influencing vegetation cover in the southern delta, including (1) alluvial fans from rivers draining the Cheringoma escarpment; (2) delta floodplains of the Zambezi River, (3) estuary deltas of the Cheringoma river mouths, and (4) straight barrier beaches with recurved spits, dune ridges, and small parabolic dunes.

Tinley’s doctoral thesis (1977) remains the seminal body of ecological research explaining the genesis and maintenance of the delta landscape. He was also the first scientist to observe the effects of Kariba Dam on the delta, and raise concerns about the future impact of Cahora Bassa Dam (Tinley 1975). Collectively, the Tinley and Loxton, Hunting, and Associates *et al.* studies provide the scientific foundation for evaluating future vegetation change in the delta.

In 1982, the government commissioned SWECO/SwedPower to conduct preinvestment studies for development of a North Bank hydropower station at Cahora Bassa Dam. As part of the feasibility studies the SWECO team investigated the effects of past and future river regulation on the lower Zambezi Valley and delta. SWECO (1983) attempted to map the vegetation of the delta using a 17 August 1981 Landsat MSS satellite image. They conducted a supervised classification scheme to identify thirty-two unique spectral signatures, and merged them into fifteen land cover classes. Because several major vegetation communities including palm and acacia savanna could not be classified using spectral data, the SWECO team relied heavily on the Loxton, Hunting, and Associates *et al.* work to complete their assessment.

Nonetheless, SWECO provided an important historical record by mapping the coastal mangrove in detail and pinpointing the locations of strips of dead mangrove trees (Figure 3-2). The SWECO studies provide the last assessment of conditions in the delta region before the civil war precluded further research.

Recent vegetation studies

Ellenbroek (1987) studied the ecology and productivity of the Kafue Flats in Zambia. He described the phytosociology, diversity, vegetation structure, and productivity of the flats, as well as below-ground plant structure and decomposition. Ellenbroek assessed the influence of fire, grazing, and especially flooding on the vegetation of the flats. Most of the vegetation associations in this study include similar species or genera as found in the Zambezi delta, and provide an invaluable reference. Ellenbroek concluded his research by considering the probable future changes in the ecology and productivity of the Flats due to the construction of Kafue Gorge Dam.

Dunham (1989a, 1989b) studied the relationship between environmental factors and species composition of vegetation on the Zambezi River downstream of Kariba Dam. Grass, sedge, and woody species were recorded in 73 stands in Mana Pools National Park, Zimbabwe, and analyzed through detrended correspondence analysis. Grass and sedge species were closely correlated with soil moisture regime, as indexed by soil texture and flooding frequency. Dunham observed a decline in perennial grass frequency following a period of several years without flooding, but also notes that there has been less woody regeneration in the lower floodplain than expected since Kariba Dam was built. He attributed this to the effects of large mammal browsing and frequent waterlogging of alluvial soils during rainy season.

In October 1990, a survey team was hired by LOMACO to conduct an evaluation of the wildlife resources of the Marromeu complex following the cease-fire in Mozambique (Anderson *et al.* 1990). The LOMACO team described changes in land cover and land use that had occurred over the civil war period. They noted the terrestrialization of waterways on the delta south bank, and the widespread desiccation of the delta floodplain.

In 1996, the IUCN Zambezi Basin Wetlands Conservation and Sustainable Utilization Project was initiated in 1996 to promote the wise use of natural resources in the wetlands of the Zambezi Basin, including the Zambezi Delta (Hiscock *et al.* 1996). A series of reports describe vegetation and land use patterns in the delta (Schmidt 1997, DNFFB 1998, DNFFB 1999, Timberlake 1998). As part of the project, The Zambezi Society and the Biodiversity Foundation for Africa were contracted to assess the biodiversity of the delta, including vegetation mapping (Timberlake 2000). Mapping was based on the visual classification of a 1996 Landsat TM satellite image with ground truthing by aerial reconnaissance. Fourteen vegetation classes are recognized (Figure 3-3). These maps provide a broad overview of the vegetation cover, but are not sufficiently detailed to enable comparisons with previous mapping efforts.

Projecto de Gestao de Mangais (GEMA) conducted baseline surveys of the coastal mangrove of the delta region, towards developing a national mangrove resource management plan. Studies include the physical characterization (Vilankulos and Marquez 2000) and inventory (Cuambe 2000) of coastal mangrove areas. Dodemma and Manjate (2000) mapped the distribution of coastal mangrove and associated soils using a 1999 SPOT satellite image. Data include mangrove density, species composition, threats, and regeneration potential.

Most recently, the Joint Venture IGNFI-CENACARTA produced a series of 1:250,000 land use/land cover maps for Zambezia and Sofala provinces, including the Zambezi Delta (Figure 3-4). Floodplain grasslands are classified as “natural grassland” (controlled by edaphic conditions, with seasonal or permanent waterlogging) and “anthropogenic grassland” (created by forest clearing for grazing or agriculture). Natural grasslands that are inundated throughout the year are classified as “aquatic meadow,” and high water table wetlands subject to seasonal flooding are classified as “meadow, liable to flood.” Other mapping units include “bare soils”, “mangrove”, “wooded grassland”, and “open woodland”. Each mapping unit, with the exception of mangrove, is subdivided into natural and anthropogenic origin. As with the Timberlake study, the CENACARTA mapping is not sufficiently detailed to enable the assessment of vegetation change over time.

METHODS

Vegetation mapping

For the present study, I classified the vegetation of the Zambezi Delta following the concept of "pedo-ecological units" used by Loxton, Hunting, and Associates (Phillips 1971). Pedo-ecological units are broad natural units representing the interplay of vegetation, microclimate, physiography, and soils. Each pedo-ecological unit is described in terms of the dominant vegetation species in the canopy (and sub-canopy) and herbaceous layer (based on percent cover), key physiognomic characteristics of the canopy (especially height and cover), hydrological signature (range of water tolerance in terms of depth and duration of inundation and soil moisture), position in the landscape, and soil morphology and texture. These characteristics were determined from field research (using a combination of field sampling, aerial surveys, and boat surveys described below) and interviews with local residents during the study period, and through collaboration with the study team of Timberlake (2000).

The composition of each pedo-ecological unit represents a mosaic of vegetation species in association over a range of conditions of different densities and physiognomies. The physical and biological conditions that distinguish between two pedo-ecological units are rarely abrupt in space, but rather occur along a continuous gradient. Therefore, the boundaries between the vegetation units should not be viewed as fixed, nor should the composition of a particular unit be viewed as uniform.

I created two maps using these pedo-ecological units. The historical map describes the vegetation of the delta in 1960, and represents conditions in the delta just prior to the construction of Kariba and Cahora Bassa Dams. Although these conditions cannot be considered "pre-impact" because ecological changes resulting from the construction of roadway and railway embankments along the mainstem Zambezi were already underway since the turn of the century, they do pre-date the period of regulated Zambezi runoff described in Working Paper #2. This is also the earliest map that can be reliably compiled for the delta region, because of the availability of archival aerial photographs. The current map describes the vegetation of the delta in 2000, providing a basis for assessing 40 years of vegetation change.

Historical vegetation mapping

To map the historical distribution of vegetation, I obtained a set of 1:49,350 scale aerial photographs dated 6 August 1960 from the Direção Nacional de Geografia e Cadastro (DINEGECA) in Mozambique. A total of 435 airphotos cover the Zambezi Delta region. With the assistance of a GIS analyst, the vertical, black and white airphotos were mosaicked into a single image using ERDAS OrthoBase software. The resulting mosaic was geo-referenced to 1960 topographic maps produced by DINEGECA. Most of the dominant plant communities were readily delineated from the airphotos based on gray scale tone and texture (*e.g.*, Dunham 1989a). I also identified geomorphic features of the channel and floodplain affecting broad patterns of plant distribution (*e.g.*, Gurnell 1997). Delineation was aided by supervised on-screen-digitizing techniques with ArcView 3.1 GIS software, a process that enables continuous scaling to identify features ranging from individual trees to broad land cover features (Figure 3-5).

To aid in historical airphoto interpretation, I used several additional resources. Land cover and soil maps (scale 1:100,000) produced by Loxton, Hunting, and Associates *et al.* (1975c,d,e,&f) were scanned and geo-referenced to the 1960 airphoto mosaic and used as a computer overlay for interpretation. A 1:50,000 topographic map of the delta with 0.3 m contours was created by digitizing more than 10,000 elevation points from a series of archived 1960 topographic maps (Figure 2-51). For field ground truthing, I obtained archive photos dating back to the early 1900s and re-located each photopoint in the field. I interviewed local chiefs and other long-term residents, safari operators, and naturalists in the field to collect details on the historical vegetation of specific areas of the delta. The records of Tinley (1977) and Loxton, Hunting, and Associates (1975e&f) was also invaluable. From these historical reports and accounts, and inferences based on current vegetation composition, I compiled species lists for each mapping unit.

Current vegetation mapping

For current vegetation mapping, I obtained a Landsat 7 ETM image dated 16 July 2000 from the USGS (Figure 3-6). A single image (path 166, row 73) covers the entire Zambezi Delta. The image was georeferenced to the 1960 airphoto mosaic. I classified vegetation units using supervised on-screen-digitizing with ArcView GIS software, a process that enables scaling down to level of individual pixels (30 x 30 m resolution). The image was classified using various false-color combinations of the six visual ETM bands (blue, green, red, and three infrared bands) for interpretation (Figure 3-7). The classification units follow from those adopted for the historical vegetation map. To aid in image interpretation, I used several additional resources. An unsupervised classification of 50 spectral ranges was generated using the ETM image. Unique spectral signatures and patterns were recognized for many of the mapping units, including mangrove forest, saline mudflats, papyrus and deepwater swamps, acacia thicket, palm savanna, acacia woodland, secondary grassland associations, dry forest on the Cheringoma plateau, miombo woodland and alluvial fans, wetland pans, communities on parallel dune ridges, and open water. Dry season fires that alter reflectance values masked some of these patterns. I used the unsupervised classification image as a computer overlay with the false color image, with both images used interchangeably during the classification process. A Landsat 7 ETM image dated 31 August 1999 and Landsat 5 TM image dated 16 July 1996 were georeferenced to the 2000 Landsat ETM image, and used to clarify spectral features that vary year-to-year as function of soil moisture. A July 1986 Landsat 5 TM image was also used to assess midpoint changes in channel morphology. Recent airphotos comparable to those used for the historical vegetation mapping were not available for the present study. To ensure that any differences between the historical and current vegetation maps were not due to the use of different remote sensing media, I followed a two-step process. First, I obtained a set of 400 1:50,000 scale aerial photographs covering the Zambezi Delta, dated 1 September 1972, from DINEGECA. I compared each 1972 airphoto scene with each 1960 airphoto scene, and recorded changes in land cover during the period 1960-1972. I assessed difficult-to-identify features using stereo pairs of overlapping photographs. Second, I obtained a Landsat MSS image (80-m resolution) dated 1 August 1972 from USGS (Figure 3-8). This is the oldest cloud-free satellite image of the Zambezi Delta available. After geo-referencing the 1972 Landsat image to the 1960 airphoto mosaic I related spectral features of the 1972 satellite image to the 1960 airphotos using tone and texture patterns, noting where actual differences between the 1972 and 1960 airphotos occurred.

Because of the vast size and inaccessibility of much of the delta, ground truthing of the current vegetation map included aerial and boat surveys in addition to field sampling. I conducted three low-level aerial surveys between 1998 and 2000 for the purpose of vegetation mapping. The first two surveys were flown in September 1998 and September 1999 using a Cessna 206 fixed-wing aircraft at 100 m elevation, covering the delta south bank with a series of sixteen, 4 km width transects running parallel to the coastline and the delta north bank with a series of seven transects. Three transects ran in an east-west direction near the Morrumbula ecotone, and a fourth ran in a north-south direction perpendicular the Chinde distributary channel. For each transect, I recorded a continuous, timed record of each successive vegetation unit encountered. I noted the relative cover of visually dominant species (cover-abundance) and general hydrological conditions for each unit. To aid in identification, several oblique color slide photographs were taken of each vegetation mapping unit observed and projected on a screen. The transect lines were overlaid on the 2000 Landsat ETM satellite image. Survey observations and photographs from known points were linked to observed features on the satellite image.

A third survey was conducted in a SRA helicopter in October 2000, with a series of twenty, 4-km width transects on an east-west grid pattern across the delta. Along each transect, I recorded GPS points for each vegetation mapping unit. At representative areas for each vegetation unit, we landed the helicopter and I undertook detailed vegetation sampling (described below).

I conducted field surveys to describe the vegetation units during the dry seasons in 1997, 1998, 1999, and 2000 in the following areas: (a) secondary grassland and palm savanna between Marromeu and Malingapans along the main Zambezi channel, (b) alluvial communities and *Acacia* savanna along the Marromeu-Chupanga road, (c) dry lowland forest, wetland pans, and miombo woodland/wet grassland on alluvial fans

bordering the Zambezi Delta in two hunting concessions (Coutada 11 and 12), (d) floodplain grassland communities, including tussock wet grassland, stoloniferous swamp grassland, and papyrus swamps in the western portion of the delta in Coutada 10, and (e) coastal mangrove, saline mudflats, dune grasslands and beach ridges along the coastline near Chinde. A boat survey of the delta was carried out in 1998 to assess coastal mangrove and mudflats, riverine, and sandbar vegetation associations along the length of the Zambezi from Marromeu to Chinde.

At each survey site, I sampled vegetation along fixed transect lines. I randomly selected a starting point and extended line transects in each cardinal direction, four in total, for 500 m. Along each transect line, I recorded vegetation cover (by line intercept extending vertically between the ground and upper canopy) at 5-m intervals. I recorded vegetation height using measuring poles to estimate height of grassland and lower- strata components, and triangulation to estimate canopy heights. I recorded phenology for woody species as either new leaf, dry leaf, bare branch, flowering, or fruiting. I recorded phenology for grass and sedge species in the following categories: new shoot, dry shoot, flowering, fruiting (in seed). I also recorded average water depth and general soil texture at each sampling interval. All species encountered were either identified in the field using Coates (1983), Van Wyk and Van Wyk (1997), Oudtshoorn (1999), or Skerman and Riveros (1990), or collected for later identification at the herbarium of the University of Eduardo Mondlane in Maputo. Wet season field surveys were not possible because of the impassability of roads.

Vegetation change analysis

After the vegetation maps were completed and verified, I assessed quantitative and qualitative changes in the vegetation and related geomorphic features of the delta. I computed the total area, perimeter, and number of units for each vegetation class and the area and perimeter of each individual vegetation unit for the historical and current vegetation maps using ArcView. From these data, I estimated the total change and percent change of cover of each vegetation unit. Changes in the distribution of species across the delta were estimated by overlaying the historical and current vegetation maps to locate specific areas where vegetation change has occurred (*e.g.*, Milton *et al.* 1995). Inset boxes were prepared to show eight examples of areas where substantial changes in vegetation cover have occurred (Figure 3-9). I verified results of the vegetation change analysis through interviews and discussions with chiefs and other long-term residents of the delta. Informants were asked to describe long-term changes in the vegetation and to point out specific species that had increased or decrease over time, or shifted in distribution.

I assessed factors affecting vegetation change in the delta through field interviews, aerial surveys, ground surveys, boat surveys, and literature review. I interviewed chiefs and other long-term residents of the delta about changes in their land use practices and settlement patterns, changes in river and floodplain morphology, and the occurrence and impact of climatic and hydrological phenomena such as large floods, droughts, and hurricanes. The informants were also asked for their explanations about why vegetation change was occurring. I interviewed safari hunters about changes in the status and distribution of wildlife and the carrying capacity of the delta grasslands. I also interviewed consultants and government staff working in the delta region to better understand patterns of socio-economic change and resource utilization.

I flew eight aerial surveys between 1995-2001, including three reconnaissance flights (1995, 1996, and 1997) to count and map the distribution of waterbirds and large mammals in the delta, two reconnaissance flights to observe vegetation during and after the large Zambezi flooding event of 2001, and the three vegetation mapping surveys described above. During the vegetation mapping surveys, I recorded land use practices along each transect, with GPS points recorded for transect endpoints. All observations of grazing activity, fire, human settlements, and agricultural development were recorded. The transect lines were overlaid on the 2000 Landsat ETM satellite image, and survey observations and photographs from known points along the transects were linked to observed features on the satellite image. Ground surveys and boat surveys were conducted as described above. Additional ground and boat reconnaissance was conducted in October-November 2001 to assess vegetation changes resulting from the 2001 Zambezi floods.

RESULTS

Vegetation Mapping

Twenty-five mapping units are classified on each of the vegetation maps. The historical (1960) vegetation map of the delta is shown in Figure 3-10. The current (2000) vegetation map is shown in Figure 3-11. The total area of vegetation mapped in the delta region is 1,317,000 ha. This includes all of the Quaternary Deltoid Plain and associated waterways (1,198,000 ha.) and several communities on the Cheringoma and Morrumbula Plateau near the delta ecotone. Each mapping unit is described below in terms of the hydrogeomorphic conditions and disturbance processes that maintain community, and the dominant and characteristic species.

Vegetation communities of the Cheringoma and Morrumbula Plateau ecotone

Five vegetation communities are mapped on the escarpment surfaces that rise immediately adjacent to the Quaternary Deltoid Plain, including dry lowland forest with associated wetland pans, miombo woodland/humid grassland/riverine forest mosaic on alluvial fans, Acacia thicket on the low-level Zambezi terrace, and Hyphaene palm savanna and associated species on outwash sands. Although not technically part of the Zambezi Delta, these vegetation communities are included in the vegetation change analysis because they are important source areas for vegetation recruitment in the delta floodplains, affect local fire and grazing patterns, and influence the hydrological regime and water quality of the region.

(1) Dry lowland forest on the escarpment

This vegetation mapping unit comprises tall, dry forest with dense understory on the well-drained, coarse sandy soils of the Cheringoma escarpment near the delta ecotone. The overlapping canopy is dominated by deciduous *Millettia stuhlmanni* (Panga-panga), often exceeding 25 m in height. *M. stuhlmanni* comprises about 30-40% of the canopy, and occasionally occurs in pure stands. Other dominant tree species include various *Brachystegia spp.* (10-20%) and *Pteleopsos myrtifolia* (7-10%), with a mix of deciduous and evergreen species including *Azelia quarensis*, *Balanites maughanii*, *Berchemia zeyheri*, *Burkea africana*, *Celtis mildbraedii*, *Chlorophora excelsa*, *Cleistanthus schlechteri*, *Cordyla africana*, *Erythrophleum suaveolens*, *Inhambanella henriquesi*, *Lecanoidiscus fraxinifolius*, *Morus mesozygia*, *Parinari curatellifolia*, *Pterocarpus angolensis*, *Scleocarya birea*, *Sterculia appendiculata*, and *Strychnos potatorum*. Saket *et al.* (1999) identified more than 120 woody species in the dry lowland forest, including 58 of commercial value.

The underlying water table may fluctuate by more than 5 m each year from the late dry season to the end of wet season. The low water-holding capacity of the escarpment soils prevents vigorous grass growth, and a deep-rooted woody thicket with several midstory strata and a herbaceous ground flora dominates the understory. Midstratum thicket species include *Cola mossambicensis*, *Hunteria africana*, *Millettia usaramensis*, *M. mossambicensis*, *Rinorea arborea*, *Salacia madagascarensis*, *Strychnos usambarensis*, and *Trema orientalis*. *Alchornea laxiflora*, *Drypetes natalensis*, *Strychnos mitis*, *Suregada zanzibarensis*, and *Tapura fisheri* occur in the lower stratum. The tangled growth form is often impenetrable to large mammals.

Loxton, Hunting, and Associates *et al.* (1975e) considered dry *Millettia* forest to be a climax community in the absence of disturbance, noting that forest fires were rare in the understory. However, late dry season fires are now becoming a serious threat to forest cover in this region, and some areas exhibit an almost complete lack of native understory regeneration. Logging has also heavily degraded parts of the forest, especially closer to the Inhanga-Muanza Road. In these areas the present floristic composition, largely secondary thicket, does not reflect the historical flora of the region (Saket *et al.* 1999).

The boundary between the relatively dense dry lowland forest and open Hyphaene palm savanna on outwash sands to the east is clearly identified on aerial photographs and satellite imagery. On its southern border, the dry forest grades into miombo woodland (described below). A similar unit is mapped by Timberlake (2000) as "Dry Forest with *Pteleopsis* and *Millettia*" and by Loxton, Hunting, and Associates *et al.* (1975e) as "Mild Subarid and Subhumid *Millettia* Communities." The total area of dry lowland forest was not calculated because it extends outside the local delta catchment.

(2) Wetland pans in the dry lowland forest

Wetland pans are a distinct feature of the dry lowland forest. These poorly drained depressions are scattered throughout the forest, with black vertisols overlain by fine grain sands from eroded termitaria (Tinley 1977). The pans have a distinct zonation pattern. Outer rings of *Brachystegia* spp. and *Hyphaene coriacea* palms occur at the forest periphery, surrounding a zone of stoloniferous and tussock grasses that may include *Eriochloa procera*, *Hermarthria altissima*, *Hyparrhenia* spp, and *Imperata afrum* among other species. At the center, rings of emergent macrophytes dominated by *Cyperus papyrus*, *Phragmites australis*, and/or *Typha latifolia* are interspersed with floating aquatic species such including *Nymphaea* spp. and *Nymphoides* spp. in shallow standing water. Artisan upwelling maintains the permanently flooded conditions in many pans.

(3) Miombo woodland/humid grassland/riverine forest mosaic on escarpment alluvial fans

This vegetation mapping unit is a mosaic of several communities occurring along a soil moisture gradient on alluvial fans that drain from the dry lowland forest of the Cheringoma Plateau to the floodplain grasslands of the delta. The sandy, well-drained convex fan surfaces (interfluves) are covered in dense, deep-rooted miombo² woodland, typically 20-30 m in height, dominated by *Brachystegia spiciformis*, other *Brachystegia* spp., *Erythrophleum suaveolens*, *Julbernardia globiflora*, and *Pteleopos myrtifolia*. There is one midstory stratum below the canopy, dominated by *Albizia adianthifolia*, *Hymenocardia acida*, *Parinari curatellifolia*, *Syzygium guineense*, *Tabernaemontana elegans*, *Trema orientalis*, and *Vitex doniana*. *Grewia* spp. and *Guettardia speciosa* form large tracks towards the coast on the wettest soils still capable of supporting thicket. The upper branches of *Brachystegia spiciformis* are covered with epiphytic staghorn ferns such as *Platyserium alcicorne* and *P. elephantotis*, and orchids. Woodland communities are less dense than forest with crowns spaced up to 10 m apart, but grass cover is generally sparse on the convex surfaces. *Azelia quarensis*, *Cordyla africana*, *Millettia stuhlmanni*, and other forest elements occur on the slightly raised, better drained surfaces that grade to the dry lowland forest. Tinley (1977) notes that the differences in floristic composition between mosaics of deciduous and evergreen species in the delta are controlled by soil moisture conditions, with evergreen species generally occurring on soils with relatively higher moisture-holding capacity.

Humid grasslands occur on the concave drainage slacks that interfinger with the miombo woodland surfaces. The underlying high water table (hydromorphic) grey sands have sufficient moisture to preclude tree growth. Species include a mosaic of tall and medium height bunchgrass species, including *Alloteropsis semialata*, *Andropogon* spp., *Digitaria adscendeus*, *Elionurus argenteus*, *Eragrostis chapelieri*, *Hyparrhenia* spp., *Imperata cylindrica*, *Ischaemum* spp., *Monocymbium ceresiforme*, *Pogonarthria squarrosa*, *Trachypogon spicatus*, and *Urelytrum squarrosom*, with the bracken fern *Pteridium aquilinum*. Common forbs include *Drosera burkeana*, *D. indica*, *Ericaulon subulatum*, *Fuirena umbellata*, *Lindernia* sp., *Lobelia erinus*, *Lycopodium caolinianum*, *Kyllinga pauciflora*, *Mesanthemum africanum*, *Polygala capillaris*, *Rhynchospora rugosa*, *Sauvagesia erecta*, and *Xyris staminea*. Shallow depressions of hydromorphic and humid gley soils occupy the deepest depressions where runoff channels are not deeply incised, and may support wetland sedges such as *Cyperus* spp., *Eleocharis acutangulis*, and *Scirpus* spp.

Island thickets on termitaria dot the moist grassland slacks, with a variety of mostly evergreen species including *Hyphaene coriacea* and *Phoenix reclinata* palms and dense thickets of *Diospyros mespiliformis*, *Manilkara mochisia*, *Parinari curatellifolia*, *Syzygium guineense*, *Tamarindus indica*, *Uapaca kirkii*, *Uapaca nitida*, *Vitex doniana*, *Xanthocercis zambesiaca*, and many others. Scattered individuals of *Hyphaene coriacea* have established in the open humid grasslands near termitaria, up to 100 m from the woodland edge.

Along the banks of the more deeply incised streams draining the concave slacks, the humid grasslands give way to narrow bands of riverine (fringing) forest on recent alluvium. The forest canopy, typically 20-25 m high, includes evergreen and semi-deciduous species such as *Adina microcephala*, *Azelia*

quarensis, *Anthocleista grandiflora*, *Cassipourea gummiflua*, *Celtis gomphophylla*, *Chlorophora excelsa*, *Ficus* spp., *Funtimia latifolia*, *Hirtella zanguebarica*, *Khaya nyasica*, *Manilkara discolor*, *Morus mesozygia*, *Olea capensis*, *Pachystela brevipes*, *Pseudobersama mossambicensis*, *Syzygium guineense*, and *Vitex doniana*. The midstratum riverine forest thicket includes *Craterispermum schwinfurthii*, *Diospyros natalensis*, *Memecylon sansibaricum*, *Rothmannia fischeri*, *Scolopia stolzii*, and *Suregada zanzibariensis*. Grasses are absent. Riverine forests are well developed on the Mungara, Tandoni, Sassone, Ruave, Nhaguaze, Nhabadu, Chingara, Chandwe, and Zuni Rivers. *Barringtonia racemosa* swamp forest (described below) becomes dominant at the floodplain ecotone.

The relative distributions of miombo woodland and humid grassland associations are edaphically controlled by subtle hydrogeomorphic gradients and difficult to distinguish at the mapping scale. The strong striated pattern of the alluvial fans, however, is clearly identified on aerial photographs and satellite imagery. Riverine forest is too narrow to map at the mapping scale, but fringes the escarpment runoff streams shown in Figures 3-10 and 3-11. Timberlake (2000) mapped the mosaic as “Dense Miombo Woodland with *Brachystegia* and understory of Forest Shrubs and Tussock grassland, seasonally wet.” Loxton, Hunting, and Associates *et al.* (1975e) mapped the miombo woodlands as “Subhumid to Humid *Brachystegia* Communities.” Because this unit extends beyond the local delta catchment, total coverage was not estimated.

(4) Acacia thicket on the low-level Zambezi terrace

Acacia thickets occur on the low-level Zambezi terrace at the base of the Cheringoma and Morrumbula escarpments near the apex of the delta. Deciduous Acacia thicket is transitional between the dry lowland forest and more open floodplain savanna communities. The thicket units are shorter than adjoining forest and woodland associations, generally less than 15 m in height, with variable density and species composition. Characteristic species include *Acacia robusta*, *A. welwitschii*, *Albizia harveyi*, *Combretum imberbe*, *Drypetes mossambicensis*, *Lannea stuhlmannii*, *Manilkara mochisia*, *Spirostachys africana*, and others. Substrate thicket includes *Allophylus africanus*, *Bridelia micrantha*, *Diospyros usambarensis*, *Dalbergia melanoxylon*, *Grewia inaequilater*, *Maytenus senegalensis*, *Xylothea tettensis*, and *Zizphus mucronata*. Grass cover is moderate, with tall and medium tussock species such as *Digitaria* spp., *Hyparrhenia rufa*, *Hyperthelia dissoluta*, and *Sporobolus* spp.

The transition from Acacia thicket to more open woodland and savanna areas is not discrete but rather occurs along a hydrogeomorphic gradient, the borders of this vegetation unit are difficult to distinguish using aerial photographs and satellite imagery. The unit was delineated during the aerial surveys, using low-level oblique aerial photographs, and verified on the ground. Boundaries should not be considered absolute. A similar unit is mapped by Loxton, Hunting, and Associates *et al.* (1975e&f) as “Acacia-Combretum imberbe-Spirostachys communities on the Low-level Terrace—High-level Terrace Transition.” Timberlake (2000) does not map this community. The total area of Acacia thicket was not calculated because it extends outside the local delta catchment.

(5) Hyphaene palm savanna and associated species on outwash sands at the escarpment base

Hyphaene palm savanna occurs on wet hydromorphic sands at the base of the Cheringoma and Morrumbula escarpments along the dry forest-floodplain ecotone. The medium to coarse textured dark outwash sands cover an undulating, incised region where the escarpment surface formations fold under the Quaternary Deltoid Plain (Loxton, Hunting, and Associates *et al.* 1975e&f). The soils are shallow on steeper, less stable slopes and deeper on the more gentle slopes. Subsurface runoff from the escarpment percolates slowly downslope and saturates the outwash sands for six months or longer depending on local rainfall, or discharges into a series of shallow lakes sandwiched between the escarpment and open floodplain.

Hyphaene coriacea palms form dense, monotypic stands (10-30 m canopy spacing) on the outwash sands, colonizing far into the open grassland on small termitaria. Other associated species such as *Annona senegalensis*, *Ficus doniana*, *Parinari curatellifolia*, *Piliostigma thonningii*, *Strychnos spinosa*, *Syzygium*

guineense, *Uapaca kirkii*, *U. nitida*, *Vitex doniana*, and *V. payos* are more restricted to the fringe of the dry forest. Understory grass cover includes bunchgrass associations of *Digitaria milanjian*, *Eragrostis chapelieri*, *Heteropogon contortus*, *Hyperthelia dissoluta*, *Pogonarthria squarrosa*, and other species.

This vegetation unit is easily distinguished from the Acacia thicket and Dry forest associations at the base of the Cheringoma and Morrumbula plateaus, respectively, on airphotos and satellite imagery. The transition from palm savanna on outwash sands to tussock wet grassland on the hydromorphic vertisols of the open floodplain is less distinctive. The historical boundary is mapped on airphotos based on estimated tree density, and mapped on current satellite imagery from aerial transect surveys, using oblique color photographs to gauge density.

Woody communities on the Quaternary Deltoid Plain

Five predominately woody vegetation communities are mapped on the Quaternary Deltoid Plain. Each of these communities is edaphically controlled. Acacia woodland and savanna, *Borassus* palm savanna, and *Hyphaene* palm savanna occur along a gradient of increasing moisture on hydromorphic vertisols in the upper delta plain, eventually giving way to open tussock grasslands where seasonal flooding is more prolonged. Acacia thicket occurs on slightly raised coastal saline vertisols that are only briefly inundated. Mixed palm-Acacia thicket occurs on the stratified alluvium of relict and current river levees. Grass growth may be vigorous, but the woody canopy is generally spaced less than 100 m apart.

(6) Acacia woodland and savanna on floodplain vertisols

A mosaic of Acacia woodland and savanna is mapped over widespread areas of the more elevated delta plain. *Acacia polyacantha* is dominant, in association with *A. sieberana*, *A. xanthophloea*, *Antidesma venosum*, *Capassa violacea*, *Cordyla africana*, *Kigelia africana*, *Lannea stuhlmannii*, *Lonchocarpus capassa*, *Piliostigma thonningii*, and *Trichilia emetica* depending on subtle variations in topography and soil moisture. Dense mixed stands of *Borassus aethiopum* palm occur on slightly wetter substrates near escarpment ecotone. Canopy density varies from less than 10 m spacing between crowns (woodland associations) to up to 100 m spacing (savanna associations). Acacia savanna is typically single-storied, with a midstory shrub layer of *Diospyros mespiliformis*, *Ficus* spp., and associated species on slightly drier soils, and light penetration is high. Grass growth is vigorous, with dense cover of tussock species including *Hyparrhenia dichroa*, *Ischaemum afrum*, *Panicum maculatum*, *Setaria* spp., and *Vetiveria nigriflora*.

Extensive areas of *A. polyacantha* savanna are cultivated. In these areas, mango (*Mangifera indica*) and cashew (*Anacardium occidentale*) trees are often the dominant canopy species, with an understory of papaya and banana trees. These areas may also be considered with other secondary communities on the Quaternary Deltoid Plain, described below.

A. polyacantha communities are edaphically controlled, occurring on vertisols of the seasonally wet or periodically flooded floodplain fringe and on slightly elevated areas within the grassland mosaic. Acacia savanna is transitional in soil moisture status between relatively dry Acacia thicket communities on the low-level Zambezi terrace and the seasonally inundated palm savanna associations on the upper floodplain vertisols. Deciduous *Acacia polyacantha* persists with minimal moisture availability at the end of the dry season, and tolerates only very short-duration flooding (Tinley 1977). Seasonal grassland fires help maintain the open savanna structure, eliminating invasive thicket species, but areas subject to heavy livestock grazing in the past (especially heavily settled areas) had a high density of woody species (Loxton, Hunting, and Associates *et al.* 1975b).

The total area of Acacia savanna on the Quaternary Deltoid Plain is currently about 140,000 ha, the most extensive vegetation association in the delta. Because this vegetation unit represents a mosaic of communities with varying canopy density and cultivation patterns, it is difficult to distinguish from open areas of Acacia thicket and dense areas of *Borassus* palm savanna using airphotos and satellite imagery. Boundaries are drawn where species composition more closely resembles one unit over another, but should be considered as approximate only. This community is mapped by Loxton, Hunting, and

Associates *et al.* (1975e&f) as “Acacia-Combretum Woodland and Open Woodland Communities.” Timberlake (2000) maps “Acacia savanna with *Hyphaene*” for the north bank region, but lumps it together with “*Borassus* and *Hyphaene* palm savanna” on the south bank.

(7) *Borassus* palm savanna on floodplain vertisols

Tall *Borassus aethiopum* (up to 20 m) is a common and often conspicuous component of the floodplain margin on hydromorphic vertisols. *Borassus* palm savanna occurs along a narrow transitional moisture gradient from *Acacia polyacantha* savanna on slightly drier soils to *Hyphaene coriacea* on slightly wetter floodplain soils. At the upper extent of its range, *B. aethiopum* forms a fairly dense thicket, with crowns only 10-20 m apart and a variety of associated species similar to Acacia savanna. With increasing soil moisture content, *B. aethiopum* forms mostly monotypic stands with only 5-10% cover and vigorous grass growth. *Hyparrhenia dichroa*, *Imperata cylindrica*, and *Ischaemum afrum* are dominant bunch grasses below the *B. aethiopum* canopy, with *Setaria* spp. and stoloniferous grasses dominant in depressed wetter sites on humid gley soils. *B. aethiopum* is a very slow growing species with a lifespan of about 60 years, and only flowers after 30-40 years when reaching a height greater than 7 m (Schwarz 1998). In some areas, adult *B. aethiopum* palms are widespread without any evidence of regeneration, likely reflecting changes in edaphic conditions. Adult palms are fairly resistant to grassland fires, and may intensify with heavy grazing.

Borassus palm savanna is often mixed with extensive cultivation near Marromeu, with small cultivated plots covering about 40% of sub-canopy. The palms are important in the local economy for palm wine and firewood (DNFFB 1998).

Borassus palm savanna currently covers about 8000 ha. of the Quaternary Deltoid Plain. This vegetation unit cannot be easily differentiated from adjacent units of Acacia savanna or *Hyphaene* palm savanna using airphotos or satellite imagery, especially where the species are mosaicked along subtle moisture gradients. The unit was delineated during the aerial transect surveys for areas where *B. aethiopum* is the dominant canopy species, but boundaries should not be considered absolute. Small areas of *B. aethiopum* within extensive canopies of *Acacia* spp. or *Hyphaene coriacea* were not mapped separately. This unit is mapped separately by Loxton, Hunting, and Associates *et al.* (1975e&f), but lumped together as “*Borassus* and *Hyphaene* palm savanna” by Timberlake (2000).

(8) *Hyphaene* palm savanna on floodplain vertisols

Hyphaene coriacea (3-7 m) occurs over vast areas on the central delta floodplains on hydromorphic vertisols, especially west and south of Marromeu. *H. coriacea* typically occurs in monotypic stands, with a dense understory of tussock grassland species including *Hyparrhenia rufa*, *Imperata cylindrica*, *Setaria* spp., and *Vetiveria nigriflora*, and with stoloniferous grasses in wetter depressions on humid gley soils. The density of *H. coriacea* palms is highly variable, with areas averaging only 51 trees/ha near Marromeu (DNFFB 1998), but with areas of dense 20-25% cover. *H. coriacea* is resistant to seasonal flooding, soil saturation, and fire, and is therefore the first woody pioneer of the seasonally flooded grassland. *H. coriacea* often persists after short-duration flooding has eliminated other woody invaders (Tinley 1977). Reproductively mature *H. coriacea* palms are distinguished by their smooth bark—the trunks of immature palms are wrapped with the dry cerians of old leaf stems. Elephants and probably also baboons disperse seeds of *H. coriacea* as well as *B. aethiopum* through browsing activity. In the past, large herds of buffalo grazed the palm savanna seasonally, while zebra, sable antelope, and Lichtenstein’s hartebeest grazed the area throughout the year.

Much of the palm savanna landscape near the mainstem Zambezi has been extensively cultivated with sugarcane. The palm fronds are used for baskets, mats, and other woven items, and the sap is used to make palm wine (DNFFB 1998).

The total area of *Hyphaene* palm savanna on the Quaternary Deltoid Plain is currently about 86,000 ha. The boundary between this vegetation unit and tussock wet grassland mosaic is artificial, based only on relative canopy cover. Grass species composition between the two units is nearly identical, with a

relatively high percentage of species that are intolerant of prolonged flooding in the savanna. *Hyphaene* palm savanna is therefore mapped on airphotos for areas where canopy separation was less than 100 m, and mapped on satellite imagery during the aerial transect surveys, with the help of oblique color photographs. This unit is also mapped by Loxton, Hunting, and Associates *et al.* (1975e&f), as described above.

(9) Acacia thicket on floodplain vertisols

On the north bank floodplain, Acacia thicket occurs over a broad flat area of slightly elevated, seasonally flooded coastal saline soils southeast of Luabo. Soils are predominately humid clays and vertisols, with tidally influenced drainage lines. Dense *Acacia robusta*, 5-15 m high, is dominant along with *A. polyacantha*, *A. xanthophloea*, *Lannea stuhlmannii*, and *Phoenix reclinata*. The thicket is non-uniform, and includes patches of *A. polyacantha* woodland and more open tussock grassland on slightly depressed sites. In wetter saline areas between the thicket and coastal mangrove associations, this association gives way to more open *Setaria* spp. grassland. Further inland, *A. polyacantha* savanna and *Hyphaene* palm savanna dominate on seasonally flooded soils.

Loxton, Hunting, and Associates *et al.* (1975e&f) considered Acacia thicket to be a climax community for floodplain grassland, *Acacia polyacantha* savanna, palm savanna, and coastal inland mangrove associations in the absence of disturbances such as flooding, grazing, and fire. The presence of Acacia thicket on the delta floodplain is therefore likely indicative of natural or human-made disruptions in the floodplain disturbance regime.

Acacia thicket currently covers about 25,000 ha. of the Quaternary Deltoid Plain. Because the transition from Acacia thicket to associations of woodland and savanna is not discrete but rather occurs along a gradual gradient, the borders of this vegetation unit are difficult to distinguish using aerial photographs and satellite imagery. The unit was delineated during the aerial surveys, using low-level oblique aerial photographs, and verified on the ground. Boundaries should not be considered absolute. A similar unit is mapped by Loxton, Hunting, and Associates *et al.* (1975e&f) as “Acacia-Combretum imberbe-Spirostachys communities on the Low-level Terrace—High-level Terrace Transition.” Timberlake (2000) does not map this community.

(10) Mixed Palm-Acacia thicket with cultivars on stratified alluvium

Mixed palm-Acacia thicket associations are mapped as narrow bands of riverine thicket occupying the stratified alluvium of relict and current levees of the Zambezi and major tributary channels. The recently deposited levees, composed of well-drained light to medium textured soils with minimal hydromorphy, are superimposed on the deltoid plain and support savanna and thicket species that were historically precluded from high water table conditions in the deeper medium to heavy textured soils and vertisols that occupy the plains further from the levee-stream channel complex and the depressed and backslope areas. Microrelief is hummocky. *Acacia xanthophloea*, *A. polyacantha*, *Borassus aethiopum*, and *Hyphaene coriacea* are common upper stratum associates with a mixed evergreen and semi-deciduous sub-stratum of *Phoenix reclinata* with *Allophylus* spp., *Antidesma venosum*, *Bridelia cathartica*, *Combretum microphyllum*, *Ficus* spp., *Kigelia africana*, *Lannea stuhlmannii*, *Terminalia prunoides*, *Trichilia emetica*, and other species. Grassland cover is moderate, with *Hyparrhenia dichroa* and *Imperata cylindrica* tussock grasses typically dominating.

Because these communities occur close to water but experience only periodic flooding, they are densely settled and the natural vegetation has been altered by centuries of cultivation, livestock grazing, and burning. Trees such as mango, cashew, and banana are common cultivars, often dominating the canopy. These riverine corridors are also important for small mammals and birds in the delta, providing high ground during moderate floods (Loxton, Hunting, and Associates *et al.* 1975b).

The total area of mixed palm-Acacia thicket associations on stratified alluvium above the Quaternary Deltoid Plain is currently about 74,000 ha. The alluvial formations defining this vegetation unit are clearly distinguished on airphotos and satellite imagery. On the south bank, the Salone, Cuncue, and

Nhasua Rivers have extensive levee systems in their upper reaches near Marromeu. The Cuacua and Muta Rivers, along with a number of relict tributaries on the north bank, also feature abandoned channel-levee systems. Loxton, Hunting, and Associates *et al.* (1975e&f) divide the community into two mapping units, including a “*Hyphaene-Borassus-Phoenix* savanna-*Acacia* woodland complex” unit and a sub-unit of “Communities on stratified alluvium.” Timberlake (2000), however, does not distinguish this community from the adjacent “*Borassus* and *Hyphaene* palm savanna” in his classification.

Grassland communities on the Quaternary Deltoid Plain

More than half of the south bank including the entire area covered by the Marromeu Buffalo Reserve and vast areas of the north bank near the coastline consist of a broad mosaic of open grass and sedge associations. Woody species are absent or sparse, with canopies more than 100 m apart. Grassland species composition is related to the frequency, duration, and depth of flooding. Tussock wet grass associations cover broad floodplain areas that are seasonally inundated by rainfall or Zambezi floodwaters. Stoloniferous swamp grasses occur on the lowland floodplain with prolonged inundation and perennially wet soils, with papyrus swamps common in permanently inundated depressions on the delta. Saline grasslands, often associated with *Phragmites* reed swamps, occur immediately inland from, and among, the coastal mangrove associations. Each grassland association is a mosaic of many species, related to a variety of ecological factors including microtopography, soil texture, soil chemistry, grazing tolerance, and fire frequency (Thompson 1985). Tinley (1994) stressed the importance of soil morphology in controlling grass species distribution both within and among the mapping units, noting specific associations on hydromorphic clays, duplex sands, and leached clays. Loxton, Hunting, and Associates *et al.* (1975e&f) differentiated five associations on the south bank east of the Marromeu reserve, and 14 on the north bank, based on flooding duration and salinity.

(11) Tussock wet grassland mosaic on floodplain vertisols

Tussock grasses are characteristic of seasonally flooded sites that are inundated for 2-3 months during the rainy season and moisture limited during the late dry season. Tussock grasslands occur on hydromorphic vertisols that shrink during the dry season, leaving wide and deep cracks, and swell when wet such that once saturated during the rainy season the clay becomes almost impermeable to water and is frequently anaerobic. Hydromorphic vertisols occupy the broad regionally depressed plains covered by deltoid deposits, and depressed areas along the reverse slopes of river levees (Loxton, Hunting, and Associates 1975c&d). Soil patterns are generally uniform over large areas. In the lowest depressions where runoff accumulates and groundwater is influenced by tidal fluctuations, humic gleys supporting stoloniferous grasses become dominant. Surface microrelief is often hummocky. The vertisols typically overly saline gley soils. In the wettest sites, the gley approaches within 30 cm of the surface, while on the drier more elevated sites dark colored A horizons may be more than 100 cm thick (Loxton, Hunting, and Associates 1975c&d).

Dominant tussock grasses tend to have wide ecological tolerance, adapted to prolonged drought conditions as well as seasonal inundation (Thompson 1985). Many species are tall and rank. *Hyparrhenia dichroa* is dominant in the driest sites still supporting grassland, along with *Imperata cylindrica*, and is generally associated with lightly scattered *Hyphaene coriacea* palm trees. These massive, deep-rooted grass species, widespread on expansive clay soils of the upper floodplains and woodland, are unpalatable to most species except hippo (Tinley 1977). *Ischaemum afrum* is locally dominant on wetter sites transitional to *Hyparrhenia dichroa*, along with *Panicum maculatum*. On slightly lower floodplain areas, several species of *Setaria* spp. bunch grasses (including *S. holstii*, *S. woodii*, and *S. phaneococca*) form extensive stands associated with *Vetiveria nigriflora*. These are among the most flood-tolerant of the bunch grasses. Near the escarpment-floodplain ecotone, tussock grasslands on sandy hydromorphic soils include *Brachiaria humudicola*, *Eragrostis* spp., *Loudetia simplex*, *Pennisetum polystachion*, and *Sporobolus pyramidalis*. Common sedges include *Fuena ciliaris*, *Phynchospora corymbosa*, *Pycreus macrostachyos*, and other *Cyperus* spp. Herbaceous species include *Drosera burkeana*, *D. indica*,

Ericaulon subulatum, *Lindernia* sp., *Lobelia erinus*, *Lycopodium caolinianum*, *Kyllinga pauciflora*, *Mesanthemum africanum*, *Polygala capillaris*, *Rhynchospora rugosa*, *Sauvagesia erecta*, and *Xyris staminea*.

Many of the tussock grasses are palatable during the early wet season, when buffalo, zebra, waterbuck, and other species of wildlife migrate from the more deeply inundated floodplains to graze heavily on the new shoots. The grasses become coarse and unpalatable during the dry season (Ellenbroek 1987). Where heavily grazed, a shorter bunch grass community may dominate including some prostrate rhizomatous species such as *Acrocerus* spp., *Cynodon* spp., *Digitaria* spp., *Panicum* spp., and others (Tinley 1977). The general inaccessibility of the grasslands due to long periods of floodwater inundation have resulted in very few human settlements, and the effects of human activity on the grassland vegetation are relatively minor.

The total area of seasonally wet (freshwater) tussock grassland in the delta is currently about 115,000 ha. This vegetation unit is not readily distinguished from Hyphaene palm savanna and stoloniferous swamp grassland with which it forms a mosaic. Hyphaene palm savanna, as described above, is delineated for grassland areas where the canopy separation is less than 100 m. Stoloniferous grasslands areas are delineated as darker grassland areas of low elevation on airphotos and have different spectral signatures on satellite imagery (verified by aerial survey transects and field surveys in accessible areas). The boundaries between these communities should not be treated as absolute, especially where stoloniferous and tuft grass species intermix along zones of transitional moisture. Within the tussock grassland associations, small depressions of stoloniferous grassland on humic gleys in low-lying depressions are not distinguished. Loxton, Hunting, and Associates *et al.* (1975e&f) divides tussock grassland into four sub-units, including, “*Vetiveria-Ischaemum* tall bunch grass mosaic,” “*Ischaemum-Setaria* tall bunch grass mosaic,” “*Setaria-Vetiveria-Hyparrhenia* tall bunch grassland mosaic,” and “*Hyparrhenia* bunch grass-savanna associations,” with an additional unit, “*Setaria* grassland mosaic,” at the transition between stoloniferous and tussock growth forms. The authors cautioned that the scale of mapping and difficulties of grass identification in the dry season limited the usefulness of these delineated units, however. Timberlake (2000) does not separate stoloniferous and tussock grassland associations.

(12) Stoloniferous swamp grassland mosaic on floodplain humic gleys and strong vertisols

Stoloniferous grasses are characteristic of wetter sites with prolonged inundation, from 4-8 months or more during the flooding season, and saturated soils throughout the dry season. Stoloniferous grasslands occur on humic gleys and strongly expansive, hydromorphic vertisols occupying broad regionally depressed plains on the deltoid deposits. Thin topsoil directly overlies the gleyed clay subsoil that, on drying, tends to form a hard crust. Where the area is slightly elevated and better drained, the topsoil is thicker and vertisol characteristics are evident. The soils are fairly acid but strongly saline (Loxton, Hunting, and Associates 1975c&d).

Characteristic species of the stoloniferous swamp grassland mosaic include a *Echinochloa pyramidalis*, *E. scabra*, *Cyperus digitatus*, *C. exaltatus*, *C. distans*, *Leersia hexandra*, *Oryza longistaminus*, *Hemarthria altissima*, *Paspalum orbiculare*, *Panicum maximum*, *P. repens*, and *Setaria* spp. *C. exaltatus* is often dominant in semi-permanent deep water areas, especially old anastomosing channels, over vast areas of the southern delta. In deepest water conditions, *C. exaltatus* gives way to papyrus swamps and open water communities of floating and submerged aquatic macrophytes. *E. scabra* is also characteristic of the deeper-flooded lowland areas on the floodplain, often mixed with swards of *Vossia cuspidata*. *C. digitatus*, *C. holubii*, *E. pyramidalis*, and *L. hexandra* associations characterize areas of prolonged inundation at a medium depth, often at the edges of water channels, along with *Acrocerus macrum*, *O. longistaminus*, and *Paspalum vaginatum* on shallower-flooded soils. Herbaceous species occur on floating mats of emergent macrophytes. *Hemarthria altissima*, a rhizomatous species with floating stems, is commonly associated with *Panicum repens* on sandy hydromorphic soils at the drier end of the perennially wet grassland mosaic. Most of the soft-leaved grasses and sedges of the wet grassland mosaic have very high grazing value for wildlife, especially buffalo and waterbuck (Ellenbroek

1987). *Eleocharis acutangula* and *E. dulcis* are locally important in seasonally inundated floodplains near drainage lines at the Cheringoma ecotone. *E. acutangula* may occur as an emergent from deep, permanent waters near papyrus swamps, or as a minor component of the deepwater *Vossia cuspidata*/*Echinochloa scabra* communities. *Eleocharis acutangula* is more typical of shallow-flooded *Cyperus* communities frequently associated with *Cyperus issocladus*, *Fuina ciliaris*, *Pycneus* spp., *Scirpus inclinatus*, and *S. cubensis*.

The total area of stoloniferous swamp grassland in the delta is currently about 117,000 ha., similar in extent to the area of seasonally wet tussock grassland. As with the seasonally wet tussock grassland, the boundaries of this mapping should not be treated as absolute. Loxton, Hunting, and Associates *et al.* (1975e&f) defined three sub-units representing stoloniferous wet grassland associations, including *Echinochloa* swamp grassland mosaic, Chimanganyati swamp grassland mosaic, and *Cyperus digitatus*-*Leersia* swamp grassland mosaic.

(13) Papyrus swamps on floodplain waterways and lagoons

Papyrus swamps occur in deep, permanently inundated areas of the delta. On the north bank, a vast *Cyperus papyrus* swamp (more than 50,000 ha.) occurs in the floodplain of the Cuacua distributary channel near Quelimane. On the south bank, papyrus swamps with mixed peripheral grasses occur in old anastomosing channels that traverse the seasonally and perennially flooded grasslands. The floating papyrus mats support a diversity of shallow-rooted plants, including *Echinochloa scabra*, *Ipomea aquatica*, *Melanthera scandens*, *Pycneus nitidus*, *Polygonum* spp, and *Vossia cuspidata*.. Floating and submerged communities of *Nymphaea caerulea*, *Nymphoides indica*, *N. nilotica*, and *Utricularia* spp. occur in wet troughs and pans in the papyrus mosaic, often with invasive *Pistia stratiodes*, *Eichhornia crassipes*, and *Azolla filiculoides* where standing water is frequently absent at the end of the dry season.

Papyrus and deepwater swamp vegetation currently cover about 84,000 ha. of the delta. The extent of papyrus swamps is clearly delineated on airphotos and satellite imagery. Loxton, Hunting, and Associates *et al.* (1975f) and Timberlake (2000) map the large papyrus swamp unit on the north bank, but lump papyrus swamp with other wet grassland associations on the south bank.

(14) Saline grassland mosaic with *Phragmites* reedswamp on floodplain gleys and waterways

Saline grassland mosaics occur along the delta coastline on gleyed halomorphic soils. These plains are not subject to direct tidal inundation, but are influenced by subsurface tidal movements and receive irregular freshwater flushing from Zambezi floodflows. Groundwater is strongly saline.

Salinity is a major controlling factor in vegetation species distribution in addition to flooding regime (Thompson 1985). Dense reed grasslands of *Phragmites australis* occur on acid saline soils in the coastal mangrove belt, occasionally with *Typha latifolia*, and often bordered by *Leersia hexandra* grassland associations. *T. latifolia* also occurs in pure stands in tidal areas near coastal mangroves along the north bank coast. These species replace papyrus, which is less salt and drought tolerant, on the highest tidal reaches of the streams entering the delta mangrove estuaries. *Eriochloa borumensis*-*Hemarthria altissima* grasslands dominate on saline soils less influenced by tidal waters, and may be considered as transitional between saline and freshwater grasses. *Cyperus digitatus*-*Leersia hexandra* associations occupy brackish areas near the coastal mangrove subject to prolonged inundation. Other dominant species include *C. procurus* on saline flooded sites with *Scirpus maritime* and *Panicum repens*, and short grass areas composed of *Cynodon dactylon*, *C. laevigatus*, *Diplanthe fusca*, *Paspalum vaginatum*, and *Sporobolus virginicus* on saline clays. Open water areas among the reedswamps include *Nymphaea caerulea*, *Nymphoides indica*, *N. nilotica*, and floating invasive aquatic species.

The total area of coastal saline grassland with *Phragmites* reedswamp in the delta is currently about 147,000 ha., almost 32% of the total area of grassland communities on Quaternary Deltoid Plain. *Phragmites* reedswamps are easily delineated on airphotos and satellite imagery, but other saline grassland associations are not readily distinguished from perennially wet or seasonally wet tussock grassland using remote sensing. Historic saline grassland associations are delineated from archival soil maps

and the Loxton, Hunting, and Associates *et al.* (1975e&f) reports, based on species composition and proximity to the coastline and tidal drainages. The current distribution of saline short grass species is mapped from aerial survey transects on the satellite imagery, and verified by ground truthing at several areas on the south bank coastline. The boundaries between these communities should not be treated as absolute. Loxton, Hunting, and Associates *et al.* (1975e&f) maps three saline grass communities, “*Eriochloa borumensis* grassland,” “*Sporobolus* grassland-*Phragmites* reedswamp mosaic,” and “*Phragmites australis* reedswamp.” Timberlake (2000) does not differentiate saline grassland, but incorrectly maps the open saline grassland area in the southwest corner of the delta as *Borassus* and *Hyphaene* palm savanna (Figure 3-3).

(15) Aquatic macrophytes on floodplain swamps and lagoons

Shallow oxbow lagoons and swamp depressions occur in low-lying areas throughout the delta floodplain, underlain by humic gley soils. Most of these water bodies are permanently flooded. Lagoons and swamp depressions are colonized by a variety of floating, floating-leaved, and submerged aquatic macrophytes, including *Vossia cuspidata*, *Lemna* spp., *Nymphaea lotus*, *N. cerulean*, *N. `petersiana*, *Utricularia livida*, *U. subulata*, *Wolffiella denticulata*, and others. *Cyperus papyrus* and *Typha latifolia* may also be present. Floating aquatic vegetation is strongly developed where flows are very slow or stagnant, including the invasive aquatic macrophytes *Pistia stratiotes*, *Eichhornia crassipes*, *Azolla filiculoides*, and *Salvinia molesta*.

Larger water bodies densely covered with floating aquatic vegetation were identified from airphotos, and during aerial transects. Smaller swamps and lagoons that occur in a mosaic pattern with Tussock wet grassland, Stoloniferous swamp grassland, Papyrus swamps, and Saline grasslands with *Phragmites* reed swamps were not mapped separately. The total area of shallow swamps and lagoons with aquatic flora was not estimated.

Cultivated areas with secondary vegetation

For centuries, widespread areas on the delta floodplain have been cleared of most native vegetation and developed for agriculture. The two most altered communities are the formations on recent alluvial deposits from the Zambezi and major distributary channels that are cultivated with a variety of traditional crops, and the vast areas of the floodplain grassland near Mopeia, Luabo, and Marromeu that have been developed by Sena Sugar Estates. Nearly all of the delta vegetation communities have been modified to some extent by human activity, however, including logging in the escarpment areas, cultivars and small plantations in the upper delta floodplains, and coconut plantations on coastal ridge and swale topography.

(16) Cultivated areas with secondary vegetation associations on stratified alluvium

Recent deposits of the Zambezi River and its major distributaries, superimposed on the Quaternary Deltoid Plain, have a medium textured, dark colored surface horizon (to a depth of 30-100 cm) overlaying a stratified light textured alluvium. Low-lying areas have heavier textured soils with a deeper horizon above the light textured alluvium (Loxton, Hunting, and Associates *et al.* 1975c&d). These soils are ideal for traditional cultivation, and have been heavily exploited for centuries. Typical crops include maize, rice, sorghum, beans, cassava, and millet.

Secondary grassland derived from cultivation includes widespread areas along the mainstem Zambezi River and abandoned distributaries in the upper delta that have been cleared for cultivation during the past century, some of which have since reverted to grassland and thicket. The species mosaic includes a mix of riverine thicket and *Acacia* woodland, often mixed with a canopy of cultivated plants. Grasslands are tall and coarse, and dominated by *Hyperthelia dissoluta* and *Pennisetum polystachion* on lighter sands and *Hyparrhenia* spp. and *Setaria incrassata* on heavier clay soils, occasionally with scattered *Borassus* palm savanna. These grasses were grazed heavily in the past prior to the civil war, leading to local intensification of savanna species. Newly established *Acacia* savanna and thicket associations include *Acacia polyacantha*, *A. sieberiana*, and *A. xanthophloea* in the upper stratum, with *Antidesma venosum*,

Bridelia cathartica, *Combretum microphyllum*, and *Allophylus* spp. common in the sub-stratum. Other common species of alluvial communities included the palms *Borassus aethiopum* and *Phoenix reclinata* and evergreen *Ficus sycamorus*, *Kigelia africana*, and *Trichilia emetica*. Mango, cashew, and banana are common cultivars, often dominating the canopy. Riparian areas along the mainstem Zambezi are mostly cultivated, but include dense stands of *Phragmites mauritanus* in shallow flooded areas.

Currently, about 34,000 ha. of the delta is in secondary grassland-savanna-thicket associations on cultivated delta alluvium. This vegetation unit, with its characteristic riverine morphology is clearly delineated from surrounding communities on airphotos and satellite imagery. Loxton, Hunting, and Associates *et al.* (1975e&f) maps this area in two sub-units, including “*Acacia polyacantha* savanna” along the upper reaches of the Zambezi River between Chupanga and Marromeu, and “*Borassus-Phoenix* palm savanna with various cultivars” along the backslope levees of middle reaches of the Zambezi River from Marromeu to the Mucelo River branch.

(17) Sugar plantations with secondary grassland-savanna associations on the delta vertisols

Widespread sugar plantations occur on the fertile floodplain vertisols near Marromeu and to a lesser extent Luabo. These diked, irrigated plantations replaced Hyphaene palm savanna and open tussock wet grassland. Stratified alluvium, supporting traditional cultivation and secondary grassland-savanna-thicket associations, dissect the planting units. Secondary grassland with scattered *Borassus aethiopum* palms cover large areas of abandoned sugar fields, but these areas are being actively rehabilitated and will be soon under production³. The total area of sugar plantation fields and associated secondary vegetation in the delta is currently about 30,000 ha. These units are readily mapped from airphotos and satellite imagery by their distinctive irrigation grid pattern.

Mangrove and associated communities

The delta coastline includes some of the most extensive mangrove forests on the Indian Ocean coast (Goodman 1992). Near the distributary mouths, mangrove and associated species stretch about 35 km up the banks of the Zambezi and Mucelo Rivers, and about 23 km inland along the Mungari River. Away from the major rivers, mangrove radiates inland up to 10 km along the deeply incised tidal channels that dissect the coastal plain. Three mapping units are distinguished, including dense mangrove forest associations on coastal waterways, pioneering *Avicennia* mangrove on estuarine mudflats, and *Barringtonia* swamp forest at the upper extent of tidal influence.

(18) Mangrove forest on the coast estuary

Coastal mangroves and associated species occur on structureless, halomorphic clay mudflats mixed with pockets of sand and peat (Vilankulos and Marquez 2000). The mudflats are strongly saline and inundated by tides at or above the topsoil level. Numerous drainage creeks dissect the mangrove flats.

The mangrove forest unit includes eight species of true mangrove, occurring mostly in a conspicuous pattern of zonation with monospecific bands in narrow transition zones according to tidal variation in water depth, salinity, and shade tolerance (Mac Nae 1968, Vilankulos and Marquez 2000). Each mangrove species is uniquely adapted to survive in highly saline and anaerobic soils. *Sonneratia alba* and *Avicennia marina* have the greatest range of all the species and are common pioneers on the exposed seaward front. A zone of *S. alba* forms on muddy and firm soils, with zones of tall *A. marina* developing on firm sandy soils in the seaward same niche. As sediments accumulate in the *S. alba* and *A. marina* rooting systems, they are replaced by *Rhizophora mucronata* and *Ceriops tagal*. A zone of tall *R. mucronata* often develops behind the *A. marina* zone, followed by a zone of *C. tagal* thicket on thicker sediments. *Bruguiera gymnorrhiza* (sometimes in association with *Ceriops tagal* in the substratum) replaces *A. marina* in shallow waters frequently flooded by tides to a moderate depth. *Rhizophora mucronata* replaces *B. gymnorrhiza* at the seaward limit of mangroves in deeper waters, in frequently flooded areas with a wide tidal range. *R. mucronata* is also a primary colonizer of up-river sandbanks. *Xylocarpus moluccensis* co-occurs with the *C. tagal-B. gymnorrhiza-R. mucronata* association in the

interior along small inlets. *Lumnitzera racemosa* is found along riverbanks associated with *B. gymnorrhiza* and *X. moluccensis*. *Heritiera littoralis* is found at furthest inland extent of mangrove, giving way to associations of *Barringtonia racemosa* in the landward zone. Associated plants, usually on sites least flooded by tides include the large shrubs *Guettarda speciosa*, *Hibiscus tiliaceus*, *Pemphis acidula*, *Suriana maritima*, and *Thespesia populnea* and the large fern *Achrostichum areum*.

Although most of the coastal mangrove region is sparsely inhabited, parts of the mixed mangrove belt are cultivated with coconut, mango, banana, and rice, usually on levee areas near the larger drainage lines. Mangrove trees are utilized for construction and firewood, especially *Rhizophora mucronata* which produces the best building poles (Chande 2000). Intensive fishing and shellfishing occur in the mangrove channels.

Mangrove forest currently covers about 100,000 ha. in the delta. Mac Nae (1968) suggests that mangrove forests are not as extensive as might be expected along the Zambezi coastline, perhaps limited by high banks that may prevent mangrove roots from reaching into the salt water horizon that underlies the surface freshwater. Mangrove areas are clearly identified by tone and texture on airphotos, and have very unique spectral characteristics on satellite imagery. Loxton, Hunting, and Associates *et al.* (1975e&f) map a similar unit. Timberlake (2000) mapped coastal mangrove together with saline mudflats and inland freshwater mangrove associates. Vilankulos and Marquez (2000) map a small section of delta mangrove along the south bank from 1999 SPOT imagery.

(19) Saline mudflats with pioneer mangrove communities on the coastal estuary

Large areas of hypersaline estuarine mudflats occur on the inland margin of the coastal mangrove associations. The largest mudflat areas occur on the north bank near Quelimane. These bare flats were formerly covered with mangrove, until sediments trapped by mangrove roots accumulated above the high tide level and created hypersaline conditions too toxic for the mangroves to persist (Tinley 1977), as evidenced by dead and dying mangroves along the margins of the flats. As springtide scour and localized rainfall runoff incise the bare flats, the surface cuts are re-invaded by *Avicennia marina* shrubs and *Salicornia* spp. succulents. *Hibiscus tiliaceus* is common in the narrow ecotone between the mudflats and coastal sand dunes. The unit includes abandoned cultivation and clear-cut areas.

The total area of saline mudflats in the coastal mangrove forest is currently about 45,000 ha. The mapping units are small but clearly differentiated from mangrove on airphotos and satellite imagery. Loxton, Hunting, and Associates *et al.* (1975e&f) map these areas as “*Avicennia* mangrove--hypersaline estuarine mudflat complex” and “*Avicennia* mangrove--wet grassland complex with mixed cultivation near settlements.”

(20) *Barringtonia* evergreen swamp forest on coastal waterways

Evergreen "inland mangrove" thickets of *Barringtonia racemosa* and associated species occur on muddy alluvium at the margin of tidal influence along tortuous meandering channels that extend far into the saline grassland floodplain. *B. racemosa* (10-15 m high) forms dense, often monotypic stands along the channel margin. The upper canopy is sometimes dominated by tall *Adina microcephala* (15-20 m). Other characteristic trees in the midstratum include *Anthocleista grandiflora*, *Cassipourea gummiflua*, *Celtis gomphophylla*, *Ficus trichopoda*, *Funtimia latifolia*, *Hirtella zanguebarica*, *Khaya nyasica*, *Manilkara discolor*, *Mascarenhasia arborescens*, *Olea capensis*, *Pachystela brevipes*, *Parkia filicoidea*, *Pseudobersama mossambicensis*, *Salicornia* spp., *Syzygium guineense*, *Vitex doniana*, *Voacanga thouarsii*, and *Xylopiya aethiopica*, with *Phoenix reclinata* palms. Grass cover is rare or absent.

Barringtonia swamp forest covers a fairly small areas on the delta coast, about 3000 ha. At the escarpment ecotone the swamp forest gradually gives way to riverine (fringing) forest along the deeply incised runoff streams, although species composition is similar. This unit is clearly identified by tone and texture on airphotos, and is distinguished from true mangrove by spectral characteristics using an unsupervised classification on satellite imagery. Loxton, Hunting, and Associates *et al.* (1975e&f) mapped a similar unit, but included adjacent areas of swamp grassland and cultivated areas.

Coastal dune communities

Along the delta coastline, straight barrier beaches form parallel dune ridges, fronted by a wave-eroded shore with hummock dunes stabilized by pioneer strand plants. The dune barrier is cut at intervals by shifting tidal inlets that link the estuaries with the sea. Near the Zambezi distributary mouths, large areas of alternating dune and slack relief occur in curved lines parallel to the coastline. These ridge and swale formations, mapped as one vegetation unit, are covered in succession by pioneer dune species, dune thicket, and woodland communities, with freshwater or brackish troughs in between supporting tussock grassland. On the north bank between Chinde and Quelimane, these communities have been mostly replaced by coconut plantations with a mix of native and cultivated understory, and are mapped separately. The largest parallel dune area extends 5 km inland from the beach, but older isolated groups occur nearly 30 km inland from the delta coast near the escarpment ecotone.

(21) Pioneer dune/littoral thicket/woodland mosaic on parallel ridges with tussock wet grassland swales

The vegetation of the parallel dune ridges and swales is a mosaic of species related to successional status, soil moisture, and salinity. Adjacent to the coastal beaches, the hummock foredune zone is pioneered by low creeping and tufted plants such as *Dactyloctenium germinatum*, *Halopyrum mucronatum*, *Ipomea pes-caprae*, *Scaevola thunbergii*, and *Sporobolus virginicus* in association with *Cyperus maritima*, *Ipomoea stolonifera*, *Launaea sarmentosa*, *Sophora tomentosa*, and *Tephrosia purpurea*. These species bind the sands and create suitable conditions for the establishment of dune scrub thicket. Dune scrub thicket is composed of small trees and shrubs, ranging from only 1 m in height where exposed to heavy saltspray to 5 m or more where sheltered from the sea winds (Tinley 1977). The woody thicket cover is composed of species such as *Brexia madagascarensis*, *Diospyros natalensis*, *Enterospermum littorale*, *Eugenia capensis*, *Flacourtia indica*, *Macphersonia hildebrandtii*, *Maerua triphylla*, *Maytenus undata*, *Mimusops caffra*, *Psorospermum febrifugum*, *Rhus natalensis*, *Sideroxylon inerme*, *Tournefortia argentia*, *Trachylobium verrucosum*, and *Vepris lanceolata*. Grass cover on the dunes is sparse but includes tufts of *Halopyrum mucronatum*.

Further inland from the coast, dune thicket gives way to various associations of taller woodland species, including a mosaic of *Hyphaene coriacea*, *Parinari curatellifolia*, *Strychnos madagascarensis*, and *Vitex* spp. on wet sands, sometimes with *Albizia adianthifolia*, and slightly drier associations of *Borassus aethiopicum* and *Phoenix reclinata* palm, *Acacia xanthophloea*, *Combretum imberbe*, *Kigelia africana*, *Lonchocarpus capassa*, and *Trichilia emetica*, with *Barringtonia racemosa* on the edge of mangrove forests. These include also a series of relict dune islands located nearly 30 km from the present shoreline, which support large nesting colonies of storks, herons, and egrets during the rainy season.

Because the dune ridges provide the only elevated grounds in the delta that are free from flooding, these communities are mostly highly modified by human activities, including cultivation, fire, and grazing. Various cultivars are a common part of the canopy.

The grassland slacks include mixed stands of *Eragrostis chapelieri*, *Hyperthelia dissoluta*, *Pogonarthria squarrosa*, and *Themeda triandra*, with *Setaria sphacelata* in more saline areas, and *Digitaria* spp., *Eragrostis heteromero*, *Hyparrhenia filipendula*, *Imperata cylindrica*, *Paspalum orbiculare*, *Vetiveria nigriflora*, and others on slightly higher ground.

The total area of ridge and slack vegetation on coastal dunes is currently about 37,000 ha. The individual mosaic components could not be separated at the mapping scale, but the parallel dune ridges are readily identified and clearly bounded on airphotos and satellite imagery. Areas with more natural vegetation associations are distinguished from coconut plantations during aerial surveys. Loxton, Hunting, and Associates *et al.* (1975e&f) sub-divide this area into several vegetation units, including “Mosaic of *Parinari-Hyphaene* open woodland, *Ischaemum* grassland, and cultivars” and “*Borassus-Acacia* open woodland-grassland-mangrove complex” on the south bank and “Complex of *Setaria sphacelata* grassland, dune thicket, *Annona-Hyphaene* open woodland, and cultivars” on the north bank. Timberlake (2000) combines the various natural and cultivated communities on coastal sands as “undulating terrain, cultivated with coconuts and woodland patches.”

(22) Coconut plantations on parallel ridges with cultivated swales

Extensive coconut (*Cocos nucifera*) plantations occur on parallel dune ridges of the north bank coastline. Mango and cashew trees are also common cultivars. *Stenotaphrum secundatum* is commonly cultivated under the coconuts, with secondary grassland associations of *Dactyloctenium giganteum*, *Digitaria spp.*, *Diplanthe fusca*, *Eragrostis ciliaris*, *Imperata cylindrica*, *Perotis patens*, and others. Swales are used for rice cultivation near Chinde, often with vegetables on the slopes between rice paddy and coconuts. The total area of coconut plantations along the delta coast is currently about 55,000 ha., covering 59% of the total extent of coastal ridge and swale vegetation.

Unvegetated landforms

(23) Open beaches

Open beaches occur intermittently along the coast above the high water mark. Beach areas that have been colonized by pioneer dune-forming species are mapped separately. Open beaches are easily mapped from airphotos and satellite imagery because of their high reflectance values.

(24) Unconsolidated sandbars

Unvegetated, unconsolidated sandbars are mapped in the mainstem Zambezi channel for low water conditions. Stable, vegetated sandbars are mapped separately. Open sandbars are easily mapped from airphotos and satellite imagery because of their high reflectance values.

(25) Open water

Open water areas include the Zambezi River and its distributary network, coastal inlets, and ocean. Open water areas are easily distinguished on airphotos and satellite imagery.

Vegetation Change Analysis

Vegetation change in the delta can be described in terms of changes in the aerial extent, distribution, density, and species composition of the mapping units. A comparison of the vegetation maps and remote sensing imagery, in combination with repeat aerial surveys and field observations, reveals several clear patterns of directional vegetation change in the delta over the period 1960-2000. Table 3-1 provides the area of each vegetation unit on the historical and current vegetation maps, the total change in area over time, and the percentage change.

From these data, substantial changes are evident that relate to several broad patterns of vegetation change. In general, species characteristic of higher areas on the floodplain and surrounding escarpment are establishing in relatively low-lying areas. Thicket species are increasing in frequency and biomass in areas of open woodland and savanna. Savanna species are increasing in frequency and biomass in areas of open floodplain. The area of open floodplain is decreasing, and the composition of large expanses of floodplain is changing from species characteristic of long-duration, deep-flooding conditions to short-duration, shallow-flooding conditions. Along the coast, species characteristic of saline grassland communities are increasing in frequency and biomass in areas occupied by freshwater grassland species. Mangrove species are decreasing at the inland margin of the coastal mangrove associations. These changes are described below in detail.

On the south bank, Acacia thicket elements are increasing in density and extent on the upper margin of the delta. Acacia thicket formerly occurred almost exclusively on termitaria at the floodplain ecotone and was otherwise restricted to the lower terrace. The total area mapped as Acacia thicket has increased about 25% over the past 40 years (Table 3-1). Figure 3-12 shows an example of the invasion of thicket species into Acacia savanna. Colonizing woody species such as *Acacia robusta*, *Combretum imberbe*, and *Lannea stuhlmannii* are expanding into relatively dense areas of Acacia savanna. Young deciduous substratum thicket species such as *Zizphus mucronata*, *Bridelia micrantha*, and *Grewia inaequilatera* were observed beneath mature *Acacia polyacantha-Borassus aethiopum* canopy. Several open floodplain areas in Acacia woodland that were observed on the 1960 airphotos have also filled with woody species.

On the north bank, Acacia thicket species have spread into relatively dense areas of Acacia savanna on

Table 3-1. Total change in area of each vegetation mapping unit, and percentage change, 1960-2000.

Vegetation mapping unit	Area in hectares			%
	1960	2000	change	change
WOODY COMMUNITIES ON THE QUATERNARY DELTOID PLAIN				
Acacia woodland and savanna	40000	45000	5000	13
Borassus palm savanna	9000	8000	-1000	-11
Hyphaene palm savanna	72000	86000	14000	19
Acacia thicket	113000	140000	27000	24
Mixed Palm-Acacia thicket with cultivars on abandoned river levees and coastal highlands	71000	74000	3000	4
	223000	268000	45000	20
GRASSLAND COMMUNITIES ON THE QUATERNARY DELTOID PLAIN				
Tussock wet grassland mosaic on floodplain vertisols	158000	122000	-36000	-23
Stoloniferous swamp grassland mosaic on the floodplain gleys and vertisols	125000	118000	-7000	-6
Papyrus swamps on floodplain waterways and lagoons	91000	84000	-7000	-8
Saline grassland mosaic with Phragmites reedswamp on floodplain gleys and waterways	127000	133000	6000	5
	559000	518000	-41000	-7
CULTIVATED AREAS WITH SECONDARY COMMUNITIES				
Cultivated areas with secondary vegetation associations on stratified alluvium	30000	30000	0	0
Sugar plantations with secondary grassland-savanna associations on floodplain vertisols	30000	30000	0	0
	559000	518000	-41000	-7
MANGROVE AND ASSOCIATED COMMUNITIES				
Mangrove forest on the coastal estuary	105000	103000	-2000	-2
Saline mudflats and pioneer mangrove communities on the coastal estuary	42000	44000	2000	5
Barringtonia evergreen swamp forest on coastal waterways	7000	8000	1000	14
	154000	155000	1000	1
COASTAL DUNE COMMUNITIES				
Pioneer dune/littoral thicket/woodland mosaic on parallel ridges with tussock wet grassland swales	33000	31000	-2000	-6
Coconut plantations on parallel dune ridges with cultivated swales	54000	55000	1000	2
	87000	86000	-1000	1

slightly depressed sites at the inland extent of coastal saline grasslands. *A. robusta*, *A. xanthophloea*, *Lanana stuhlmannii*, *Phoenix reclinata*, and associated species have formed a dense understory among the *A. polyacantha* canopy. Loxton, Hunting, and Associates *et al.* (1975b) observed the early stages of this phenomenon more than 30 years ago.

A. polyacantha, *A. sieberiana*, and other species characteristic of open Acacia savanna are invading and establishing in the *Hyparrhenia dichroa*-dominated bunch grasses associated with *Borassus* and *Hyphaene* palm savanna (Figure 3-12) and open tussock grassland (Figure 3-13). These changes are especially conspicuous on the north bank. The total extent of Acacia savanna has increased by more than 24% over the past 40 years (Table 3-1), and the density of woody cover within the savanna has also increased dramatically. Vast areas of north bank floodplain traversed by abandoned and terrestrialized Zambezi distributary channels are now covered in *Acacia* spp. and associated species. Many of these areas were observed to be mostly open on the 1960 airphotos, with more isolated patches of woody species. There is strong anecdotal evidence that this change occurred rapidly after the 1960s. Tinley (1975) considered the invasion of Acacia savanna tree species into the floodplain grasslands to be the most conspicuous change in the delta landscape during the seven years that he was based in the region. Loxton, Hunting, and Associates *et al.* (1975b) reported the encroachment of *A. polyacantha* into low-lying sites in the northeastern floodplain areas. A comparison of the Loxton, Hunting, and Associates *et al.* land cover maps with current satellite imagery reveals a further restriction in the extent of open floodplain, which is now mainly confined to the floodplain areas along the coastline towards Quelimane and parts of the interchannel area near the Zambezi mouth.

On the south bank, palm savanna is spreading into the upper margin of the open floodplain, decreasing the extent of open floodplain contiguous with the Marromeu Buffalo Reserve. Extensive areas of young *Hyphaene coriacea* palms, up to 25% cover, were observed in several areas of the delta that were clearly open floodplain on the 1960 airphotos. On both north bank and south bank, palms are radiating into the open floodplain from the backslopes of elevated levees along abandoned distributary channels that support palm and woodland thicket species (Figure 3-14). Vast areas of formerly open tussock and stoloniferous grassland have been invaded in the upper floodplains. In many areas of the floodplain mapped as palm savanna in 1960, the overall density of palms has increased and young palms have colonized isolated patches of open floodplain. Loxton, Hunting, and Associates *et al.* (1975e) observed young *H. coriacea* invading into *Setaria* Grassland and *Hyparrhenia* Grassland units in the low-lying parts of the floodplain on north bank during the early 1970s, and Anderson *et al.* (1990) reported widespread encroachment of woody species into the south bank floodplain between 1979 and 1990. Nearly all palms observed on the floodplain in the present study are less than 25 years old, with many less than 10 years old. Local inhabitants note that palms were historically very rare on the open floodplains near the ecotone (Mr. Florindo Antonio *pers. comm.*, Mr. Tama Albertol *pers. comm.*). The total extent of *Hyphaene* savanna has increased by about 19% since 1960 (Table 3-1).

There has also been an increase in the extent and density of *H. coriacea* palms on moist sands at the base of the Cheringoma escarpment and near the coastline. All along the delta ecotone, young palms have invaded far into the delta on small termitaria that rise about 0.1-0.2 m above the floodplain (Figure 3-15). On larger termitaria, thicket communities of *H. coriacea* and *Phoenix reclinata* palms with *Annona senegalensis*, *Ficus doniana*, *Parinari curatellifolia*, *Vitex payos*, and other woody elements from the dry forest ecotone have established. *Hyphaene* palm savanna has increased by 17% at the delta ecotone since 1960. In the southern coastal area, palm savanna has increased from less than 2% cover in isolated patches to widespread areas of 5-10% cover.

On the floodplain grasslands, several broad trends of vegetation change are evident. The spread of *Hyphaene* palm savanna into the lowland delta floodplain is clearly reducing the extent of open flooded grassland associations. The mapped area of seasonally wet tussock grassland has decreased by 24% since 1960, and perennially wet stoloniferous grassland associations have decreased by about 8%. The transition from perennially wet stoloniferous grassland to open palm savanna likely occurred in two phases, with the displacement of stoloniferous grass species by tussock species and the subsequent

invasion of palms. Several areas on the south bank mapped and described as swamp grassland by Loxton, Hunting, and Associates *et al.* (1975e) and characterized by species such as *Echinochloa pyramidalis*, *Oryza longistaminata*, *Leersia hexandra*, and *Hemarthria altissima*, now have a predominantly tussock grass structure with *Ischaemum afrum*, *Vetiveria nigriflora*, and occasionally *Hyparrhenia* spp. Hunting concession operators in the delta complain that the foraging quality of the delta grasses has decreased, due to the displacement of more nutritious stoloniferous grasses with upland species (Dr. Patrocínio da Silva *pers. comm.*). The cultivation of seasonally flooded grasslands adjacent to the Marromeu Buffalo Reserve is also occurring in areas never previously developed (Mr. Baldeau Chande *pers. comm.*).

In the deepest floodplain areas, there has been a marked reduction (8%) in the extent of papyrus swamps on waterways traversing the south bank floodplain. Many of the papyrus swamps evident on the central floodplains in the 1960 airphotos now support thick mats of stoloniferous grassland species such as *Cyperus exaltatus* and *E. scabra*. The loss of papyrus from the delta appears to date back to earlier in the century. Maugham (1910) observed “vast expanses of Papyrus marsh south of Luabo” from the south bank levee, but there is little evidence of papyrus in this area on the 1960 airphotos. Local informants also suggest that the extent of papyrus in the floodplain near the Cheringoma ecotone has decreased over the past twenty years (Chief Mvaziwa *pers. comm.*, Mr. Arnistu Chika *pers. comm.*). A very extensive papyrus swamp still occurs on the north bank floodplain of the Cuacua, although there is evidence of die-off on the periphery of the swamp and possible displacement by grassland species.

Most of the abandoned drainage lines in the delta are undergoing a long-term process of terrestrialization by deep-rooted stoloniferous grasses. Along some of relict channels in the south bank and especially north bank floodplains, secondary succession of woody thicket is evident. Open waterways are rare or covered with invasive alien species such as *Eichhornia crassipes*, *Salvinia molesta*, *Pistia stratiotes*, and *Azolla filiculoides* that were not widely observed prior to 1979 (Mr. Paul Dutton *pers. comm.*).

The riverine vegetation on the active shelf of the Zambezi River has been settled and cultivated for thousands of years and has changed relatively little in composition over the past century since first described by Maugham (1910):

“As one ascends the Chinde River...the banks are seen to be fringed by dense forests of mangroves, forming an impassable, almost impenetrable, screen or barrier which for many miles shuts out any glimpse of the grassy plains beyond. Near the main body of the Zambezi, the mangrove ceases; the river banks increase in height, and change from black, clinging viscous mud to a soil of a sandy, or more rarely clayey, nature. At the point where one turns into the Zambezi, here some 800 or 900 years wide, these banks, in the dry season, are fully 15 or 18 feet in height. Over the high banks, fringed with green reeds and high, snowy plumed spear-grass, clumps of trees now appear; several kinds of thinly-leaved acacias mingling with a curious pale green elm are most numerous, but away beyond, some-times singly and sometimes in groups of half a dozen or more, straight-trunked, clean-cut *Hyphaene* and *Borassus* palms tower 60 and 70 feet above the surrounding forest growths. Sandy islets covered with grass and reeds are passed all day long, and floating islands of marshy greenery borne down on the current. Here and there on the banks above, the hive-shaped roofs of small native villages appear.”

However, the extent of secondary grassland and associated savanna and thicket on the river shelf has increased by 3% since 1960, primarily on former sandbars of the mainstem Zambezi (Figure 3-16). The chain of sandbars between Marromeu and Luabo has been colonized by *Hyperthelia dissoluta*, *Pennisetum polystachion*, and other grass species, interspersed among small cultivated plots. Some islands and riverbank areas still support stands of riparian *Phragmites mauritanus*. Fewer sandbars occur towards the apex of the delta, and vegetation patterns there have remained generally unchanged. Secondary grassland dramatically increased during the period from 1980 to 1998 when large areas in sugar production were abandoned. Most of this area has been reclaimed over the past five years, especially at Marromeu. The decrease in extent of sugar plantation fields at Luabo, many of which have been invaded by *Acacia polyacantha* and associated savanna species has been more or less balanced by the reclamation of new production fields at Marromeu.

The net change in mangrove cover in the delta since 1960 seems fairly minimal (a decrease of about

7% or 8000 ha.) given that the net change attributed to human activities (selective cutting for fuelwood and construction and clear cutting for agricultural plots) is estimated at about 2% per annum (Saket and Vasco Matusse 1994). However, there have been substantial shifts in the distribution of mangrove, with extensive areas of mangrove loss and regeneration apparent all along the coast. The lateral migration of the Zambezi distributary channels at their coastal outlets has scoured away large patches of mature mangrove forest, with recolonization on newly deposited muds. Figure 3-17 shows the erosion of mangrove on the south bank of the Chinde channel, with dense new stands forming in areas of recent deposition on the opposite north bank. The saline mudflat pioneer *Avicennia marina* accounts for about 70% of total regeneration (Cuambe 2000). Although the Cuambe (2000) studies suggest that the coastal mangrove has a low regeneration rate relative to other areas of coastal East Africa, these areas appear to have undergone rapid recolonization in response to geomorphic change. Along the more stable coastal front between the distributary mouths of the Chinde, Catarina, and Cuama channels, however, extensive areas of dead and dying mangrove are apparent without obvious points of regeneration. These strips of dead mangrove were first mapped by SWECO (1983) (Figure 3-2), but the loss of coastal mangrove has been reported since the early 1970s by Tinley (1975, 1977), Loxton, Hunting, and Associates *et al.* (1975e&f), and Davies *et al.* (1975). These earlier studies report a 100-400 m die-back along most of the coastal mangrove frontage. The cumulative die-back over time does not appear to be extensive, though. At the minimum mapping scale (30-m resolution pixels), there was no evidence of a significant reduction of mangrove along the coastline between 1960 and 2000.

At the inland margin, coastal mangrove associations have given way to saline floodplain grasslands at the upper extent of tidal influence (Figure 3-18). The total extent of saline grasslands has increased by about 5% since 1960. The tortuous coastal inlet channels, draining from the Cheringoma escarpment in the west and papyrus waterways in the central Marromeu floodplains, have constricted in width and are colonized by grassland species. Closer to the coast, mangroves are dying back and leaving exposed hypersaline mudflats, some of which have been colonized by saline grassland species. Loxton, Hunting, and Associates *et al.* (1975e&f) observed that drier mangrove phases were regressing to *Sporobolus* spp. grasslands where local road works had blocked tidal drainage on the north bank between Chinde and Quelimane. Although small in overall extent, the loss of mangroves at the inland margin is occurring at all the major distributary channels along the delta coastline.

The gradual displacement of freshwater grassland by saline grassland is in evidence on the north bank near the mainstem Zambezi. Grassland species that have a wide range of salinity tolerance, including *Eriochloa borumensis*, *Hemarthria altissima*, *Diplanche fusca*, *Cynodon dactylon*, and *Leersia hexandra*, are spreading inland along the coast. On the south bank, *Sporobolus virginicus*, a good indicator of saline conditions (Thompson 1985), appears to be expanding inland towards the southern Marromeu floodplains from the coast. Coastal deepwater associations of *Phragmites australis* and *Typha latifolia* reedswamps appear to have changed little in their distribution between 1960 and 2000. Maugham (1910) observed “stands of *Phragmites* surrounding nearly all the inland waters” in the coastal region.

Changes in the vegetation of the parallel dune ridges along the delta coastline are most apparent in areas of high geomorphic activity. On stable dune surfaces pioneering dune scrub is displaced by dune thicket on the parallel ridges near the foreshore, but the lateral migration of Zambezi outlet channels periodically erodes areas of coastal thicket and exposes open beach ridges for primary succession. Figure 3-19 shows an area of several hundred hectares of coastal dune actively cut by Zambezi distributary channels. Most other changes in the vegetation of the parallel dune ridges are highly localized related to human activity. The coastal region of the delta has long been settled, and most of the coconut plantations in the delta region date back several hundred years with the relative proportion of coconut plantations and natural communities on the coastal parallel dunes remaining more or less unchanged. Maugham (1910) observed plantations of over 150,000 coconut palms near Quelimane, with cultivated crops of millet and groundnut, but also noted that *Borassus aethiopum* palms, along with the smaller date palm *Phoenix reclinata*, occurred in immense numbers on the coastal ridges. Loxton, Hunting, and Associates *et al.* (1975f) commented that “the indigenous vegetation on the coastal dunes has been virtually eliminated by

coconut plantations and small holder plots.”

DISCUSSION

Prior to the construction of Cahora Bassa Dam a number of scientists expressed concern about the detrimental effects of Zambezi development on the delta environment. Articles such as “What’s happening to the Zambezi”, “They pulled the plug out of the lower Zambezi”, and “Marromeu wrecked by big dams” filled the popular press (*e.g.*, Anonymous 1975, Davies 1975, Tinley 1975). These concerns were based on the perception that negative impacts were already resulting from the construction of Kariba Dam less than fifteen years earlier. Davies *et al.* (1975) predicted that the hydrological changes imposed by the dam would result in reduced silt deposition and nutrient availability, salt-water intrusion, replacement of wetland vegetation by upland species, and failure of vegetation to recover from grazing. Loxton, Hunting, and Associates *et al.* (1975a&b) further argued that because artificial levees and roads blocking former drainage lines were already causing undesirable changes in the delta, the added impact of Cahora Bassa Dam would be catastrophic. Tinley (1975) noted that the combined effects of dams and embankments had resulted in the increasing dependency of the alluvial grasslands of the Marromeu Reserve on local (silt-free) runoff from the Cheringoma Plateau. These concerns were fueled when Cahora Bassa dam commenced filling in the fastest possible time without the recommended minimum flow releases (Davies 1998). Bernacsek and Lopez (1984) later wrote:

“It is clear that in the case of Cahora Bassa there was no serious attempt to ecologically optimize the dam prior to construction...furthermore, after dam closure, proposals put forward by the ecological assessment team were not implemented and there has been no regular monitoring of the dam’s downstream effects during its lifespan. As a result, Cahora Bassa has the dubious distinction of being the least studied and possibly least environmentally acceptable major dam project in Africa.”

These scientific concerns are based on the principles later expounded in the *Flood Pulse Concept* (Junk *et al.* 1989) and *Serial Discontinuity Concept* (Ward and Stanford 1983, 1995a). These theories describe the role of natural hydrological disturbance in maintaining the structure and function of river-floodplain ecosystems, and the ecological consequences of altering disturbance patterns through river regulation or impediments to lateral flow. Although these theories were developed to explain the importance of flood pulsing to the biological activities of production, decomposition, and consumption, especially with respect to the floodplain fisheries (*e.g.*, Bayley 1991, 1995), they may be extended to predict patterns of change in macrophyte species assemblages as a function of changes in the flooding regime.

In North America, Patton and McKee (1995) predicted the affects of an altered hydrological regime on floodplain vegetation in Colorado using *vegetation response curves*. The persistence of riparian vegetation was related to the magnitude and duration of subsurface water availability. Middleton (1999) adapted the flood pulse concept to vegetation dynamics in cypress swamps, and demonstrated that water fluctuation is the controlling agent in maintaining key life processes, especially propagule dispersal and regeneration. The inherent ability of adult life stages to survive under various water regimes varies widely among herbaceous and woody species and is a major determinant of vegetative composition in wetlands. Within the same species, seeds, seedlings, and adults often depend on different hydrological conditions, requiring a dynamic floodplain environment with strong spatial and temporal variation.

In tropical and sub-tropical systems, studies have also demonstrated the relationship between seasonal flooding and vegetation patterns (*e.g.*, Finlayson *et al.* 1989, Hughes 1988, Ellenbroek 1987). Several studies have emphasized the importance of flooding dynamics for large-scale geomorphic disturbance (lateral erosion and channel changes) leading to successional development of riverine woodland communities (*e.g.*, Salo *et al.* 1986, Hupp 1988, Scott *et al.* 1996, Stromberg *et al.* 1991, others). In African floodplains, Denny (1985a) observed that “community boundaries are often indistinct because flood regimes vary from year to year, but depth of flooding and duration are clearly the primary

determinants of species composition”.

Based on these studies, one may therefore hypothesize that many of the vegetation changes observed in the delta over the past 40 years are the result of changes in the hydrological disturbance patterns of the Zambezi system. These directional vegetation changes include the invasion of woody savanna and thicket species into the floodplain grassland mosaic, displacement of flood tolerant grassland species by more upland grassland species, terrestrialization of abandoned alluvial channels, displacement of freshwater grassland species by halophytic grassland species, degradation of coastal mangrove, and stabilization and colonization of sandbars. Other disturbance factors such as changes in climate, grazing and fire patterns, and geomorphology, or human activities may also be important, however, and may serve to accelerate or counter the influence of hydrological change on vegetation change. The various factors influencing vegetation change are considered below.

Invasion of woody savanna and thicket species into the floodplain grassland mosaic

Tinley (1977) argued that the delta grasslands are maintained almost exclusively by seasonal flooding that prevented the invasion of woody species. Tinley predicted that woody vegetation would encroach upon floodplain grasslands over a large area once Cahora Bassa was built and effective flooding ceased. Over time *Hyparrhenia* and *Vetiveria-Ischaemum* grassland associations would be displaced by *Hyphaene* savanna, which would be displaced by *Acacia polyacantha* savanna, which would in turn be displaced by *Combretum fragrans-Kigelia africana* open woodland.

These predictions are sustained by the present study. The encroachment of individual woody species into the delta floodplains over the period since airphotos were taken in 1960 can be readily observed across much of the upper delta floodplain. The dramatic reduction in flooding extent over the past 40 years and widespread drying out of delta alluvium in the upper floodplain is likely a major causal factor behind this invasion. The better-drained soils of termite hills and gully edges are primary sites of woody plant invasion in the seasonally flooded grasslands.

For example, *Hyphaene coriacea* palms have invaded from the floodplain margin into widespread areas of open grassland. All along the floodplain margin, small termite mounds dot the landscape with young *H. coriacea* saplings. Palm species can tolerate seasonal waterlogging, but were previously excluded from areas that were inundated most of the year because they lack adaptations to withstand prolonged flooding (Thompson 1985). With the decrease of soil moisture on the floodplain, palms invade from the termitaria into the open grassland habitat. In the past, regular floods of the magnitude of the mean annual flood were probably sufficient to inundate woody species on the small termitaria and cause woody seeds dispersed into the open grasslands to rot, thereby restoring and maintaining open floodplain conditions. However, floods of this magnitude did not occur at all between 1978 and 2001 providing an extended opportunity for palms to invade and establish. The prolonged deep flooding of 2001 removed nearly all *H. coriacea* seedlings less than two years of age, but older seedlings appeared unaffected.

Similarly, many species associated with Acacia savanna and woodland can tolerate periodical flooding for 2-3 months, but were formerly excluded from areas with prolonged seasonal flooding. Acacia savanna has now spread across thousands of hectares of more open savanna and floodplain grassland in the upper delta, with dense Acacia-Combretum thicket forming near the low-level terrace. Dunham (1989a&b) recorded similar patterns of directional succession in the Mana Pools floodplain of the middle Zambezi after the construction of Kariba Dam, although the magnitude of change was less than he expected because of intensive browsing by large mammals at the floodplain margin.

Much of the period since construction of Cahora Bassa Dam also corresponds to the most significant drought since the early 1900s, however. From 1980 through 1994, southern Africa experienced a prolonged and devastating drought throughout the Zambezi Basin (Tiffen and Mulele 1994). At Songo, mean annual rainfall during the rainy season months of December-March decreased by 28%, from 771 mm/year during the period 1955-1973, to 566 mm during the period 1980-1994, or by more than 36% to 490 mm/year if the aberrant wet season of 1988 is excluded. Total rainfall in 1991 was the minimum on record (De Vries *et al.* 1997). Although rainfall patterns along the delta coast at Quelimane were less affected, the widespread

reduction of runoff from the Zambezi catchment caused a significant reduction in Zambezi runoff.

Because climatic cycles are a regular feature of the Zambezi catchment (Mukosa *et al.* 1995), the invasion of woody species into the lower delta floodplains may be part of long-term cyclical vegetation change in response to climatic variation, rather than directional change related to water resources development. This argument is supported in part by observations from several wetland pans in the dry *Millettia* forest above the delta floodplain. At each site, local residents reported that woodland thicket had encroached into the pans over the past 10-15 years, and young *Hyphaene coriacea* palms were observed growing up to the edge of the shallow water zone, with dry forest species invading into the outer margin (Mr. Antonio Chimuki *pers. comm.*, Mr. Francesco Penemo *pers. comm.*)

Nonetheless, substantial vegetation change in the upper delta has been reported since the construction of Kariba Dam, which was followed by a long period of above-average rainfall. Tinley (1975) observed *Colophospermum mopane*, *Acacia borleae*, and *A. polyacantha* invading the alluvial soils from the floodplain margin ten years after construction of Kariba Dam. Loxton, Hunting, and Associates *et al.* (1975f) observed the encroachment of *Hyphaene coriacea* into low lying floodplain grasslands and *A. polyacantha* into low-lying areas of the northeastern floodplain areas after the construction of Kariba Dam. This pattern has clearly continued in recent years. In all likelihood the south bank floodplains have been progressively invaded by woody species for an even longer period of above-average rainfall, dating back to the construction of dikes along the mainstem Zambezi in the 1920s. Accounts by local villagers suggest that the upper floodplains previously included extensive open expanses that flooded regularly (Mr. Simoes Fombe *pers. comm.*, Mr. Costa Chari *pers. comm.*), and woody species reportedly invaded the upper north bank floodplain following the construction of the (now abandoned) Sena Sugar Estates at Mopeia (Loxton, Hunting, and Associates *et al.* 1975f). Overall, both drought and the reduced incidence of flooding due to dams and dikes have likely contributed to the rapid rates of vegetation change in the delta. Future studies during the current wet cycle,⁴ including the long-term effects of the 2001 floods, should enable ecologists to tease out the differing effects of these phenomena more clearly.

The invasion of woody species is further complicated by changes in the timing and extent of fire in the delta. The influence of fire on African floodplain vegetation is profound (Phillips 1968, Ellenbroek 1987) and intimately connected with patterns of human activity (*e.g.*, Werger 1983). Local inhabitants light early dry season fires for a variety of reasons, including to flush and capture bush meat and to clear brush for easier foot and boat travel (Mr. Florindo Antonio *pers. comm.*). Historically, traditional burning practices produced a mosaic pattern of burned dry areas and unburned wet areas depending on the duration of floodwater inundation, with most fires occurring later in the dry season (Tinley 1977, Mr. Paul Dutton *pers. comm.*). After the construction of Cahora Bassa Dam, Bindernagel (1980) observed a notable increase in the frequency of burning (up to 3 times per year in some parts of the delta). Currently about 95% of the delta burns during the dry season, including vast areas during the early dry season, sparing only the permanently inundated floodplains and waterways with papyrus swamps (*pers. obs.*). These patterns of increasing fire are almost certainly due to the drying of floodplain, because rainfall alone in the delta region is insufficient to cause prolonged flooding that might reduce the extent and intensity of floodplain fires.

Late dry season fires, originating in open tussock grasslands, sweep into the savanna and woodland communities, top-killing many shrubs and small trees and sometimes canopy components although *Hyphaene coriacea* and *Borassus aethiopum* palms and *Acacia polyacantha* trees are relatively resistant to burning (Loxton, Hunting, and Associates *et al.* 1975e, *pers. obs.*). Conversely, the early dry season fires are thought to remove the aboveground biomass of grasses before food reserves in the leaves have been transferred to the roots (Ellenbroek 1987). The new shoots that appear after burning again stress the food reserves in the roots and may be depleted to such an extent, especially in areas of overgrazing, that perennial grasses are no longer vigorous enough to compete with fire intolerant and unpalatable bush species (Rose Innes 1972). The net effect of earlier and more widespread ground fires in the delta is likely an acceleration of woody species encroachment. Thus, hydrological changes in the delta may well be facilitating the invasion of woody species directly through drier floodplain conditions and indirectly

through changes in the fire regime.

Finally, changes in the browsing regime of the delta must also be considered. Elephants browse heavily on palms and Acacias, and are attributed with reducing the density of woody species in the Mana Pools floodplains (Dunham 1989a). Although the total population of elephants in the Zambezi Delta region has not decreased substantially in the past forty years, they have been driven from the floodplain ecotone to the deepwater Marromeu swamps because of heavy hunting pressure (Tinley 1977). While this population shift may have reduced the intensity of browsing activity (especially on *Hyphaene coriacea*) at the floodplain margin, it has also reduced the transfer of seed carried by elephants from the ecotone to the open floodplains—an important vector for seed dispersal in other floodplain systems (Gaudet 1992). Overall, the net effect of changes in browsing activity is unlikely to be significant relative to other changes in the disturbance regime.

Displacement of flood tolerant grassland species by more upland grassland species

In the low-lying Marromeu floodplains to the south and the Cuacua floodplains to the north, soil moisture conditions are sufficient to exclude the establishment of woody species. However, the duration of floodplain inundation is now significantly shorter than under historical conditions. Welcomme (1979) predicted that with the long-term drying of African floodplains, Papyrus sudd and Typha reedswamps would contract and be replaced by *Oryza* grasslands, and *Sporobolus* and *Hyparrhenia* would establish in swamp grasslands. In the Zambezi Delta, Tinley (1975, 1977) and Loxton, Hunting, and Associates *et al.* (1975b) predicted that more flood-tolerant wetland species would be displaced by relatively upland species after the construction of Cahora Bassa Dam.

Unlike the clearly observable pattern of woody invasion into open floodplain, however, changes in the herbaceous composition of the floodplain are much more difficult to detect from historical sources such as airphotos and interviews, and are more ecologically complex. Previous studies of the floodplain vegetation include only general descriptions of grassland communities in terms of dominant species and structure that restrict the assessment of broad changes in the extent of major associations of emergent, stoloniferous, and tussock species (Loxton, Hunting, and Associates *et al.* 1975e&f, Tinley 1977). For example, the significant reduction in the extent of all open floodplain communities since 1960 might be explained by the displacement of papyrus and associated deepwater swamp species by stoloniferous grassland species, which are in turn displaced by tussock grassland species. If these shifts are attributed to hydrological changes in the delta, then the net reduction in stoloniferous grassland (10,000 ha.) might include an expansion of stoloniferous grassland into 7,000 ha. of wetland formerly occupied by papyrus, and a decrease of 14,000 ha. in areas where displaced by tussock grassland. Similarly, the net reduction in tussock grassland (37,000 ha.) might include the displacement of 14,000 ha. of stoloniferous grassland and the loss of 51,000 ha. due to colonization by palm and Acacia savanna and saline grassland. Anderson *et al.* (1990) reported that the desiccation of the floodplain had accelerated the replacement of wetland vegetation by less palatable tussock grasses, rendering the floodplains less favorable for the buffalo, waterbuck and reedbuck. Coutada operators in the delta now complain that the foraging quality of the delta grasses has decreased (Dr. Patrocínio da Silva *pers. comm.*). In the Mana Pools, Dunham (1989a) observed that the frequency of perennial grasses had declined with lack of Zambezi flooding since 1981.

The magnitude of these changes suggests directional patterns of vegetation change rather than natural cyclical patterns of change, but they yield little insight into the mechanisms of vegetation change. Changes in the floodplain grassland mosaic are the sum of the independent responses of different species to changes in hydrological conditions or other environmental factors within the constraints of their individual life histories (*e.g.*, Gleason 1927, van der Valk 1981, Finlayson *et al.* 1989, Middleton 1999). Although historical data are insufficient to assess changes in the rooted frequency or percent cover of individual vegetation species at a fixed location over time, data on the spatial patterns of vegetation change along a moisture gradient from more flood-tolerant to less flood-tolerant species are valuable for interpreting the responses of individual species to changes in the flooding regime.

Vegetation associations on freshwater vertisols in the central floodplains and on colluvial sandy soils

at the floodplain margin can be described in terms of a generalized hydrosere (Figure 3-20). *Cyperus papyrus* forms extensive stands in deepwater channels and pools on the south bank delta. Papyrus only remains in healthy condition when the substrate is permanently flooded, and generally gives way to the *C. exaltatus* in the upper reaches of the deepwater channels that do not necessarily maintain standing water through the dry season. Towards the coast on saline soils, Papyrus is displaced by stands of *Typha latifolia* and *Phragmites australis*. *Echinochloa pyramidalis*, *Leersia hexandra*, and *Oryza longistaminus*, all perennial, rhizomatous grasses that tolerate periods of prolonged inundation on expansive vertisols, are often associated together but have very different growth morphologies. *E. pyramidalis* is a tall, robust grass with culms 2000 mm or longer and a short rhizome. *L. hexandra* is shorter, soft-stemmed grass with culms 300-1000 mm, and a creeping rhizome that form dense stands. Wild rice, *O. longistaminus*, is a tussock grass with floating stems, 1000-2000 mm, with C₃ metabolism for prolonged inundation (Thompson 1985). Because C₃ species are disadvantaged relative to C₄ tussock plants in harsh dry season conditions, *O. longistaminus* is particularly vulnerable to long-term drying conditions.

On heavy clay vertisols at the transition from areas of prolonged inundation to more seasonal inundation, *Setaria incrassata*, a dense, perennial tussock grass with a short, thick rhizome, is often dominant. Tall, rank *Hyparrhenia rufa*, often in association with rhizomatous *Ischaemum afrum*, occurs on weak vertisols at the floodplain margin, generally flooded only by rainwater and usually associated with Hyphaene or Acacia savanna. On lighter sandy soils, *Hemarthria altissima* and *Panicum repens* are dominant on waterlogged soils. *H. altissima* is a perennial, mat-forming creeping grass with rhizomes and floating stems, with culms up to 1500 mm. *Panicum repens* is a low-growing, rhizomatous species, often dominating regularly flooded sandy substrates. At the perimeter of the regularly flooded zone on sandy soils, robust *Vetiveria nigriflora* tussock grass is dominant, with *Hyparrhenia rufa* and *Imperata cylindrica* on somewhat higher ground with scattered woody species. Many other species are present in association with these species, as described in the vegetation mapping section.

Based on these individual species characteristics, a general pattern of vegetation succession over time may be interpreted as individual species invade into a grassland matrix by rhizome or seed, and out-compete the existing species that are stressed by increasingly unfavorable soil moisture conditions. With decreasing magnitude and duration of flooding, *Cyperus papyrus* gives way to *C. exaltatus*. Papyrus will progressively exclude other species as hydrological conditions become more stable in floodplain waterways, but cannot tolerate the hydrological instability associated with failed flooding conditions. *C. exaltatus*, not mentioned in the Loxton, Hunting, and Associates *et al.* (1975e&f) reports, is now very widespread across the low lying delta in shallow, anastomosing channels and depressions that may have previously supported papyrus stands. With reduced but still prolonged inundation, *C. exaltatus* stands may be invaded by replaced by *E. pyramidalis*, *L. hexandra*, and *O. longistaminus*. With reduced Zambezi floodwaters, this association is largely dependent on seasonal Cheringoma runoff on the south bank. On the vast areas of less expansive (higher) vertisols that are seasonally flooded, these species give way to *Setaria spp.*, and eventually to vast stands of *Hyparrhenia spp.* tussock grass. On sandy hydromorphic soils, *Hemarthria altissima* and *Panicum repens* may give way to *Vetiveria nigriflora* or *Hyparrhenia rufa* under drying conditions. Local informants note that the area of *H. rufa* has expanded deep into the south bank floodplain where the duration of regular Zambezi flooding has decreased by several months (Chief Mvaziwa *pers. comm.*, Mr. Tome Joaquim *pers. comm.*)

Grassland succession dynamics on the floodplain are also influenced by changing patterns of grazing and fire. Under natural flooding conditions, the stoloniferous wet grasses are preferentially grazed until wet season flooding limits access and wildlife and livestock are forced to higher ground (Ellenbroek 1987). Grazing activity, especially by buffalo and warthog, also disturbs the soil and enhances the diversity of floodplain vegetation. With reduced flooding, grazing pressure may remain high year round and wet grasslands are unable to rejuvenate during the normal flooding period. The full impact of year-round grazing pressure, such as has occurred in Middle Zambezi floodplains (Attwell 1970, Dunham 1989a), has not been realized on the delta floodplains, however, because of the dramatic reduction in ungulates during the civil war. Cape buffalo, waterbuck, hippo, reedbuck, and zebra were all reduced by

more than 95% during the Mozambique civil war (Anderson *et al.* 1990, Tinley 1994). The delta is now nearly depauperate of large herbivores, especially at the floodplain ecotone in the Marromeu Complex (Figures 3-21 and 3-22).

This reduction in wildlife grazing pressure has greatly contributed to the intensity of dry season wildfires. The grazing system of buffalo, waterbuck, zebra, and other species that spread across the delta from the floodplain to the woodland ecotone prior to the 1980s maintained a mosaic pattern of grazed and ungrazed grasses (Tinley 1977, Tello and Dutton 1979). This pattern created natural firebreaks to prevent or redirect the spread of wildfire. With the reduction in wildlife populations, vast expanses of ungrazed floodplain have created conditions of rank, highly combustible vegetation at the end of the dry season. Coupled with the general desiccation of the floodplain, intense wildfires now spread unchecked across extensive areas and reduce the vigor of many grassland species. There is widespread opinion among coutada operators and wildlife biologists that the delta can no longer support the large herbivore concentrations it supported prior to the 1980s (Dr. Patrocínio da Silva *pers. comm.*, Mr. Paul Dutton *pers. comm.*, Mr. Roberto Zolho *pers. comm.*).

Terrestrialization of abandoned alluvial channels

Although oxbow meanders and alluvial meander scrolls on the floodplain are a natural feature of floodplain systems, many active waterways in the delta have been severed from the mainstem Zambezi by the construction of high embankments for railways and roads and the regulation of Zambezi flows. SWECO (1983) observed that several rivers had dried up between 1960 and 1982. These abandoned channels, no longer scoured open by annual floods, are being rapidly invaded by floating aquatics and aggressive grass species. Few of the native submerged and floating-leaved aquatic plants are resistant to periods of desiccation on the floodplain (Denny 1985b), so most of the shallow flooded depressions in the delta are now covered with dense mats of *Eichhornia crassipes*, *Salvinia molesta*, and *Azolla filiculoides*, or robust stands of *Echinochloa pyramidalis*.

On the south bank, extensive areas of channel encroachment are associated with the railway line between Marromeu and Inhamitanga that impedes water movement through the Salone depression, the main water source for the floodplains of the upper delta. The alluvial depression immediately above the levee are covered in *Borassus* palm savanna and tussock grasslands, but immediately below the levee the depression is covered in dense *Acacia polyacantha* with relatively few palms. Floodplain waterways near the Sena Sugar Estates at Marromeu and Luabo have been isolated from the mainstem Zambezi for nearly a century. Many of these channels are in advanced stages of terrestrialization, with *Borassus* palms invading into secondary grassland associations in the channels.

The near extirpation of hippos from the delta during the civil war period has accelerated the process of terrestrialization of floodplain waterways. The wallowing activities of hippo are vital in maintaining open water conditions in shallow pools and distributary channels, and their paths create small incised channels between water bodies (Naiman and Rogers 1997). The removal of hippo from the delta is attributed to the loss of open water habitat and the succession of grassland in abandoned alluvial channels (Tinley 1994), which in turn reduces the area of habitat available for recolonization of hippo and other semi-aquatic mammals (Nilsson and Dynesius 1994).

Displacement of freshwater grassland species by salt-tolerant grassland species

Although the total extent of salinization over the past 40 years is unknown, changes in the distribution of salt-tolerant grassland species along the delta coast are likely due to increased soil salinity. Osmotic stress imposes a very powerful selection pressure on species occurrence (Thompson 1985). Tinley (1975, 1977) and Loxton, Hunting, and Associates *et al.* (1975b) predicted the displacement of freshwater grasslands by more saline grasslands due to Zambezi regulation, occurring progressively closer to the main river channels over time.

One of the most important roles of flood pulsing in the delta is the flushing of accumulated salts from coastal estuaries. Salinization is a function of the water regime, climate, topography, and soil type, and

these factors determine how quickly salinization proceeds. Almost all of the delta vertisols are saline at a depth, and salinity in surface soils naturally increases with decreasing distance to the sea. The rate and extent of surface salinization differs significantly between and within different physiographic regions (SWECO 1983). In the delta region, a balance between tidal saltwater and riverine freshwater is maintained by Zambezi flow and by local rainfall runoff in the delta. During the filling of Cahora Bassa reservoir, saltwater intrusion occurred more than 70 km inland (Tinley 1975). The large floods in 1978 and 2001 presumably washed out some of the salts that had accumulated as a consequence of Kariba and Cahora Bassa flood control. The replacement of regular seasonal flooding with less frequent partial flooding that temporarily raises the water table but does not flush out salts from the landscape, however, is facilitating the gradual salinization of the upper soil layers.

Coastal plant species have a range of adaptations to tolerate flooding with salt water, and differ in their response to increasing salinity levels (Wainwright 1984). Associations of salt-tolerant species on saline vertisols and estuarine muds in the coastal floodplains can be described in terms of a generalized hydrosere (Figure 3-20). With increasing salinity, *Sporobolus virginicus*, in association with *Diplanthe fusca* and *Paspalum vaginatum* and other species, will displace *Eriochloa borumensis* and *Setaria* spp. grasslands, which are transitional between saline and freshwater grasslands on the open floodplain. In permanently flooded waterways, *Phragmites australis* and *Typha domingensis* reedlands displace papyrus swamps with increasing salinity. *Cyperus digitatus*-*Leersia hexandra* communities, occupying brackish areas of more prolonged tidal inundation near the coastal mangrove, are less affected by increasing salinity. Comparable data from other floodplain systems are not available to assess the degree to which this type of displacement has occurred elsewhere. These changes can have important implications for floodplain wildlife. For example, *S. virginicus* is unpalatable to most grazing species and over time may reduce the carrying capacity of the floodplain (Ellenbroek 1987).

Degradation of coastal mangrove

The distribution of mangrove vegetation is directly dependent on the dynamics of topography, as related to tidal activity, soil water pore salinity, and soil waterlogging (Smith 1992). The sequential distribution of different vegetation zones of mangrove can be described in terms of a generalized hydrosere (Figure 3-20). Although the classic view that mangrove zonation represents a successional sequence from pioneer colonizers to mature climax forest as mangroves accumulate sediments is still pervasive (*e.g.*, Chapman 1976), there is strong consensus among many mangrove researchers that mangrove communities undergo a cyclical succession of displacement and regeneration within each zone in response to geomorphological changes (Thom *et al.* 1975, Woodroffe 1992). These geomorphic changes occur as a function of the dynamic process of riverine and coastal erosion and sedimentation (*e.g.*, Moll and Werger 1978, Thom 1984). Over time the processes of erosion and sedimentation are roughly balanced, with zones of both erosion and deposition, and are expected to result in no substantial change in total coastal mangrove cover (Woodroffe 1992). Directional changes in the distribution of coastal mangroves in the delta in which long-term rates of displacement exceed regeneration or *vice versa*, therefore, result from permanent discontinuities in the pattern of coastal geomorphology.

The Zambezi Delta is a dynamic system, undergoing constant geomorphological change in response to the natural processes of erosion and sedimentation. The Zambezi River has the capacity to modify the morphology of the coastal shelf, discharging an estimated 290 metric tons/year of sediment (Saetre and Silva 1984) and building fans of sediment down the continental slope. Shifts in channel morphology near the coast have been described since the Livingstone expeditions of 1958-1863. Maugham (1910) commented:

"A place which we call Chinde exists, it is true, but not the Chinde whose acquaintance I made fifteen years ago. That Chinde has long ago been born away in suspension in the eroding waters of the Zambezi, and now lies either at the bottom of the river, or has gone to strengthen the innumerable bars and sand-spits which constitute such a danger to vessels entering the tiny port. In a word, the Chinde of the [eighteen] nineties has been gradually

washed away, and the present aspect and appearance of the townlet is as of one which the waters have suddenly invaded, engulfing one portion and still menacing the other.....since I have known the Chinde, a valuable strip of fully 200 yards [0.91 m] has completely disappeared from the existing river bank, the width of the stream at this point having proportionately increased."

In recent years, the delta coastline has continued to change, particularly where Zambezi distributary channels (Figures 3-17 and 3-19) actively cut the barrier beaches. In response to these geomorphic changes, widespread areas of mangrove have eroded and regenerated as part of natural cyclical succession. Mr. Baldeau Chande (*pers. comm.*) reports that villagers living near the Zambezi mouth do not think that there has been a net loss of mangroves, and recall that coastal mangrove die-off has occurred for many generations.

Elsewhere along the coastal front, however, the extensive tracks of dead mangrove without obvious areas of regeneration may be indicative of directional change related to changes in the Zambezi flooding regime. Tinley (1994) observed that the delta coast and some 200 km on either side of it has been in a state of ongoing regression for about 35 years, with mangrove tree stumps and estuarine muds now exposed in the low tide surf zone of the open ocean. This time frame is coincident with that since the Kariba Dam was constructed. Reduced sediment load in the Zambezi River below Kariba, particularly the coarse sand fraction, may be starving the unconsolidated coast of adequate sand supply, resulting in accelerating erosion and a receding shoreline (Tinley 1971, 1977). Davies *et al.* (1975) also argued that the erosion and mangrove die back evident along the coastline were related to sediment trapping by Kariba Dam.

Taken over the 40-year period from 1960-present, the cumulative lack of annual sediment deposition in the delta estuaries caused by Kariba and Cahora Bassa would seem a reasonable explanation for the extensive tracks of dead mangrove observed at the mouths of the Zambezi during this study. However, mangrove die-off along the delta coast has been reported since the early 1970s (Loxton, Hunting, and Associates *et al.* 1975e&f). Attributing this die-off to Kariba Dam would suggest a large reduction in coastal sedimentation and a very rapid geomorphological response to the disequilibrium between coastal erosion and sedimentation. This is possible, but seems unlikely given that 50% of the Zambezi catchment occurs below Kariba Dam, sediment inflow to Kariba Dam is greatly reduced by the Barotse and Chobe floodplains in the upper Zambezi catchment (Bolton 1984), and the silt-hungry river was observed rapidly eroding its banks and bars along the Middle Zambezi to regain a quasi-equilibrium silt load (Begg 1973).

The dead mangrove communities observed at the Zambezi mouth may therefore be the result of other phenomena. An alternate hypothesis is that some of the coastal mangrove die-off is related to hurricane activity. Hurricanes and windstorms are a major source of disturbance in mangrove ecosystems worldwide (Elger 1950, Smith *et al.* 1994). During Hurricane Andrew in Florida, 80-95% of mature mangroves died in some areas, and Hurricane Hugo reduced above ground-biomass by about 50%. Recovery of vegetation, typically from seedling regeneration and regrowth of survivors, may be slow and show signs of hurricane damage for many years along the coastline (Middleton 1999). In the Zambezi Delta region, major tropical storms batter the coastline frequently, with an average of 5.6 tropical storm or cyclone strikes per decade over the past 50 years (Table 3-2). Particularly severe storms are capable of widespread damage. After Hurricane Elise struck the delta coastline in 2000, the exposed crowns of many *Avicennia marina* individuals were snapped off, and new areas of die-back were observed along the exposed coastline (*pers. obs.*). In the long run, these disturbances may contribute to increased species richness relative to areas less affected by storms (Smith and Duke 1987). The affect of sea-level rise on the geomorphology of delta coastline must also be considered, especially as longer time-scales are considered.

The loss of inland mangrove may be directly related to changes in the hydrological regime, and indirectly through altered patterns of burning. Mangroves are extremely sensitive to hydrological changes at the inland margin (Wolanski *et al.* 1992). The decreasing reach of effective flooding and subsequent loss of freshwater recharge for leaching out of salts is resulting in hypersaline conditions at the tidal margin, and mangrove is being displaced by *Sporobolus virginicus* grasslands and *Phragmites australis* reedswamps

on depressed sites. This follows from Loxton, Hunting, and Associates *et al.* (1975b), who predicted that **Table 3-2. Number of major tropical storm and cyclone strikes per decade to the Zambezi Delta region since 1950. Recorded strikes between S 17.3-S 20.0 and E 35.5-E 38.0. Compiled from World Meteorological Organization archives.**

Decade	Number of strikes
1950-59	6
1960-69	3
1970-79	6
1980-89	6
1990-99	7
Average	5.6

mangroves would initially encroach inland after construction of Cahora Bassa (as river flow decreased and saltwater penetrated further inland), but then alterations in the silt load and river erosion processes combined with the lowering of the regional water table would lead to a reduction in the area of tidally inundated soils and an extensive die-off of mangroves (with replacement by grasslands and thicket). Tinley (1994) also observed that tall *Avicennia* mangrove woodlands that had colonized saltflats over the twenty-five years since construction of Cahora Bassa Dam were dying back due to increasing soil hypersalinity. Similar changes were observed in the mangrove communities of the Orinoco Delta of Venezuela following dam construction (Colonnello and Medina 1998).

The increased frequency of hot dry season fires in the coastal saline grasslands is also affecting mangrove at the inland margin. Large tracts of top-killed *Avicennia marina* were observed after a late dry season fire at the mangrove-grassland ecotone near the Luaua channel. Near settlements, mangroves are also selectively cut for building materials and firewood, and occasionally clear-cut for cultivation.

Stabilization and colonization of sandbars

The mutual interactions of streamflow and channel variables control the morphology of river systems and their deltas. The unique dimensions, patterns, and profile of river systems have evolved over time to effectively manage the disposition of water and sediment originating within their watersheds. Natural or imposed changes in any of the physical processes will create a chain reaction of systematic adjustment that is often rapid (Rosgen 1996). In this context, rapid geomorphic change may be expected following Zambezi regulation by Kariba and Cahora Bassa Dams, with corresponding changes in sandbar erosion and formation.

Historically, the Zambezi was characterized as a braided river of wide channels. Sandbars were created at point bars on the convex side of river meanders, and meander scrolls were formed as the channel migrated laterally across the active floodplain. From the 1960s until the 1980s, the marked increase in dry season flows and reduction in scouring highflows have caused the Zambezi to downcut a permanent channel in the floodplain alluvium. Several square kilometers of Inhangoma Island disappeared between 1960 and 1972 (SWECO 1983). The lower Zambezi River now weaves between consolidated islands. Exposed sandbars occur only in the lower tidal zone near the coast. The consolidated sandbars support tussock grassland associations and are widely cultivated.

CONCLUSIONS

From the outwash fans of miombo woodland and wet grasslands on the backslope of the Cheringoma escarpment, across the woodland, savanna, grasslands, and papyrus swamps on floodplain alluvium, to the estuaries, mangroves, and dunes of the coastline, the delta supports a wealth of wetland habitats. But the past century has marked a period of substantial changes in the vegetation of the Zambezi Delta. Woody savanna and thicket species have increased in density and colonized far into the floodplain grassland mosaic. Relatively drought-tolerant grassland species have displaced flood-tolerant species in

the broad alluvial floodplain, and saline grassland species have displaced freshwater species on the coastal plain. Abandoned alluvial channels are undergoing advanced stages of terrestrialization. Coastal mangrove has been replaced by saline grassland at the tidal margin. Sandbars have become stabilized and colonized by grassland and woody species.

These changes threaten the mosaic of delta habitats that are maintained by subtle differences in topography, soils, and microclimate. The juxtaposition of these varied habitats creates a great diversity of ecotones across the delta landscape, supporting the seasonal and annual biological needs of a wealth of animal species. Tinley (1977) observed that in other regions of Africa, such as in the Serengeti, vast migrations are required to cover a similar sequence of habitats.

Considerable research remains to be done to document specific changes in vegetation distribution on the floodplain, to establish whether rates of change are increasing or decreasing, and to test factors contributing to vegetation change through controlled experiments. Regular resampling at permanent quadrats, now being established in each of the vegetation mapping units of the delta, will enable direct future comparisons of vegetation change relative to current conditions. Clearly, there is a paucity of historical data to establish the patterns of change and the factors responsible for the patterns of vegetation change. The body of anecdotal evidence from long-term local residents and field observations, combined with scientific theory and research from other systems, however, strongly suggests that many of the vegetation changes are directional rather than cyclical and are resulting from the hydrological degradation of the delta system.

Opportunities for traditional vegetation restoration techniques such as cutting of invasive trees or reseeded degraded areas are very limited because of the large size and inaccessibility of much of the delta. Broad-scale herbiciding is probably undesirable and impractical. But regardless of the effectiveness of initiatives such as these, restoration efforts must address the root causes of vegetation change. They must enable the resumption of cyclical vegetation patterns rather than continued directional change. Efforts to restore the historical vegetation communities of the delta will thus ultimately depend on the degree to which improved hydrological conditions can reverse some of vegetation changes that have occurred. Working Paper #4 addresses the opportunities for improving hydrological conditions and restoring historical vegetation patterns and cycles in the Zambezi Delta.

APPENDIX 1 HISTORY OF DEVELOPMENT OF THE ZAMBEZI DELTA

Spreading over more than 1.2 million hectares of coastal Mozambique, the Zambezi Delta is one of the largest wetland systems in southern Africa. The protected Marromeu Buffalo Reserve and four surrounding hunting concessions on the delta south bank (the Marromeu Complex) include more than 688,000 ha. of floodplain grasslands, deepwater swamps, and mangrove forests and supports legendary concentrations of wildlife and waterbirds (Anderson *et al.* 1990). The delta north bank has one of the largest papyrus swamps in southern Africa. The delta is also home to more than 350,000 rural villagers who depend on the floodplain's rich natural resources for their livelihoods. Because of its rich biological diversity and national economic importance, the delta is a candidate for designation as a *Wetland of International Importance* under the Ramsar Convention (Davis 1994).

But the delta lies at the downstream terminus of the great Zambezi River system, lifeline of southern Africa, and bears the cumulative effects of engineering and agricultural projects over a 1,357,000 km² catchment that extends over portions of eight developing countries. These development works are indelibly intertwined with the history of the delta and its peoples.

Over the millennia, the delta was nourished by the annual spread of Zambezi floodwaters (Figure 3-23). The fertile floodplains provided recession agriculture, hunting, fishing, and abundant natural resources for its scattered inhabitants. The delta's vast, seasonally flooded grasslands supported diverse and abundant wildlife populations, including African elephant (*Loxodonta africana*), Cape buffalo (*Syncerus caffer*), waterbuck (*Kobus ellipsipymnus*), and countless thousands of waterbirds (Tinley 1969). The healthy floodplain provided spawning grounds for riverine and anadromous fishes and critical dry-season grazing lands for livestock and wildlife (Loxton, Hunting, and Associates *et al.* 1975b). Extensive coastal mangroves

and estuaries supported a productive prawn fishery (da Silva 1986).

Between the 12th and 14th centuries, Swahili and Indian traders reached the delta and began exporting ivory and skins from the delta, greatly reducing the concentration of large herbivores, particularly elephant and hippo, from the region (Newitt 1995). In the 16th century, Portuguese settlers arrived to expropriate labor and land rights from the local communities. Under Portuguese rule, land tenure in the delta was organized around the *prazo* system. *Prazos* were parcels of land over which individual settlers were granted wide powers of jurisdiction on behalf of the colonial regime. *Prazo Luabo*, *Prazo Melambe*, and *Prazo Tembue* covered the floodplains of the delta (Newitt 1969). As the *prazos* usurped powers from the indigenous chieftaincies, successive renters of *prazo* lands controlled landholder rights, collected taxes, and traded slaves. Agricultural productivity was low, but sesame, coconut, copra, and groundnut crops were traded for gold, ivory, and cattle, and by the early 1800s the delta supported a very diverse and lucrative agricultural economy (Negrao 1995). Over time, the *prazos* exerted their independence from the Portuguese authorities, and assumed characteristics more similar to the original African chieftaincies they had tried to supplant (Isaacman 1972). The 18th and 19th centuries marked a period of struggle between the rebellious *prazos* and the colonial government, with Portugal unable to control the *prazos* through either legislation or force. Eventually, however, the central government gained economic control of the *prazo* system through the development of port facilities and land concessions for plantation agriculture (Vail and White 1985).

Toward the end of the 19th century, the delta population reached 100,000 and the ivory trade began waning due to the near extirpation of hippo (*Hippopotamus amphibius*) and elephant from the delta. The Portuguese administration began promoting large-scale cash crop production to generate revenue, and the first commercial farm, the Mozambique Opium Cultivating and Trading Company at Mopeia, was established in 1870 (Ishemo 1995). The first sugar processing plant started production in Mopeia in 1893. In 1920, the Sena Sugar Estates were founded, and by 1930 the estates had acquired more than 100,000 ha. of the most fertile agricultural lands of the delta near Marromeu, Luabo, and Mopeia (Negrao 1995). Cotton was introduced as a compulsory crop in 1926, and rice in 1941. At peak production, 346,000 ha. of delta lands were in cultivation, with more than 293,000 ha. (85%) of the total titled for commercial production of cash crops and livestock under the Sena Sugar Estates, Madal Society, and others. The allocation of land to commercial farms pushed small landowners to marginal lands and later reduced the size of lands available to them. Landholding size per family in the delta eventually decreased from 15 ha. in the 1930s to less than one ha. during the 1970s (Negrao 1995). Tinley (1977) attributed this increasing land use pressure among rural villagers to the clearing of the remaining riverine and forest vegetation in the delta. Firewood demands for the sugar processing plants further contributed to local deforestation (Schmidt 1997).

With the rise of commercial agricultural schemes in the delta began the century-long process of severing the link between the Zambezi River and its delta. In 1893, the first embankments were constructed in the delta. Low dikes were constructed to protect the sugar fields at Mopeia, cutting off the upper delta distributary channels that delivered Zambezi floodwaters to the north bank floodplains (Figure 3-24). Over the next thirty years, similar embankments were constructed at Marromeu and Luabo. After widespread flooding in 1926 damaged the sugar plantations, the flood protection dikes were raised to the maximum level of the flood (Bolton 1983). During the remaining century, this level was exceeded only five times—in 1939, 1940, 1952, 1958 and 1978. In the 1930s, a railway line between Marromeu and Sena (80 km upstream on the mainstem Zambezi) was constructed to link with the existing line from Sena to the coastal port of Beira (Bolton 1983). The railway (and parallel road system) was designed without proper hydrographic surveys and obstructed the passage of water into the upper distributaries between Chupanga and Marromeu (Tinley 1994). Water movement in this region was further restricted by the construction of a direct railway line between Marromeu and Inhamitanga (located midway along the Sena-Beira railway line on the Cheringoma escarpment southwest of the delta) during the 1970s. The cumulative impact of these road and dike works was a dramatic reduction in the movement of floodwaters between the Zambezi River and Delta.

In December 1958, Kariba Dam, the first major dam on the Zambezi River, began impounding water and

further altered flooding patterns in the delta. Previous smaller projects, including a run-of-river hydroelectric generator at Victoria Falls, had a negligible effect on the hydrology of the Zambezi. Kariba Reservoir, however, controlled more than 40% of the total Zambezi runoff and was operated to generate steady hydropower production by storing peak floods and releasing a constant outflow of water (Reeve and Edmonds 1966). During the 1960s and 1970s, a major tributary of the Middle Zambezi, the Kafue River, was dammed first at Kafue Gorge and then at Itezihitezhi Gorge, further stabilizing the Zambezi flow regime downstream of Kariba (Balasubrahmanyam and Abou-Zeid 1982, Turner 1984).

Following the construction of Kariba Dam, Portuguese colonial interests in the development potential of the lower Zambezi Valley resulted in the establishment of the *Missao de Fomento e Povoaamento do Zambezi*⁵ (MFPZ). The MFPZ aimed to undertake the systematic investigation of Zambezi basin resources in Mozambique, to organize plans for their exploitation and development, and to prepare designs for the projects that would be selected (Hidrotécnica Portuguesa 1958, 1961, 1965a). From 1966-1974, the majority of MFPZ reports and investigations in the Zambezi concerned hydropower development in the Cahora Bassa Gorge.

Control of the Zambezi River culminated in December 1974 with the completion of Cahora Bassa Dam. With the closing of the dam, the ancient flood cycles of the Zambezi River were harnessed and the spill of floodwaters from the river to the delta floodplains became a phenomenon of the past (Beilfuss and Davies 1999). Inundation of the delta, when it occurs, is now dependent on regional rainfall-runoff within the lower Zambezi Basin or on erratically timed water releases to protect the dam wall during years of exceptional upper basin floods.

The dam was constructed as part of a comprehensive plan for multi-purpose development of the Lower Zambezi system including the delta, under the auspices of the *Gabinete do Plano do Zambeze* (Zambezi Valley Planning Authority)⁶. The principle elements of the plan were (a) construction of Cahora Bassa Dam and other mainstream dams for hydropower generation, flood control, and river navigation; (b) establishment of a navigable channel along the river for transshipment to a deepwater port at Chinde; (c) establishment of large irrigated agriculture schemes in the tributary basins and main alluvial plain; and (d) development of mining and industrial projects (Hidrotécnica Portuguesa 1965a). Bolton (1983) and Isaacman and Sneddon (2000) noted that a remarkable feature of the development planning for the Lower Zambezi was the almost total disregard for the indigenous population and their established patterns of land use. Even flood control – which promised some relief from the large floods that periodically devastated households and crops in the low lying areas of the delta – disrupted the land use practices adopted by local communities to harness the flood waters for economic gain (Liesegang and Chidiamassamba 1997). As a further insult, hydropower sales were committed to South Africa (and, to a lesser extent, Zimbabwe) with minimal electrical infrastructure development in the lower Zambezi Valley itself (Middlemas 1975).

After Mozambique gained independence in 1975, the next seventeen years were marked by brutal civil war in the region (Finnegan 1992). There was a steep decline in agricultural activity throughout the delta as villagers concentrated around Marromeu and Chinde for safety. In parts of the upper delta almost the entire population resettled, while those who remained suffered from the destruction of homes, schools, clinics, and businesses. Large areas of cultivated fields were abandoned and encroached by secondary grasslands and thickets. Near 'safe zones' where people congregated during the war, there was intensive local pressure on natural resources and woodland thickets were cleared for firewood. Livestock numbers were depleted, and still remain very low (Schmidt 1997).

The prolonged civil war in Mozambique greatly changed the face of the country (Hall and Young 1997). Hundreds of thousands of people were killed, especially in rural areas, and at least three million people were displaced from their homes (Nordstrom 1993). Many rural people migrated to urban centers, especially the coastal cities where the government retained control. The country went into severe economic depression (Kyle 1991). Agriculture was disrupted, so the country could not feed itself. By the 1990s, Mozambique had one of the lowest per capita caloric intakes in the world (Sill 1992).

The war also had a devastating effect on wildlife. After the Marromeu Buffalo Reserve was established

as a protective sanctuary in the 1950s and managed hunting concessions (*Coutadas*) were granted to individual operators over large areas bordering the reserve in the 1960s, the delta floodplains were populated by a grazing regime of over 16,000 buffalo and 5,000 waterbuck, with substantial populations of elephant and hippo (Tinley 1969). By 1978, the buffalo population had ballooned to more than 55,000 and waterbuck increased to nearly 50,000 (Tello and Dutton 1979). A sustainable wildlife culling operation was initiated, with 30,000 animals harvested between 1978 and 1985, but wildlife populations remained strong (Bindernagel 1980, Tello 1986). Then, over a period of only seven years – five at the end of the civil war and the first two years following the ceasefire in 1990 – wildlife populations were decimated by illegal commercial meat hunting (Tinley 1994). Cape buffalo, waterbuck, hippo, reedbuck (*Redunca arundinum*), and zebra (*Equus burchellii*) were all reduced by more than 95% (Anderson *et al.* 1990, Tinley 1994). Zebra and hippo are on the brink of local extirpation. Populations of large waterbird species dwindled to a fraction of their former numbers (Bento and Beilfuss 1999).

Since the 1992 Peace Accord, post-war life in the delta has gradually regained a sense of normalcy. Marromeu, Luabo, and Chinde have become major population centers again. Sugar cane, maize, rice, sorghum, beans, cassava, and millet are once again widely cultivated on the delta alluvium (Schmidt 1997). Wildlife populations are slowly recovering.

But despite these gains, the past century of Zambezi River engineering threatens to undermine the hopes and aspirations for the future. The management of Cahora Bassa Dam, as with the Kariba and Kafue schemes further upstream, remains focused on maximizing hydropower production at the expense of all other potential Zambezi uses⁷. Powerlines to South Africa and Zimbabwe that were sabotaged during the war have been rehabilitated, and Cahora Bassa now operates at full capacity⁸. Additional plans are underway for the Cahora Bassa North Bank Power Station, and for a new hydroelectric dam downstream of Cahora Bassa at Mepanda Uncua Gorge. The roads and railway lines, severely damaged during the civil war, are being rapidly rehabilitated.

Now, as Zambezi basin development plans set the course for the next century (Gabinete do Plano do Zambeze 2001), a narrow window of opportunity remains. Since 1997, concerned scientists, development workers, and conservationists have called for rethinking the management of Cahora Bassa Dam towards a more sustainable management of the Zambezi system (Beilfuss 1999). Basinwide efforts are underway to strengthen and implement the Zambezi Action Plan (ZACPLAN) for environmentally sound management of Zambezi waters among the eight riparian nations (Mbumwae 1988, Pinay *et al.* 1988, Aasand *et al.* 1996). Regional efforts are underway for the integrated management of the Zambezi Delta with Gorongosa National Park (DNFFB 1994). A Strategic Development Initiative (SDI) for the Zambezi Valley is encouraging the careful development (*i.e.*, the least damaging use) of Zambezi resources in Mozambique and drawing attention to the plight of the delta. An increasingly diverse array of voices is calling for the better use of Zambezi waters, to promote local development, tourism, and conservation in addition to other national interests. At the forefront of these discussions has been the argument that outflows from Cahora Bassa Dam must be managed such that simulation of the natural seasonal and inter-annual changes in water flow in the Zambezi River are re-established (Davies 1998).

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ENDNOTES

¹As discussed in Working Paper #2, the Quaternary Deltoid Plain is the dominant geologic feature underlying the whole of the Zambezi Delta. Superimposed on the Deltoid Plain is a series of recent alluvial plains with the usual system of channels, levees, and pans. Most prominent of the alluvial plains is that of the Zambezi, although the Salone, Cuncue, and Pandue rivers have extensive systems in their upper reaches near Marromeu.

²“Miombo” is used here to refer to woodland types dominated by members of the genus *Brachystegia* and other closely related genera such as *Julbernardia*, *Isoberlinia*, and *Berlinia*. Miombo woodland occurs widely in tropical Africa (Wild and Barbosa 1967).

³The sugar refinery at Marromeu is now fully operational, and the surrounding sugar fields are in full production. Plans are underway to rehabilitate the Luabo refinery, also severely damaged during the civil war. Until that time, the former sugar production fields near Luabo remain in a mix of traditional cultivation and secondary vegetation.

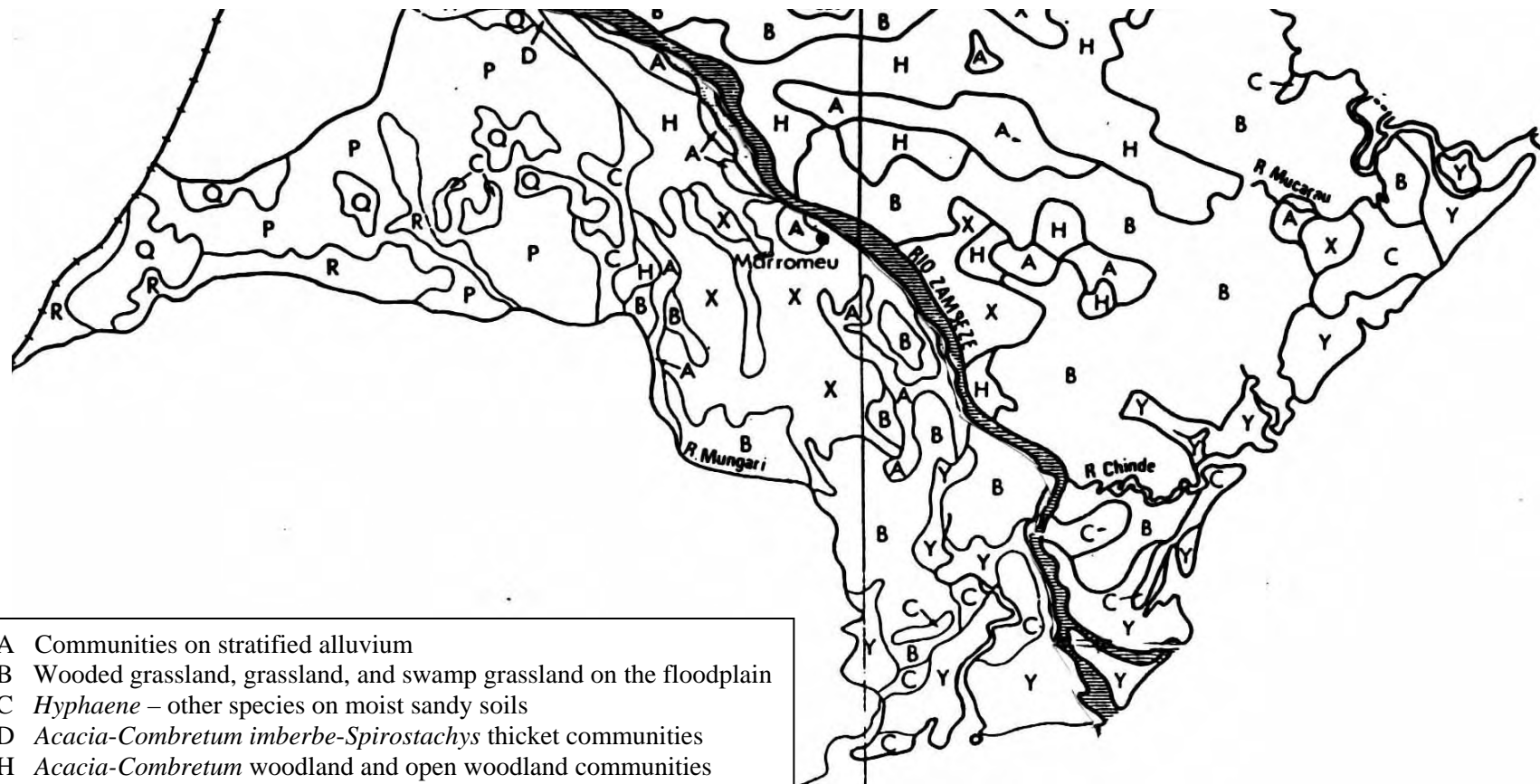
⁴Most of the Zambezi basin has received above-average rainfall in every year since 1996, including extreme rainfall events in 1997 and 2001, and appears to be entering another “wet cycle” similar to the period prior to the 1980s.

⁵The ultimate goal of the “Mission for the Development and Peopling of the Zambezi Valley” was to encourage dense Portuguese settlement in the Zambezi Valley through hydropower development, flood control, and large-scale irrigation schemes. The settlements were seen as a means of preventing the mounting Mozambican independence movement *Frente de Libertação de Moçambique* (FRELIMO) from gaining control of lands south of the Zambezi during the height of the revolutionary war (Middlemas 1975). Ironically, the major project resulting from the MFPZ, Cahora Bassa Dam, was completed only months before Mozambique gained independence from Portugal. Although FRELIMO strongly opposed Cahora Bassa Dam during its construction (Programme to Combat Racism 1971, Liberation Support Movement 1972), First-President Samora Machel embraced the dam after independence, stating that “...this venture will serve the highest interests of the development and prosperity of the People’s Republic of Mozambique.” The *Constitution of the Cahora Bassa Dam* was signed between Portugal and FRELIMO on June 23, 1975, establishing management of the dam under the Portuguese-controlled *Hidroeléctrica de Cahora Bassa* with Portugal retaining 82% share in dam ownership until the construction debt is repaid (Hidroeléctrica de Cahora Bassa 2000).

⁶The Zambezi Valley Planning Authority (GPZ) was established by the Portuguese in February 1970 to oversee the Cahora Bassa project and promote the integrated development of the Zambezi Valley. The GPZ was disbanded after Mozambique independence, but was re-created in 1995 as the statutory agency responsible for Zambezi Valley development, with administrative and financial autonomy under the direct authority of the Counsel of Ministers.

⁷A remarkable number of studies have been undertaken to assess the navigation potential of the lower Zambezi Valley since the initial MFPZ reports, including Gabinete do Plano do Zambeze (1973, 1974), DNA (1980), Savenije (1980), Institute for Hydrology (1981), and SOGREAH (1981). Others pondered the potential for navigational links between Zimbabwe and the Indian Ocean coast (Mitchell 1981). However, navigation has not been a priority for the management of Zambezi waters to date because of geomorphic instability of the coastal port at Chinde and the necessity for prohibitively expensive dredging operations (Hidrotécnica Portuguesa 1965c). There have been comparatively few studies of the irrigation potential of the Zambezi Delta region, and none since the Loxton, Hunting, and Associates *et al.* (1975i&j) studies. MFPZ studied the potential for large scale irrigation schemes for Portuguese settlers prior to Mozambique independence (Hidrotécnica Portuguesa 1965a,b,&d).

⁸The high voltage DC powerlines from Cahora Bassa Dam to South Africa were cut by the *Resistência Nacional de Moçambique* (RENAMO) opposition forces in June 1980, effectively shutting down all power production from the dam after only 11 months of full production. More than 2000 pylons were damaged, and many of these sites were landmined to thwart rehabilitation efforts (Hidroeléctrica de Cahora Bassa 2000). Power production was not fully restored until August 1998. Thus, during the first 24 years of Cahora Bassa operation the only power produced (about 15 MW, or 0.7% of the 2075 MW potential output) was for the *Hidroeléctrica de Cahora Bassa* facilities at Songo. The rehabilitated powerlines were again damaged during the floods that ravaged South Africa and Mozambique during 2000.



- A Communities on stratified alluvium
- B Wooded grassland, grassland, and swamp grassland on the floodplain
- C *Hyphaene* – other species on moist sandy soils
- D *Acacia-Combretum imberbe-Spirostachys* thicket communities
- H *Acacia-Combretum* woodland and open woodland communities
- P Mild subarid and subhumid *Milletia* communities
- Q Subhumid Mata Mista communities
- R Subhumid *Brachystegia* communities
- X Palm communities on seasonal floodplain wetlands
- Y Mangroves and associated communities

Figure 3-1. Loxton, Hunting, and Associates (1975e&f) pedo-ecological mapping units for the Zambezi Delta region.

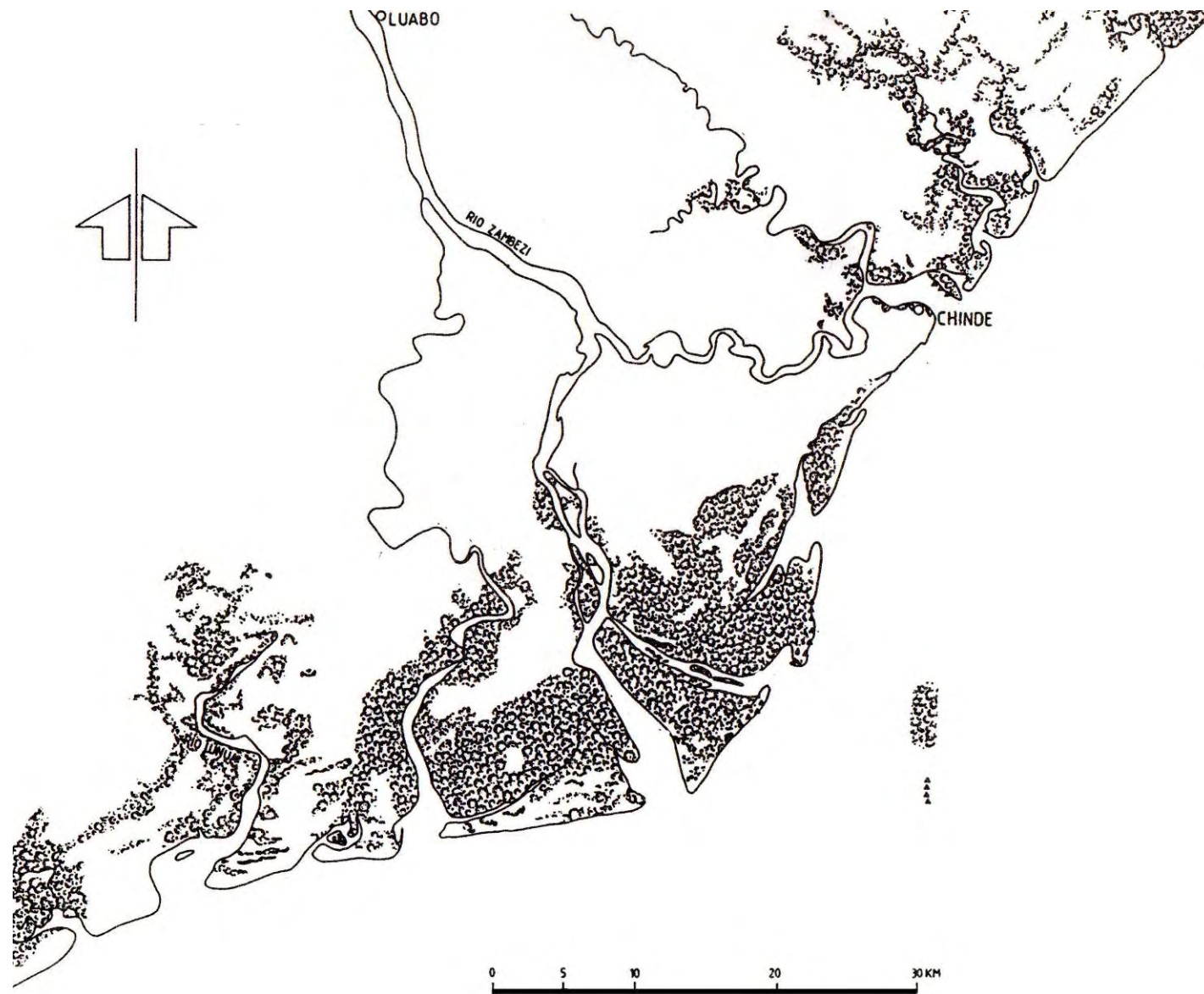


Figure 3-2. SWECO (1983) mapping of coastal mangrove distribution in the Zambezi Delta.

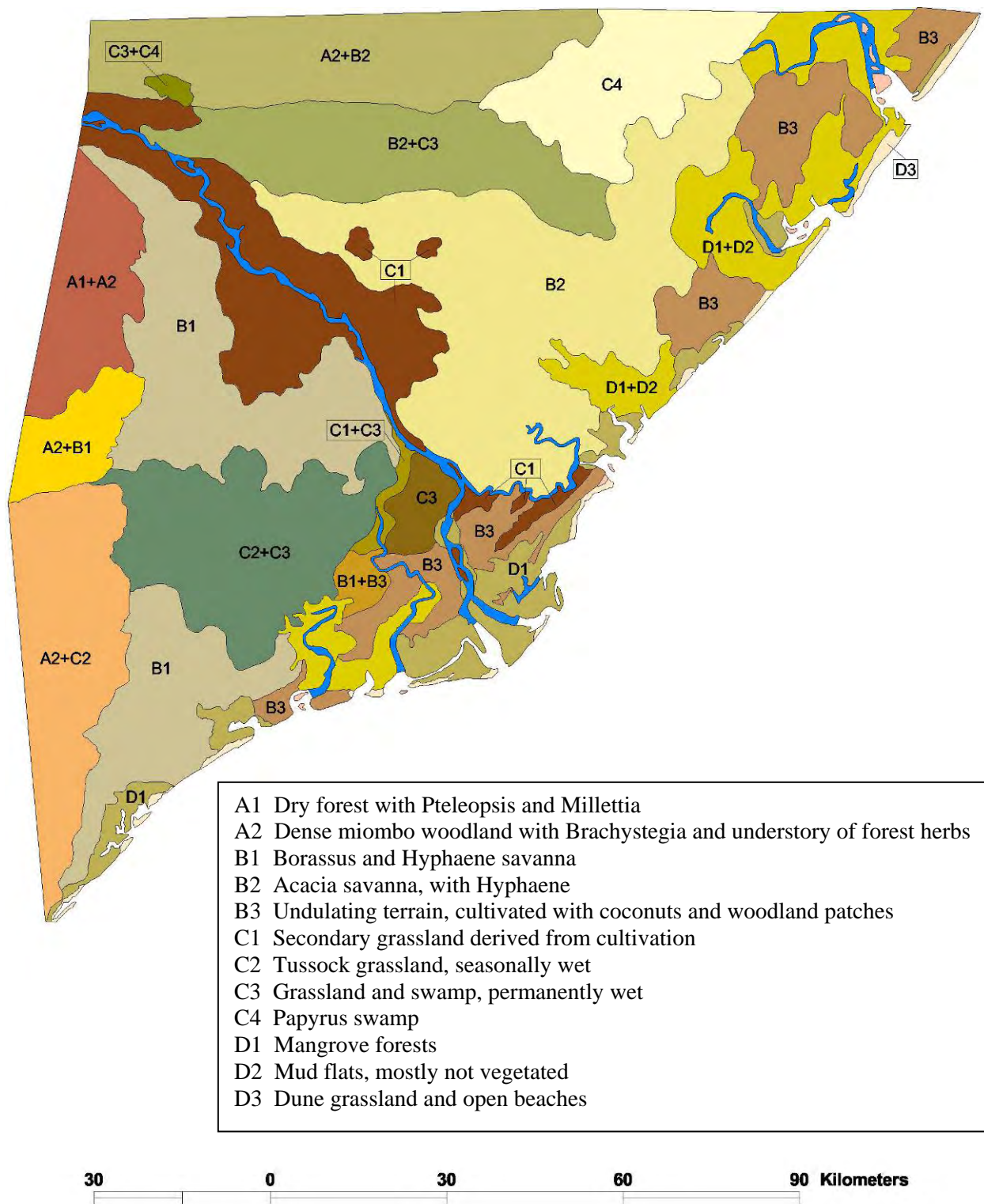


Figure 3-3. Timberlake (2000) classification of Zambezi Delta vegetation cover.

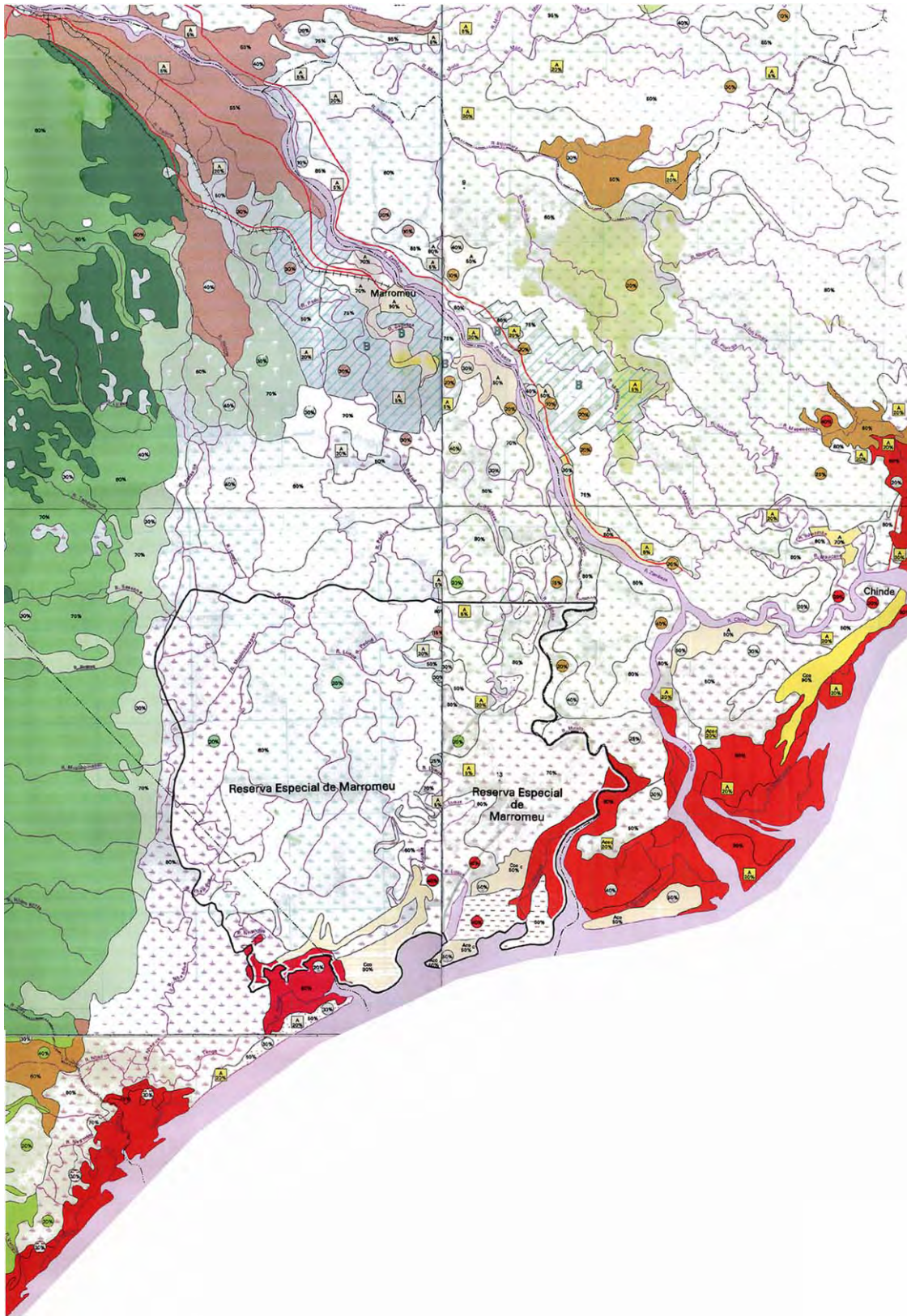
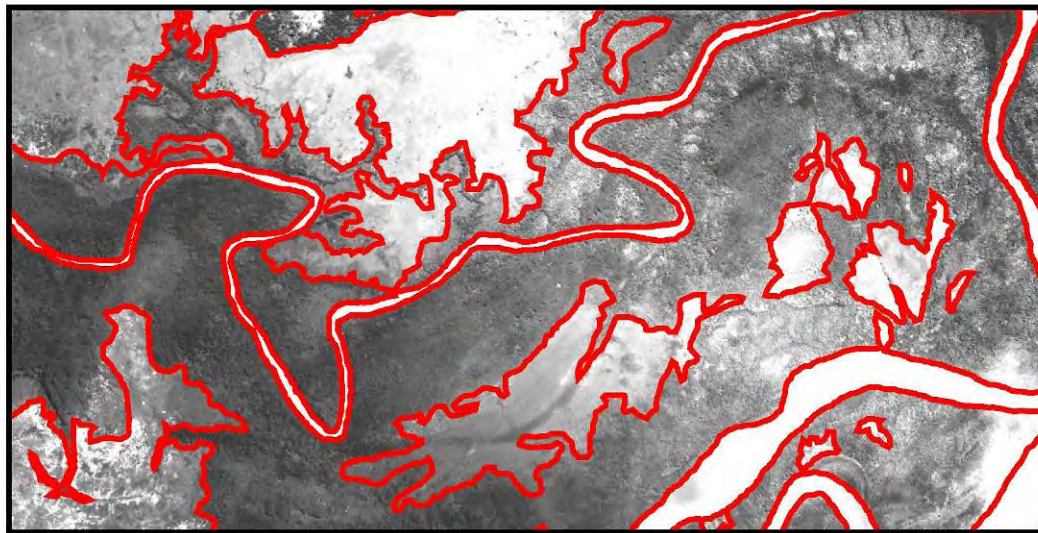


Figure 3-4. Land cover map for the south bank floodplains of the Zambezi Delta, showing the Marromeu Reserve and Cheringoma escarpment on the western boundary (CENACARTA 1998).



Legend

- Saline grassland mosaic with Phragmites reedswamp on floodplain gleys and waterways
- Mangrove forest on the coastal estuary
- Saline mudflats and pioneer mangrove communities on the coastal estuary
- Open water

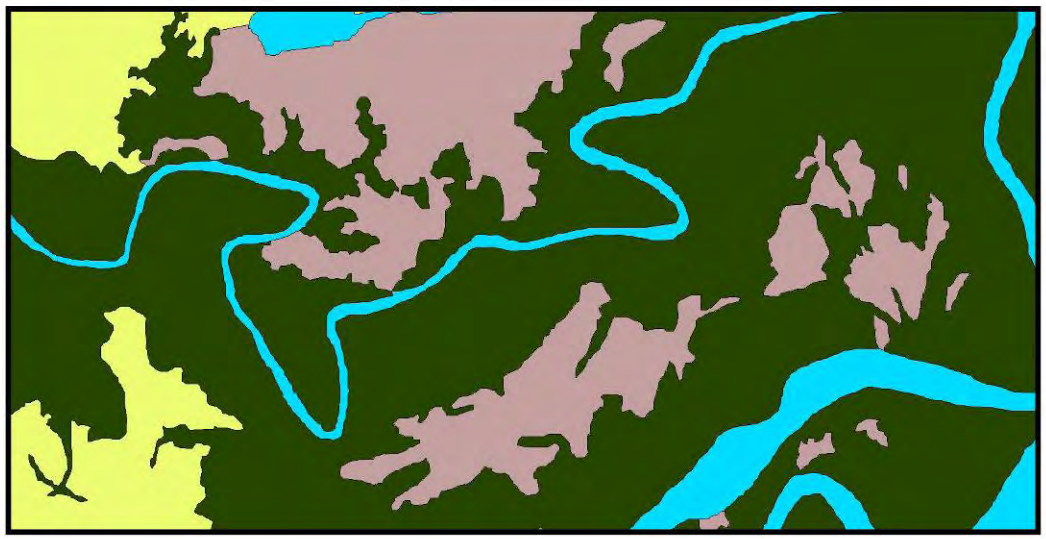
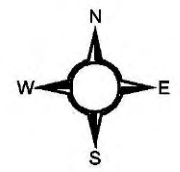


Figure 3-5. Classification of the 1960 aerial photograph mosaic (sample area).

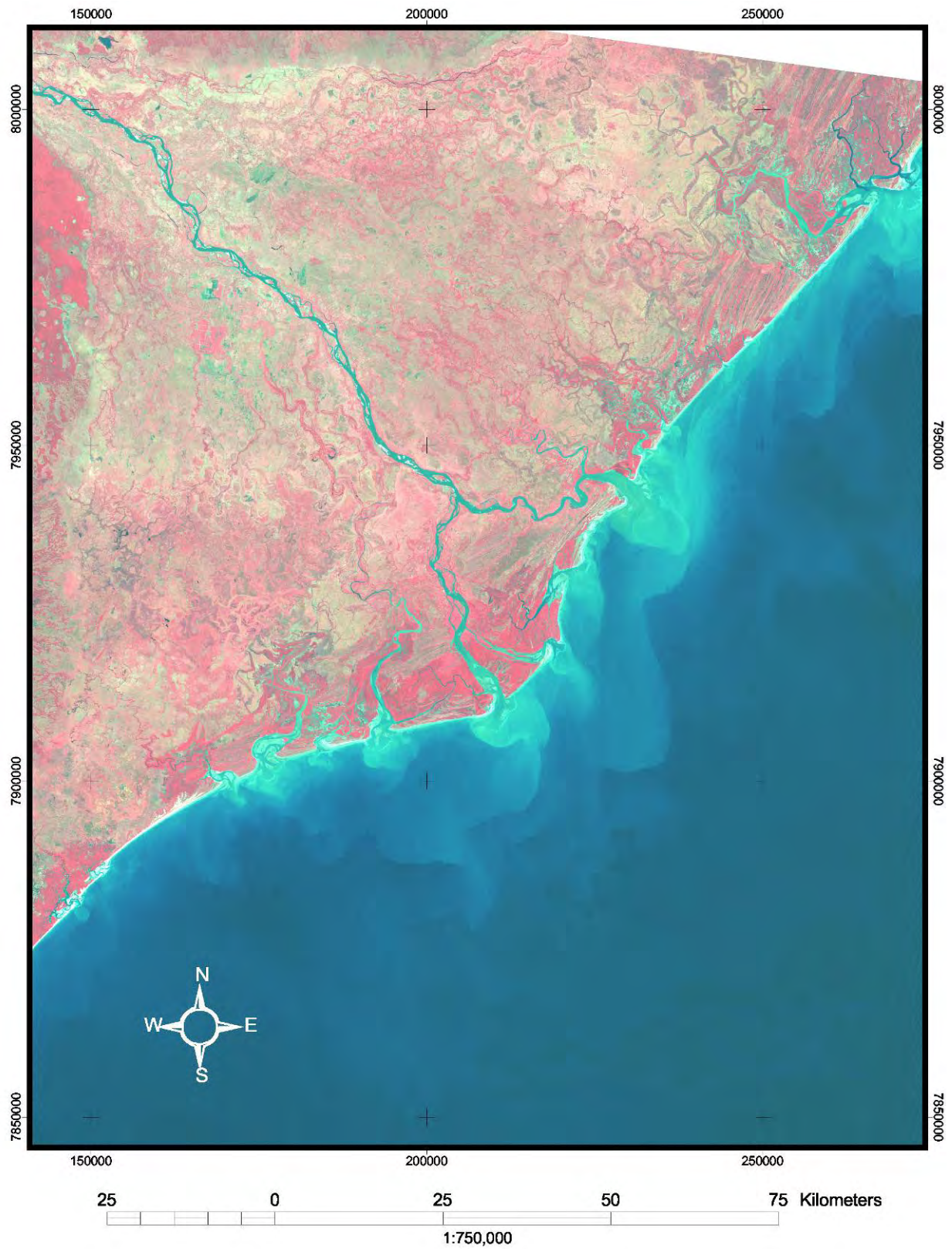


Figure 3-6. Landsat 7 ETM satellite image of the Zambezi Delta, 16 July 2000 (false color composite).

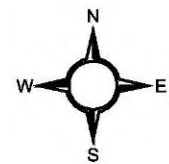
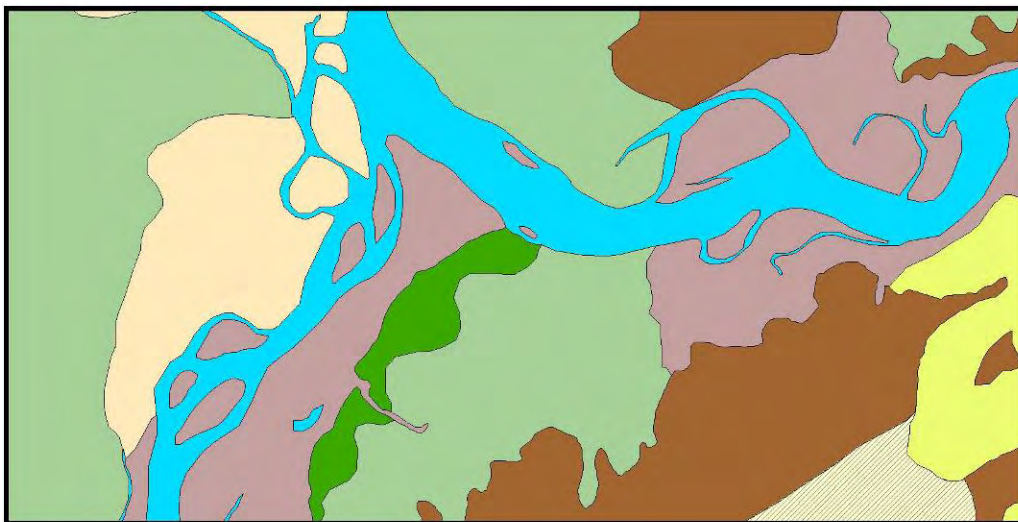
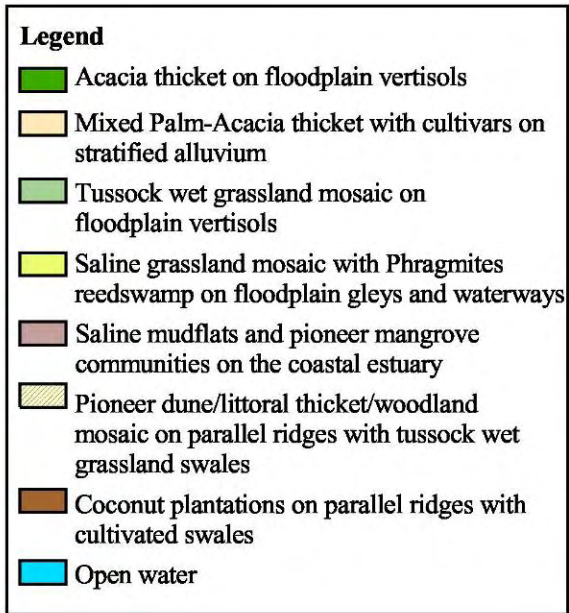
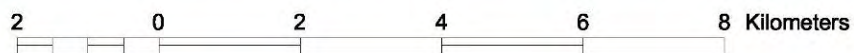
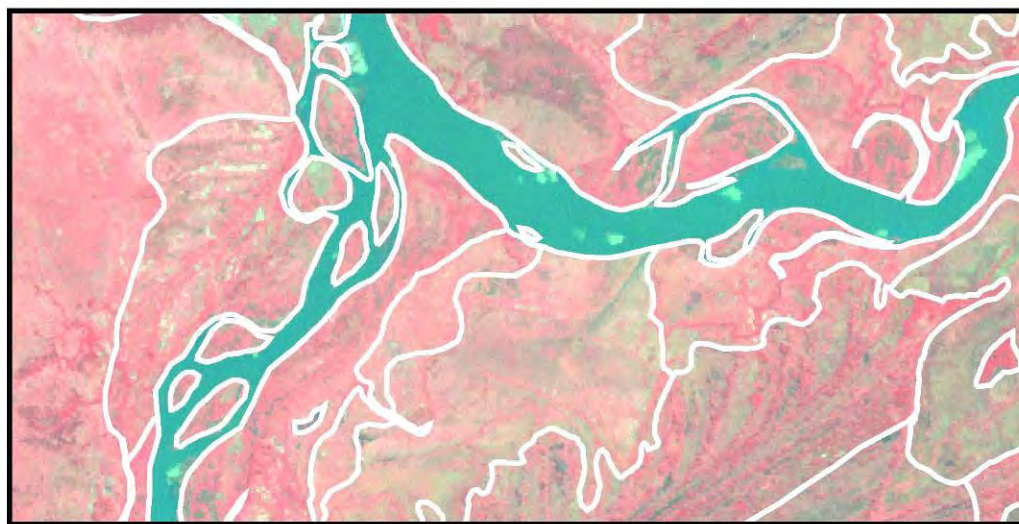


Figure 3-7. Classification of 2000 Landsat 7 ETM image (sample area).

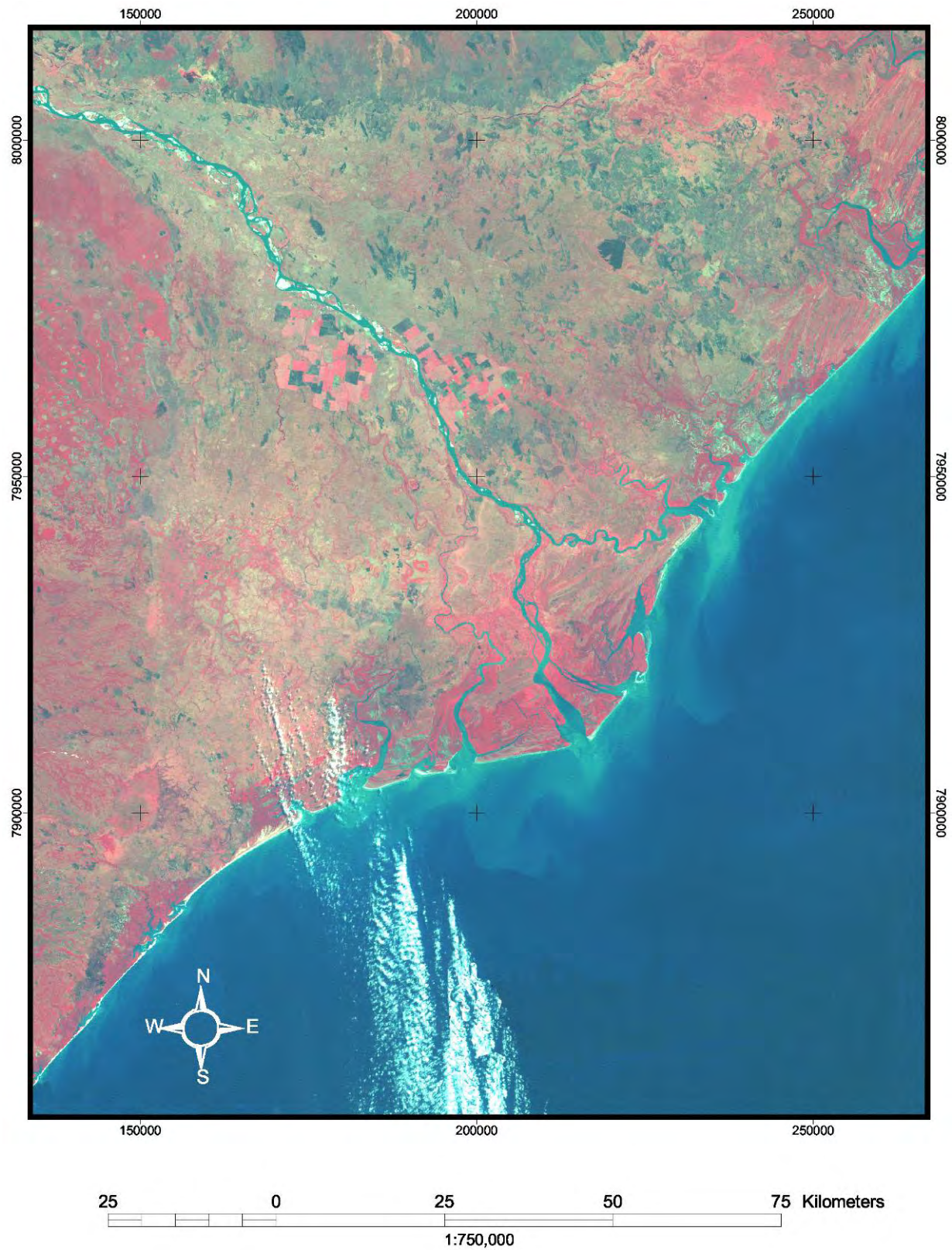


Figure 3-8. Landsat MSS satellite image of the Zambezi Delta, 1 August 1972 (false color composite).

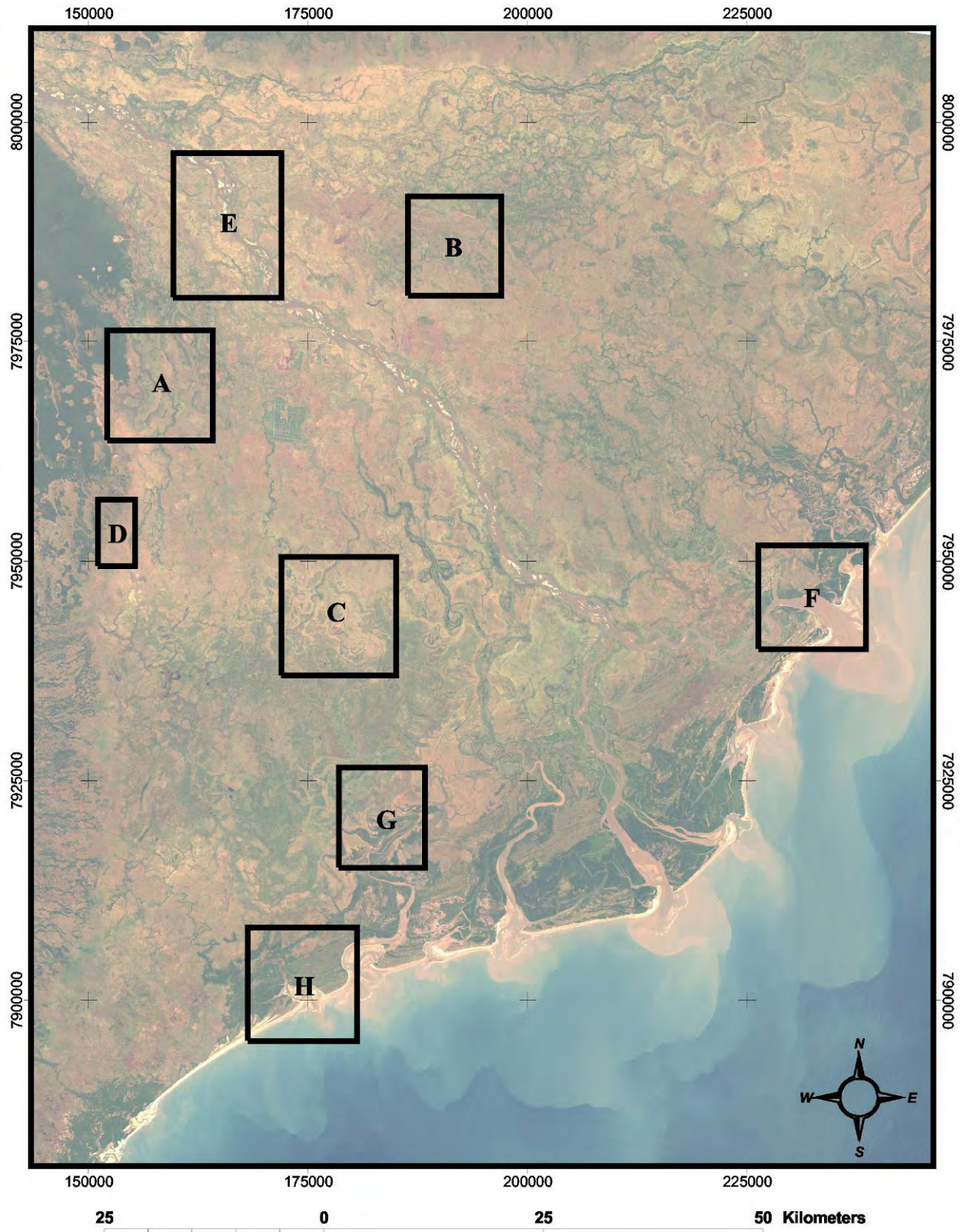
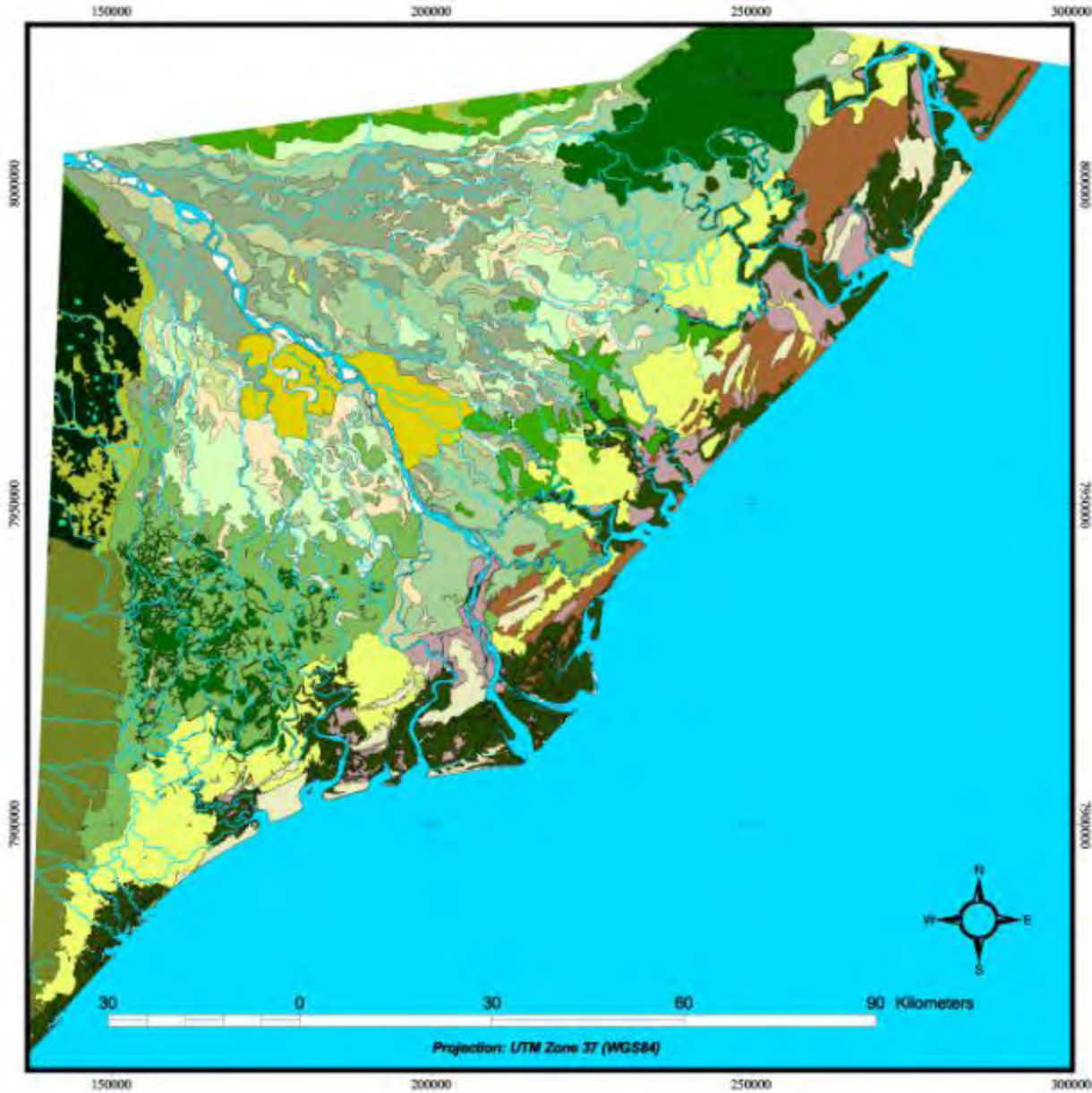


Figure 3-9. Location of inset boxes for showing details of vegetation changes over time in the following Figures 3-13 to 3-19. Landsat 7 ETM satellite image, 16 July 2000 (true color composite).



VEGETATION COMMUNITIES OF THE CHERINGOMA AND MORRUMBULA ECOTONE

- Dry lowland forest on the escarpment
- Wetland pans in the dry lowland forest
- Miombo woodland/humid grassland /riverine forest mosaic on escarpment alluvial fans
- Acacia thicket on the low-level Zambezi terrace
- Hyphaene palm savanna and associated species on outwash sands at the escarpment base

WOODY COMMUNITIES ON THE QUATERNARY DELTOID PLAIN

- Acacia woodland and savanna on floodplain vertisols
- Borassus palm savanna on floodplain vertisols
- Hyphaene palm savanna on floodplain vertisols
- Acacia thicket on floodplain vertisols
- Mixed Palm-Acacia thicket with cultivars on stratified alluvium

GRASSLAND COMMUNITIES ON THE QUATERNARY DELTOID PLAIN

- Tussock wet grassland mosaic on floodplain vertisols
- Stoloniferous swamp grassland mosaic on floodplain gleys and vertisols
- Papyrus swamps on floodplain waterways and lagoons
- Saline grassland mosaic with Phragmites reedswamp on floodplain gleys and waterways
- Aquatic macrophytes on floodplain swamps and lagoons

CULTIVATED AREAS WITH SECONDARY COMMUNITIES

- Cultivated areas with secondary vegetation associations on stratified alluvium
- Sugar plantations with secondary vegetation associations on floodplain vertisols

MANGROVE AND ASSOCIATED COMMUNITIES

- Mangrove forest on the coastal estuary
- Saline mudflats and pioneer mangrove communities on the coastal estuary
- Barringtonia evergreen swamp forest on coastal waterways

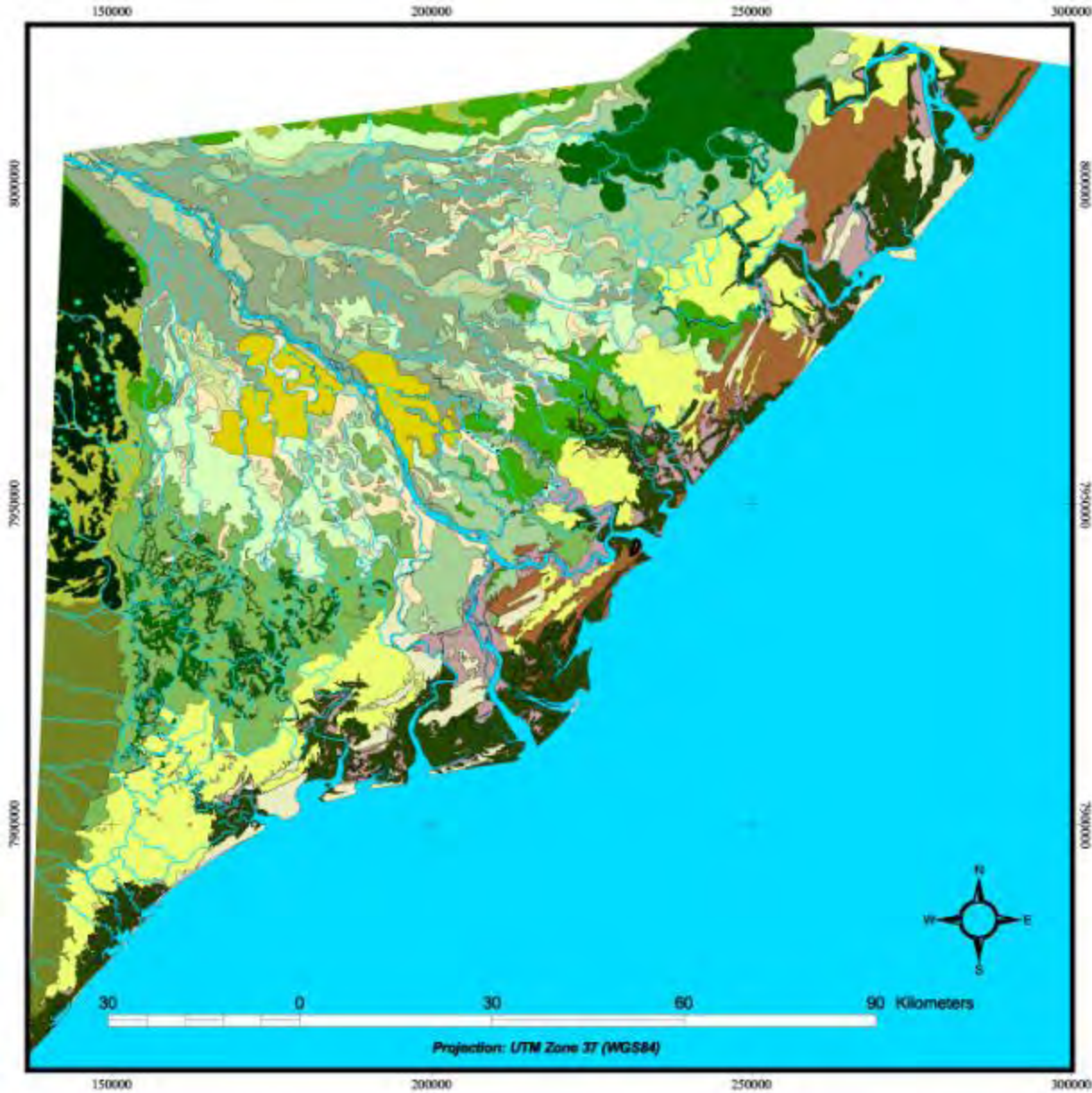
COASTAL DUNE COMMUNITIES

- Pioneer dune/littoral thicket/woodland mosaic on parallel ridges with tussock wet grassland swales
- Coconut plantations on parallel ridges with cultivated swales

UNVEGETATED LANDFORMS

- Open beaches
- Unconsolidated sandbars
- Open water

Figure 3-10. Historical vegetation map of the Zambezi Delta region based on 1960 aerial photographs.



VEGETATION COMMUNITIES OF THE CHERINGOMA AND MORRUMBULA ECOTONE

- Dry lowland forest on the escarpment
- Wetland pans in the dry lowland forest
- Miombo woodland/humid grassland /riverine forest mosaic on escarpment alluvial fans
- Acacia thicket on the low-level Zambezi terrace
- Hyphaene palm savanna and associated species on outwash sands at the escarpment base

WOODY COMMUNITIES ON THE QUATERNARY DELTOID PLAIN

- Acacia woodland and savanna on floodplain vertisols
- Borassus palm savanna on floodplain vertisols
- Hyphaene palm savanna on floodplain vertisols
- Acacia thicket on floodplain vertisols
- Mixed Palm-Acacia thicket with cultivars on stratified alluvium

GRASSLAND COMMUNITIES ON THE QUATERNARY DELTOID PLAIN

- Tussock wet grassland mosaic on floodplain vertisols
- Stoloniferous swamp grassland mosaic on floodplain gleys and vertisols
- Papyrus swamps on floodplain waterways and lagoons
- Saline grassland mosaic with Phragmites reedswamp on floodplain gleys and waterways
- Aquatic macrophytes on floodplain swamps and lagoons

CULTIVATED AREAS WITH SECONDARY COMMUNITIES

- Cultivated areas with secondary vegetation associations on stratified alluvium
- Sugar plantations with secondary vegetation associations on floodplain vertisols

MANGROVE AND ASSOCIATED COMMUNITIES

- Mangrove forest on the coastal estuary
- Saline mudflats and pioneer mangrove communities on the coastal estuary
- Barringtonia evergreen swamp forest on coastal waterways

COASTAL DUNE COMMUNITIES

- Pioneer dune/littoral thicket/woodland mosaic on parallel ridges with tussock wet grassland swales
- Coconut plantations on parallel ridges with cultivated swales

UNVEGETATED LANDFORMS

- Open beaches
- Unconsolidated sandbars
- Open water

Figure 3-11 Current vegetation map of the Zambezi Delta region based on 2000 satellite imagery.

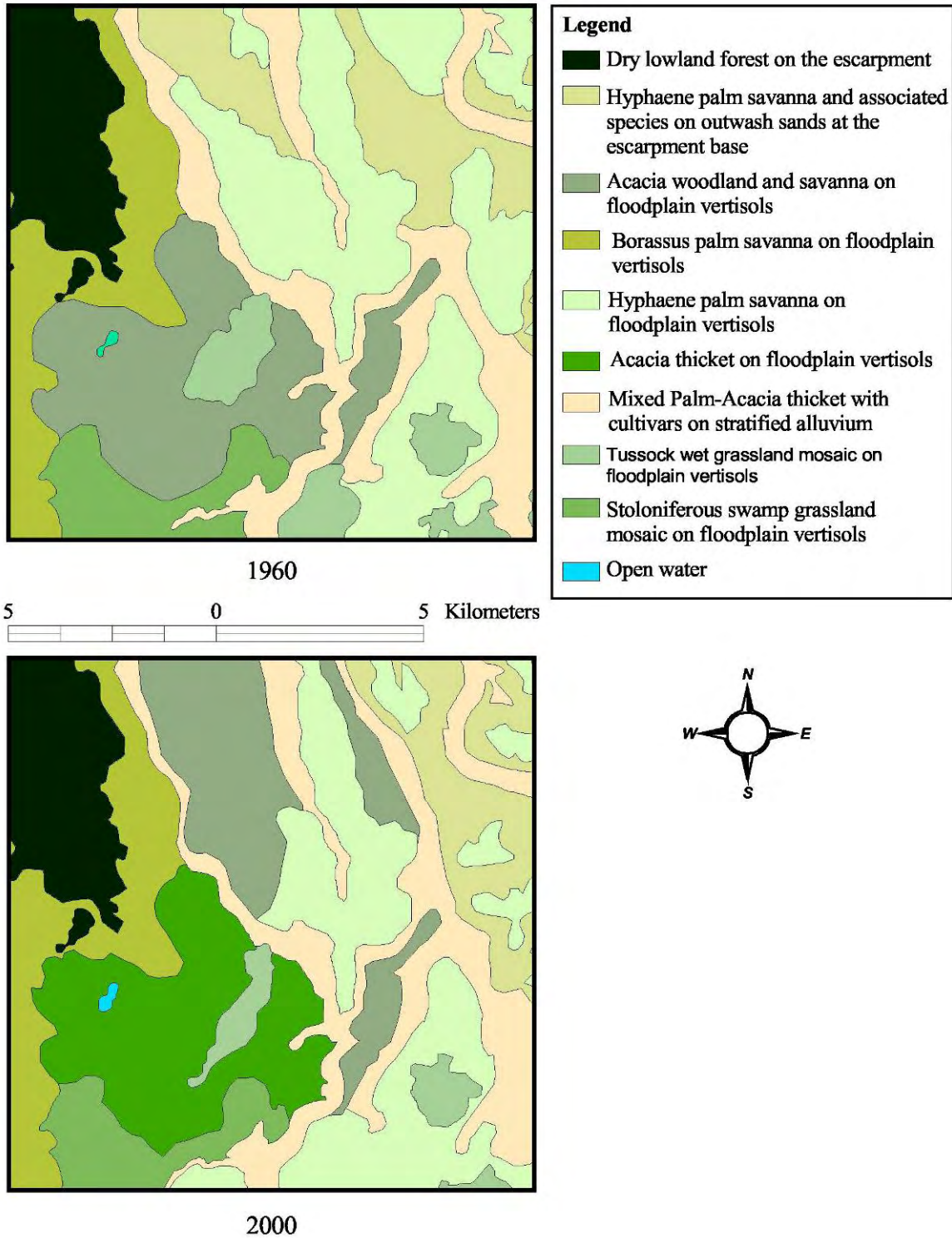
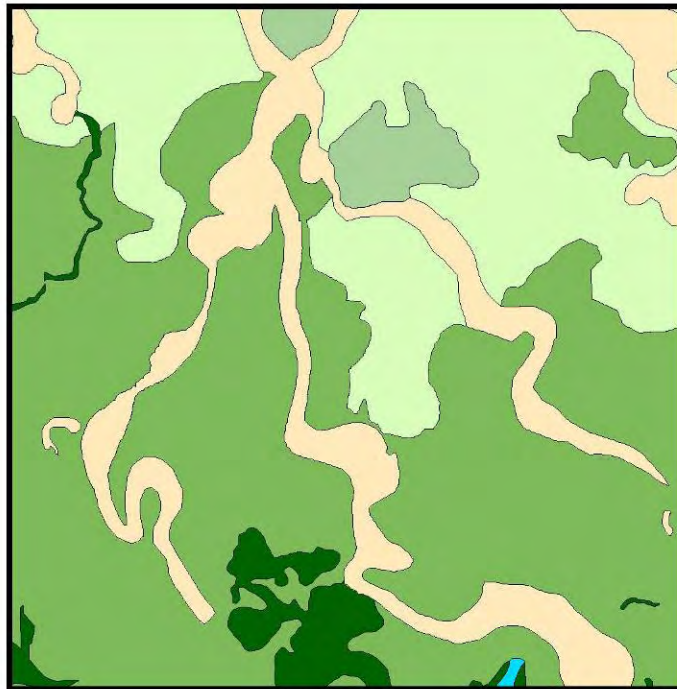


Figure 3-12. Inset box A showing an example of the transition from tussock grassland to Hyphaene palm savanna to Borassus palm savanna to Acacia savanna and woodland to Acacia thicket on the delta floodplain over the past 40 years.



Figure 3-13. Inset box B showing an example of the establishment of Acacia savanna and Hyphaene palm savanna in areas formerly occupied by seasonally wet tussock grassland.

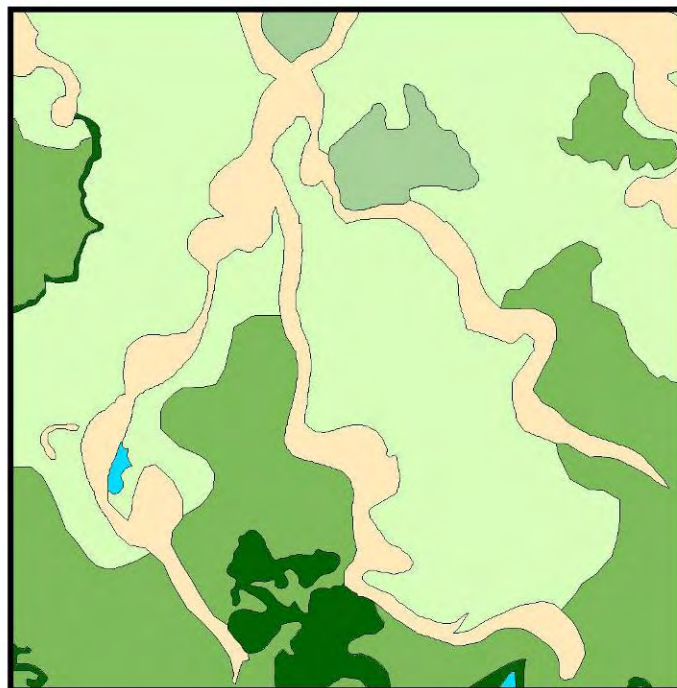
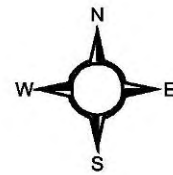
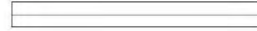


1960

Legend

- Hyphaene palm savanna on floodplain vertisols
- Mixed Palm-Acacia thicket with cultivars on stratified alluvium
- Tussock wet grassland mosaic on floodplain vertisols
- Stoloniferous swamp grassland mosaic on floodplain gleys and vertisols
- Papyrus and associated species in waterways and backwater swamps on the delta floodplain
- Open water

0 5 Kilometers



2000

Figure 3-14. Inset box C showing an example of the establishment of Hyphaene palm savanna in areas formerly occupied by perennially wet tussock grassland. Palms have invaded from stratified alluvium on the backslopes of river levees into the hydromorphic vertisols of the open floodplain.

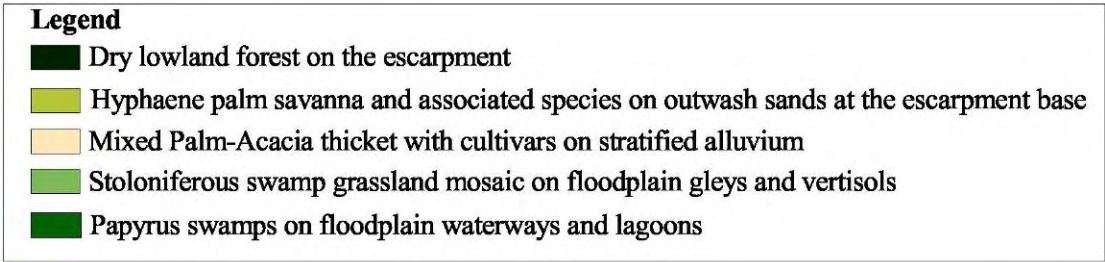
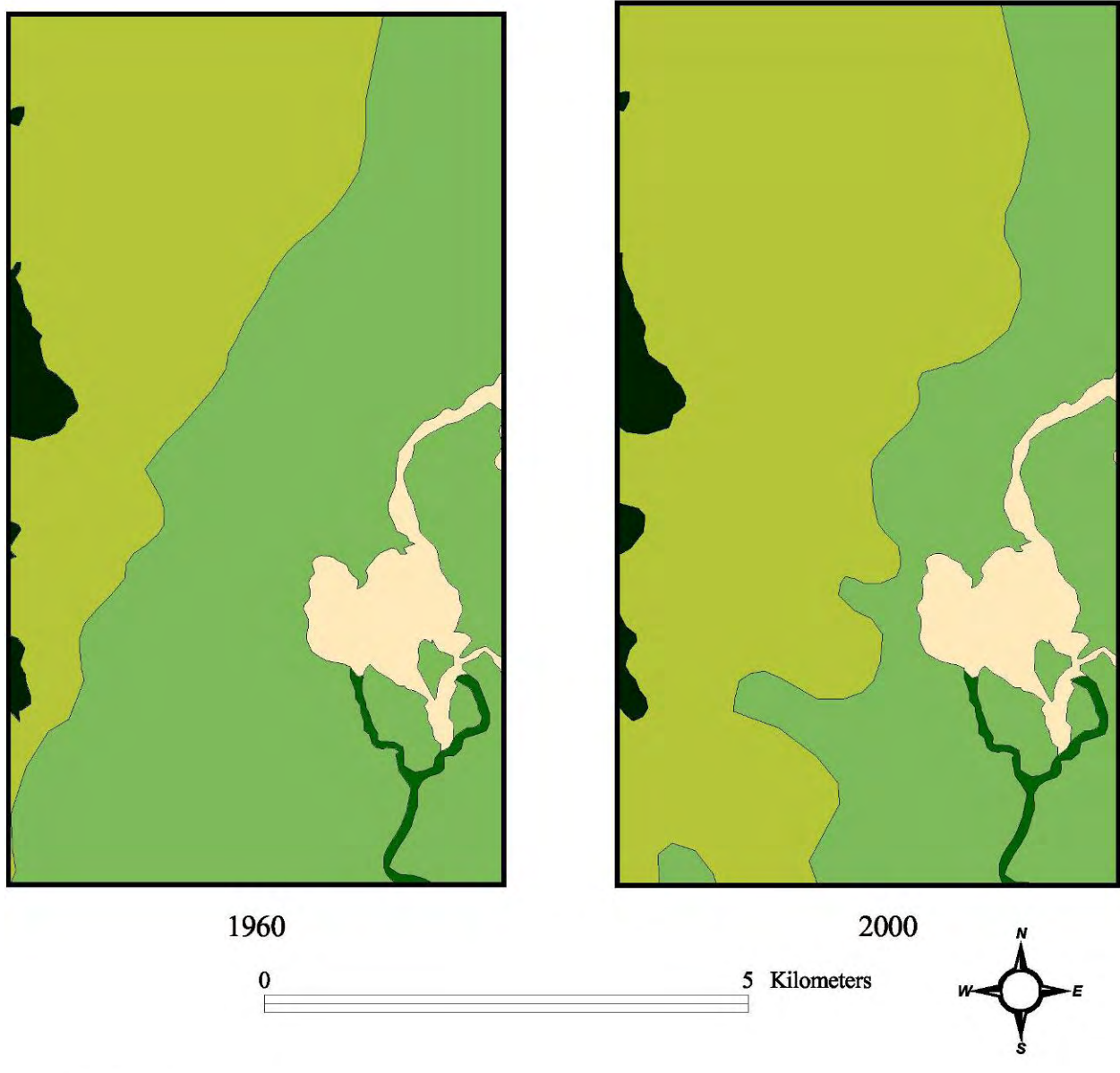


Figure 3-15. Inset box D showing an example of the establishment of Hyphaene palm savanna in areas formerly occupied by perennially wet tussock grassland. Palms have invaded from outwash sands on the floodplain margin into the hydromorphic vertisols of the open floodplain.

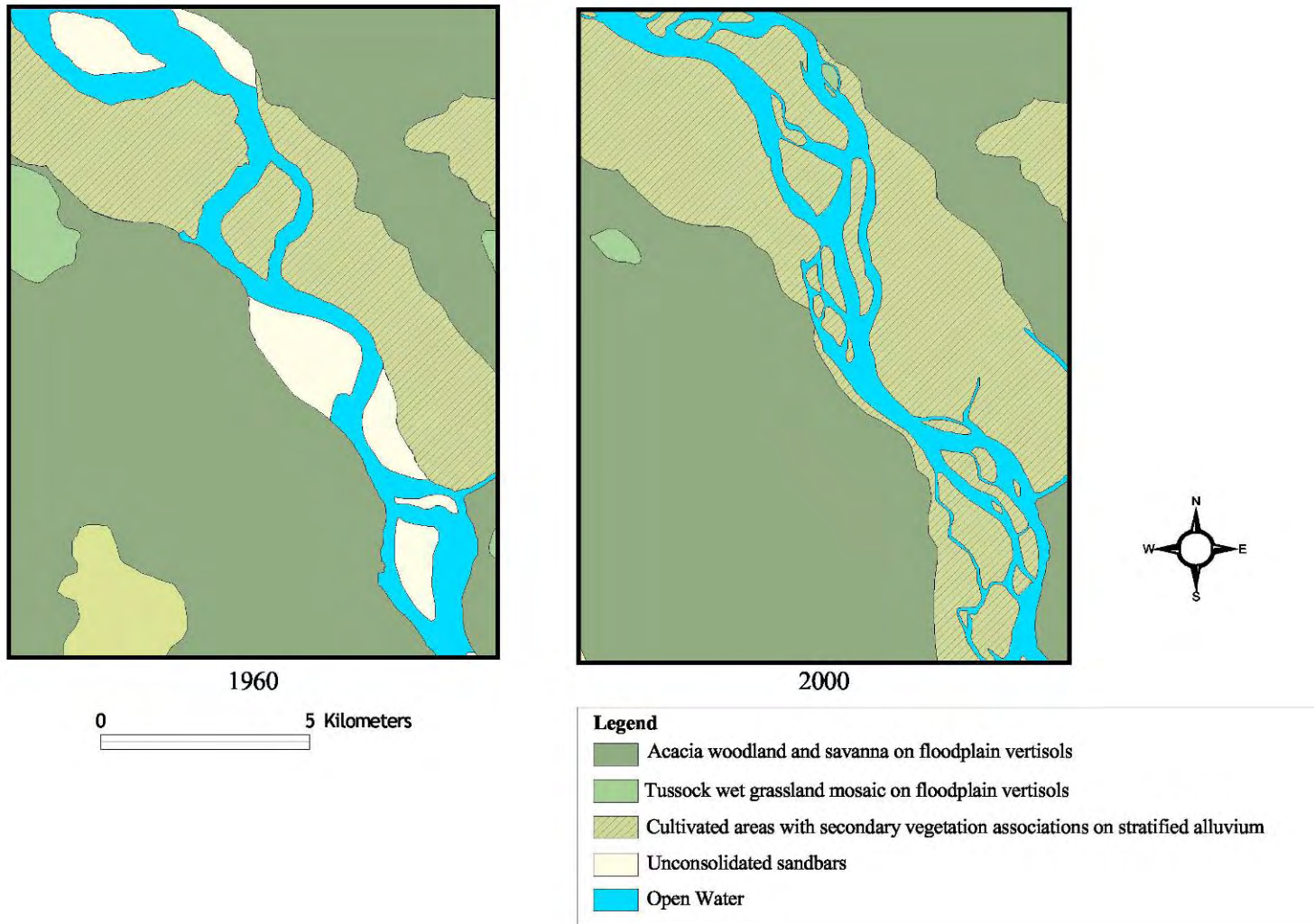


Figure 3-16. Inset box E showing an example of changes in Zambezi River morphology between 1960 and 2000. The active, shifting Zambezi River channels have become a stable braided meander chain of rivulets weaving between consolidated islands, resulting in permanent sandbars with riverine grassland and cultivated fields.

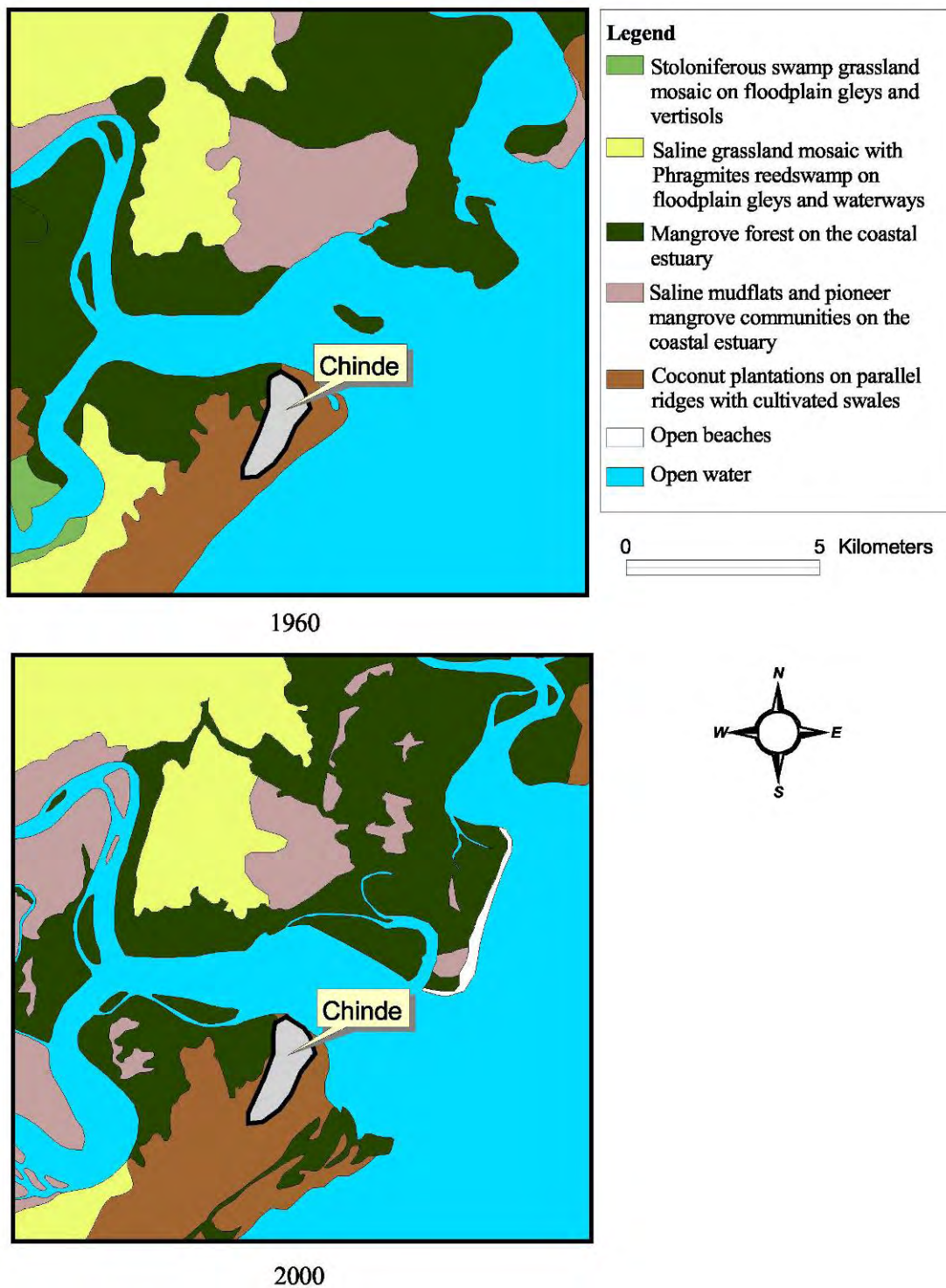
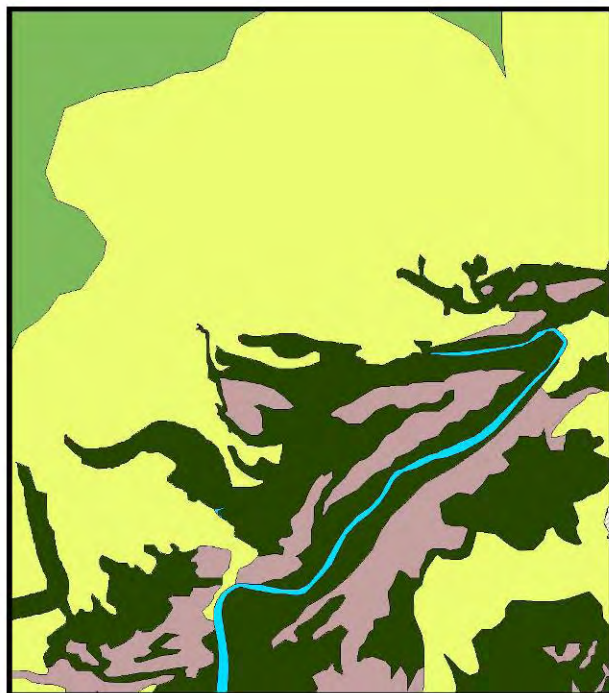
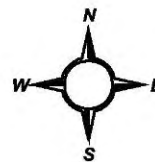
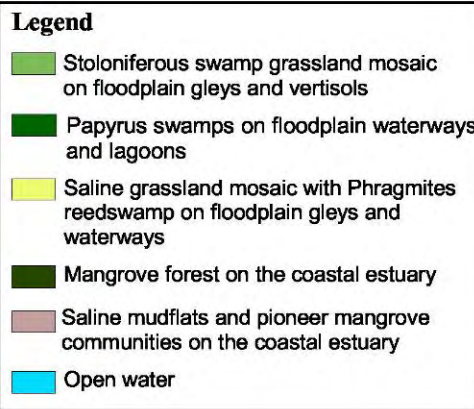


Figure 3-17. Inset box F showing an example of changes in coastal geomorphology between 1960 and 2000. Large tracks of mangrove forest have been scoured away by shifts in the Zambezi River, with pioneering *Avicennia* mangrove establishing on recently exposed mudflats. Prior to 1960, the large coastal port village of Chinde was relocated twice after the original settlements were destroyed by geomorphic changes at the Zambezi mouth.



1960



2000

Figure 3-18. Inset box G showing an example of the displacement of inland mangrove forest and open mudflats by saline grassland mosaic. Note also the constriction of the coastal inlet channel. Saline grassland species have also encroached into areas formerly occupied by freshwater floodplain grassland associations.

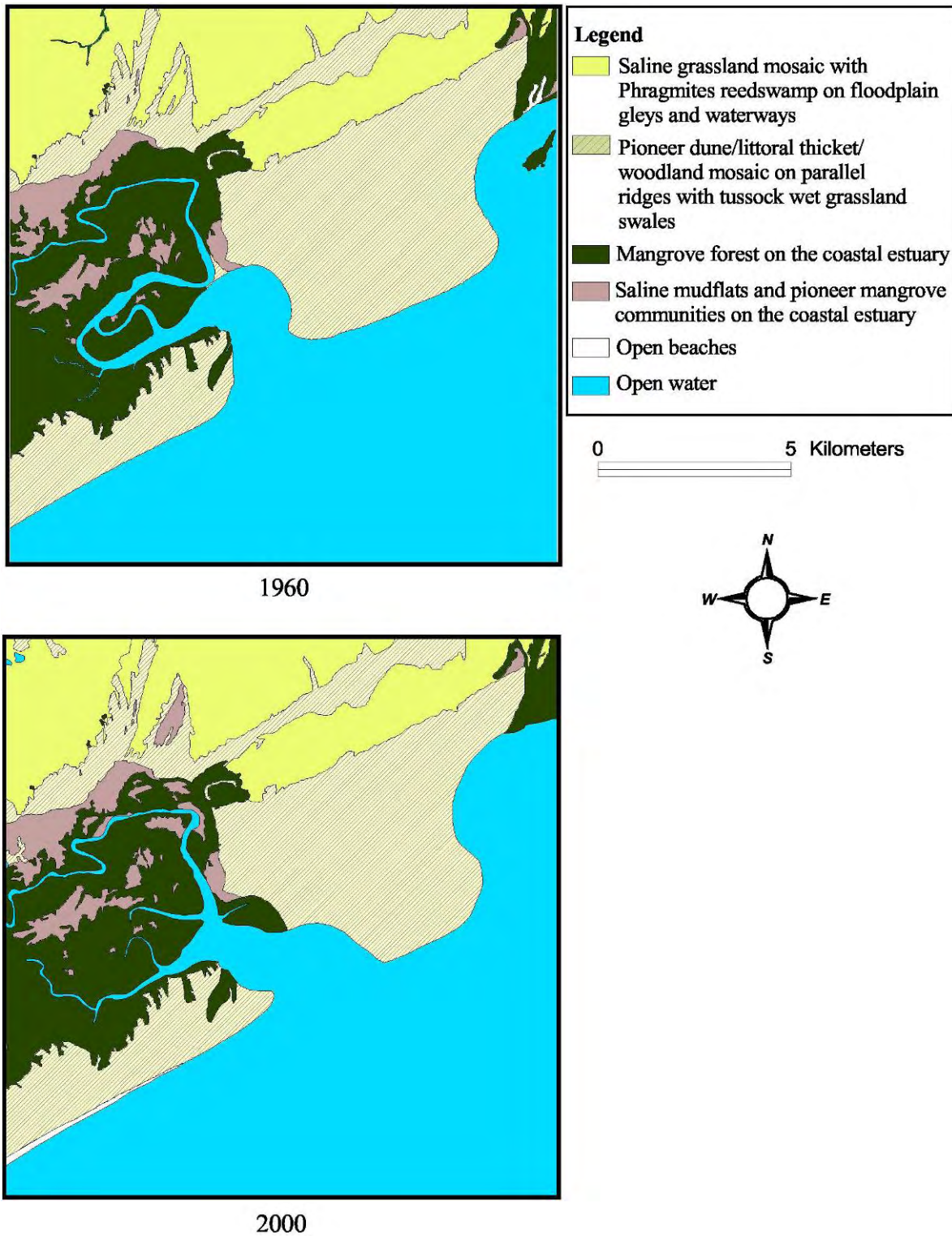


Figure 3-19. Inset box H showing an example of changes in coastal geomorphology between 1960 and 2000. Note erosion of coastal dune thicket and terrestrialization of inlet meander bends with mangrove thicket.

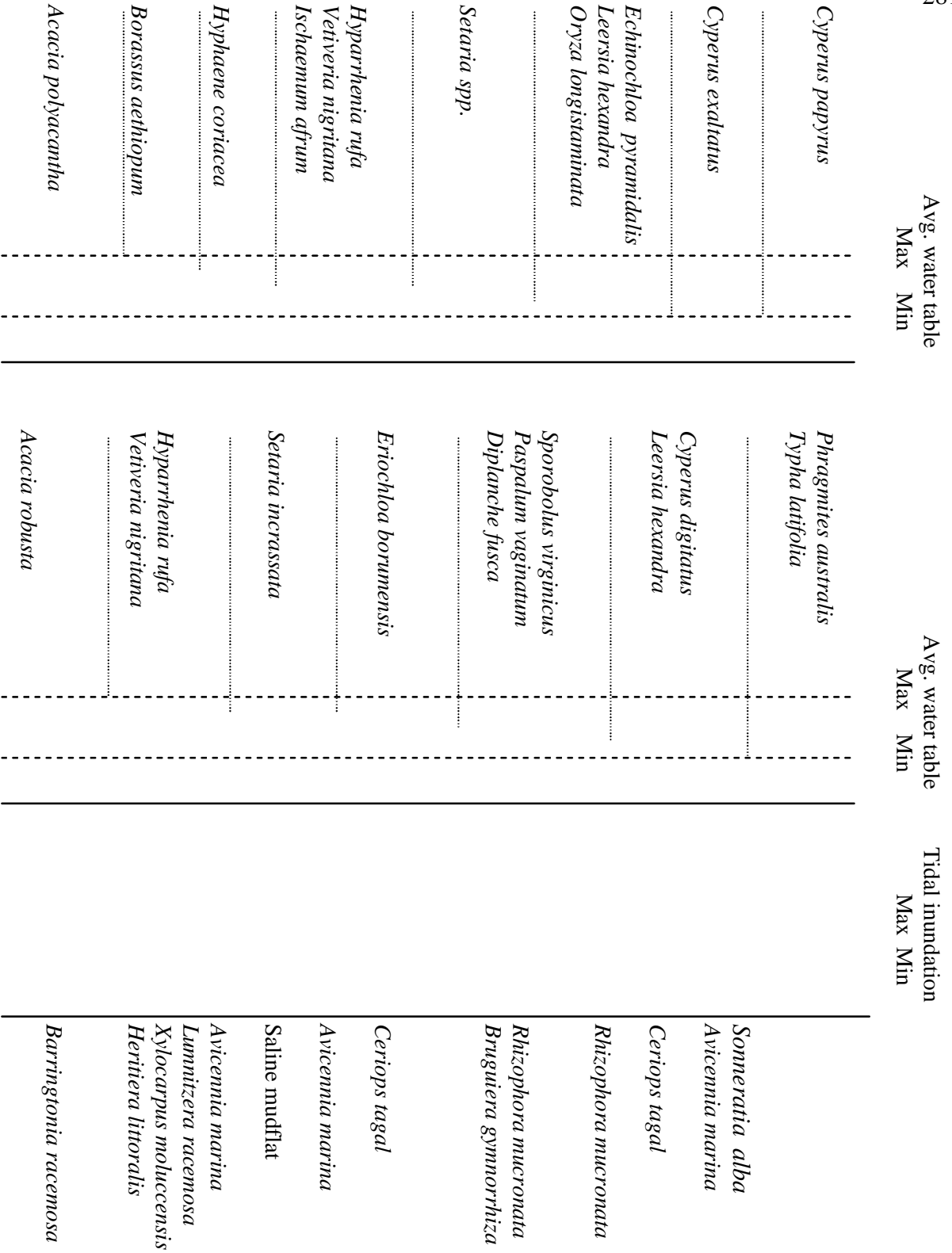


Figure 3-20. Typical hydroseres for vegetation succession in freshwater grasslands (top), saline grasslands (middle), and mangrove forests (bottom) in the Zambezi Delta. Adapted from Loxton Hunting and Associates (1975b), Thompson (1985), and SWECO (1983).

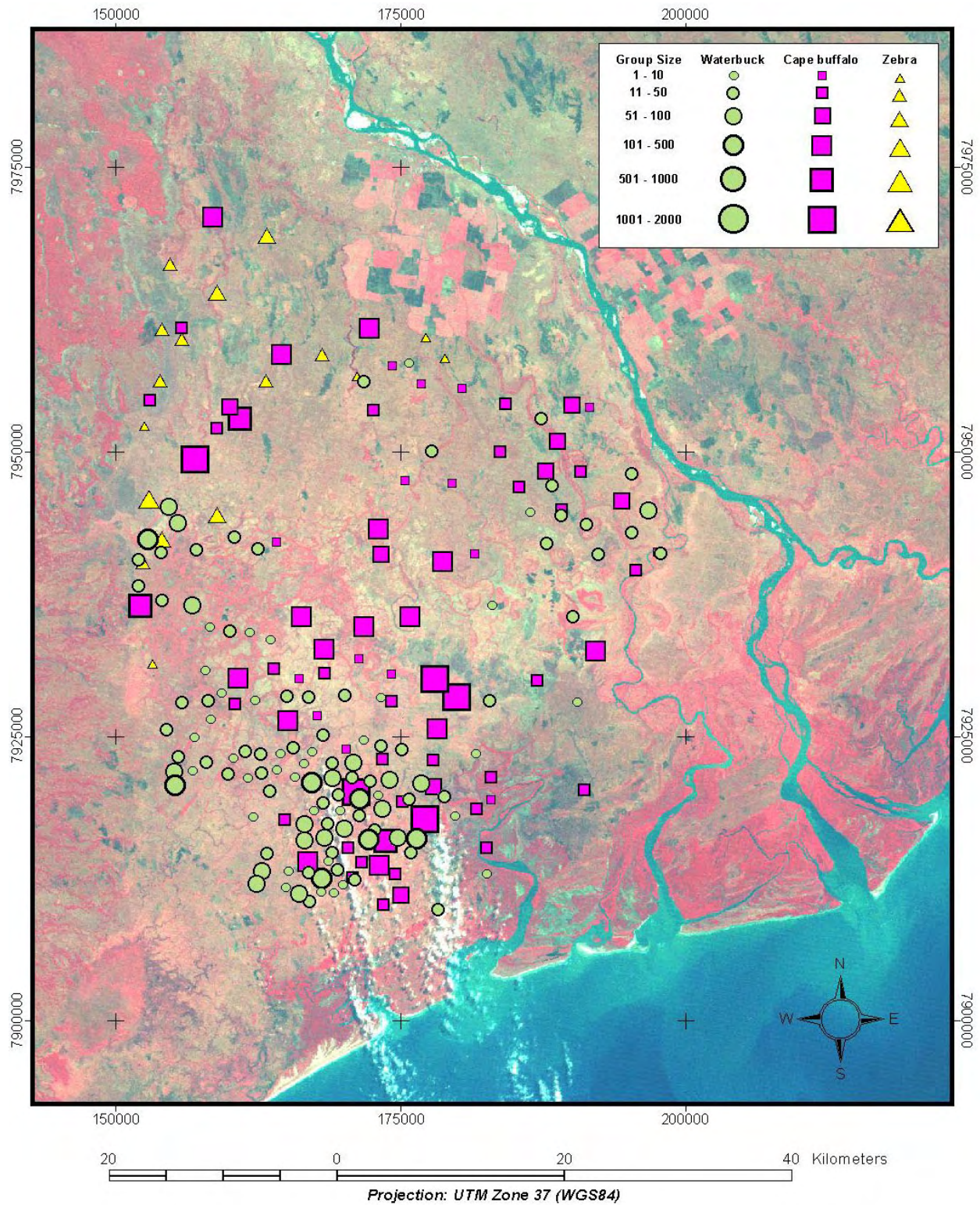


Figure 3-21. Historical distribution of Cape buffalo, waterbuck, and zebra in the southern half of the Zambezi Delta, reflecting intensive grazing and browsing pressure on the delta grasslands. Based on Tinley (1969) aerial survey data plotted on a 1972 Landsat MSS image (false color composite).

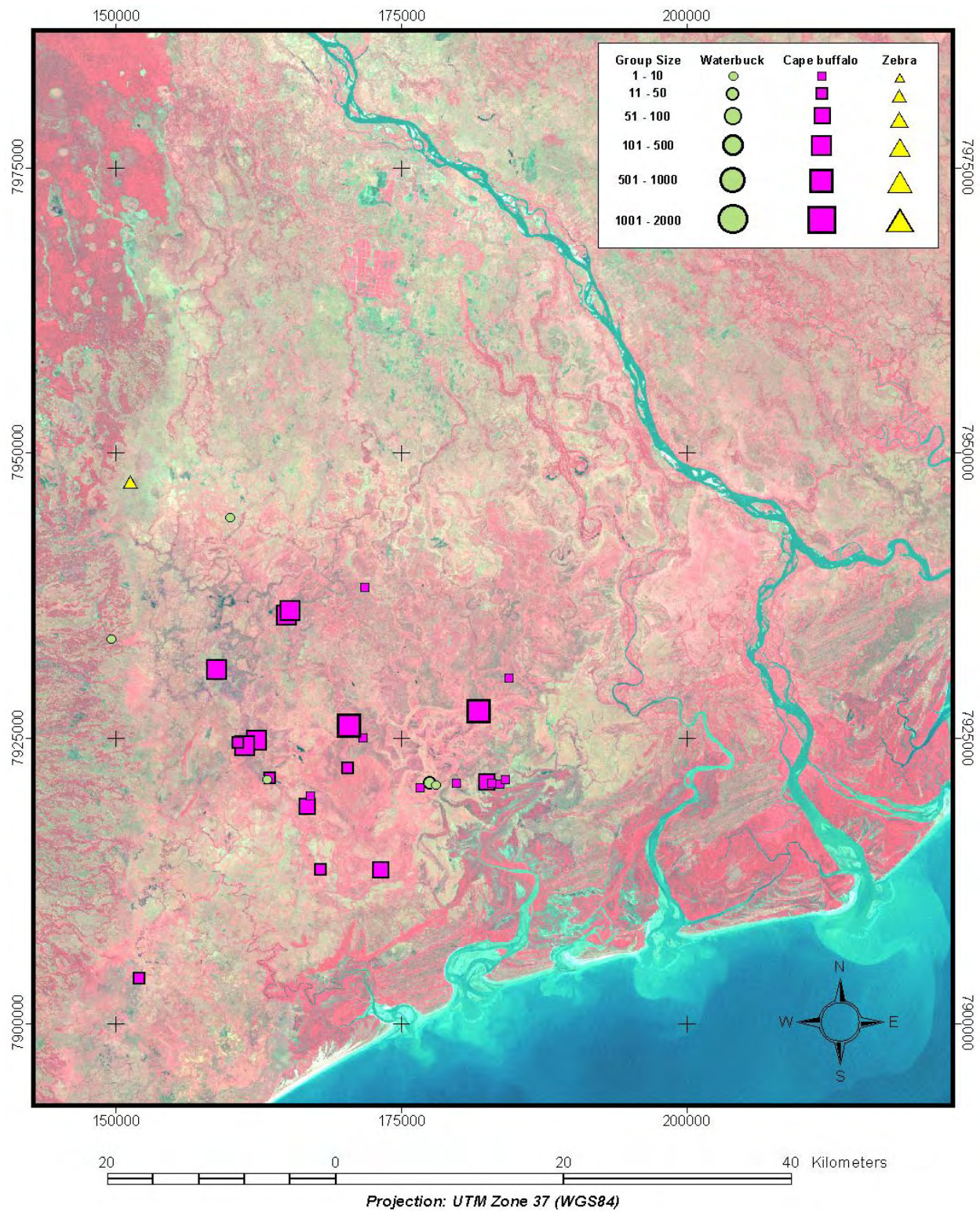


Figure 3-22. Current distribution of Cape buffalo, waterbuck, and zebra in the southern half of the Zambezi Delta, reflecting minimal grazing and browsing pressure on the delta grasslands. Based on October 2000 helicopter survey data plotted on a 2000 Landsat ETM image (false color composite).

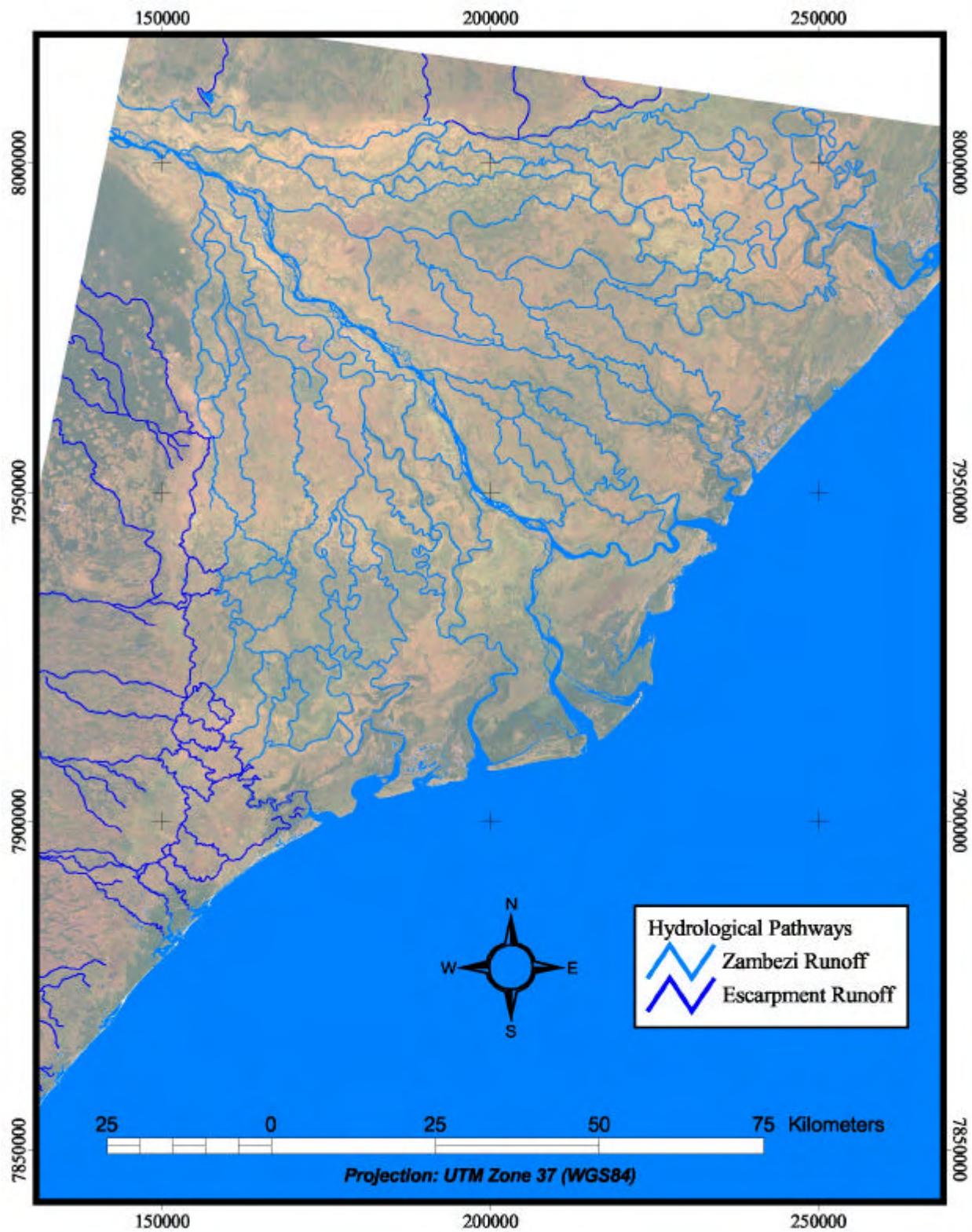


Figure 3-23. Hydrological pathways in the Zambezi Delta under historical conditions, showing runoff contribution from the Zambezi River and the surrounding escarpment.

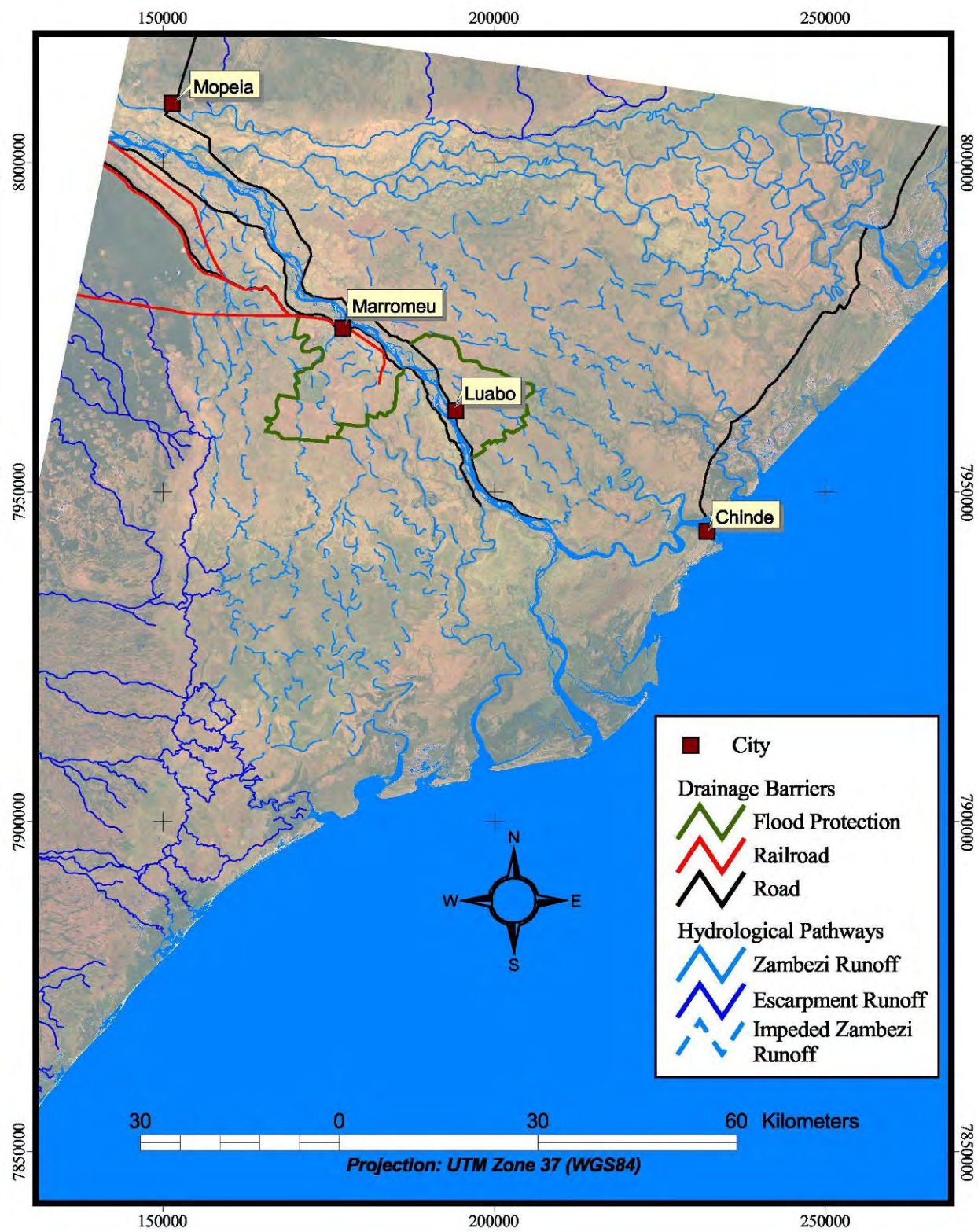


Figure 3-24. Hydrological pathways in the Zambezi Delta under current conditions, showing effects of dike construction for roads, railroads, and flood protection around sugar plantation lands.