3 The Okavango Delta Peatlands

William N. Ellery and Karen Ellery

Abstract

The presence of a large (approximately 2000 km^2) peatland in a semi-arid climatic setting such as the Kalahari is unusual. Peat forms in permanently flooded areas in the Okavango Delta primarily due to the perennial input of large volumes of water from a distant catchment in the highlands of Angola, into a valley formed by rifting. Peat deposits form in three distinct settings in the Okavango: backswamp settings where open water is converted into homogeneous emergent peatlands, lake and channel margins where the peatland is patchy, and the inlets to lakes that connect to the primary distributary channel, which presently is the Okavango-Nqoga-Maunachira River system. An unusual feature of peat formation in backswamp areas, as well as in lake and channel margin settings, is that frequently mats of fine organic detritus on the bed rise to the water surface and are colonised by emergent plants. Once thus colonised, peat production is accelerated due to the higher productivity and less easily decomposed tissue of emergent plants compared to submerged and floating-leaved plants. In backswamp settings, the floating mats are extensive (hundreds of square metres to hectares) and lead to the formation of homogeneous plant communities that cover large areas. In the case of lake and channel margins, floating mats form small isolated features (up to a few square metres) that are blown to the lake or channel margin by wind. Their accumulation on the leeward sides of lakes and broad streams gives rise to a patchy and heterogeneous plant community. Where lakes are connected to the primary distributary channel, papyrus debris collects as large floating rafts along channel margins, ultimately to be deposited in the lake inlet. Thus, large lakes are converted to papyrus swamp over periods of decades. Channel switching of primary channels leads to radical changes in the flow such that formerly flooded areas dry out and peat deposits are destroyed over periods of decades due to desiccation. However, a new cycle of peat formation takes place in the newly flooded area. Peat deposits in the Okavango are thus not permanent features but have a lifespan of about one or two centuries. Given increasing recognition that peat formation in “dryland” wetlands requires an elevated base level, the hypothesis proposed here is that chemical sedimentation in the lower reaches of the Okavango elevates the base level, and peat formation is an inevitable and passive consequence. This leads to the formation of an alluvial fan with a remarkably uniform slope from the fan apex to the toe of the system.

Keywords

Wetlands in Drylands • Vegetation succession • Peat fires • Clastic • Organic and chemical sedimentation

3.1 Introduction

Although much of southern Africa is classified as “dryland”, it is characterised by several freshwater wetlands greater than 2000 km^2 in extent (Lidzhegu et al. 2019), all of which occur along the courses of large rivers such as the Zambezi and its tributaries. One of the largest freshwater wetlands in the region is the Okavango Delta in northern Botswana with an estimated area of approximately 12,000 km^2 (McCarthy and Ellery 1998). It is remarkable that this large peatland landscape occurs in a region with a negative water balance where potential evapotranspiration exceeds rainfall annually by a factor of three.

W. N. Ellery (✉)
Geography Department, Rhodes University, Grahamstown, South Africa
e-mail: f.ellery@ru.ac.za

K. Ellery
Science Extended Studies Unit, CHERTL, Rhodes University, Grahamstown, South Africa

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This chapter describes the three distinct settings that host peat formation in the Okavango Delta: backswamp, channel margin and lake inlet. Compared with many peat swamp forests, bogs and fens that develop over millennia, the Okavango Delta peatlands exist for much shorter periods because of dramatic switches in the flow that take place over timescales of centuries. It is only through understanding the interplay between processes of peat formation, peat destruction, clastic and solute sedimentation, and changing water distribution, that we can appreciate the significance of peatlands in the morphology of the Okavango Delta ecosystem as a whole. This chapter is therefore wide-ranging, not only describing the peatlands themselves but also the broader landscape-level processes that characterise the system.

3.2 The Inputs and Distribution of Water in the Okavango Delta

The Okavango River rises in the highlands of eastern Angola, which receives rainfall greater than 1500 mm a^{-1}. Runoff from the catchment drains south-eastwards, entering Botswana at the town of Mohembo (Fig. 3.1). Downstream of Mohembo the Okavango River is confined within a fault-bounded depression in a region known as the Panhandle. At the toe of the Panhandle, and perpendicular to it, lies a half-graben between the Gomare Fault in the north and the Kunyere and Thamalakane Faults in the south. When the Okavango River reaches this half-graben it divides into a number of distributary channels to form the Okavango Delta, or, more correctly, Fan.[1] Connected directly to the Okavango River is the main distributary Nqoga River, which flows eastwards to the north of Chief's Island. The remaining distributary channels receive the bulk of their water supply as overbank flow and seepage of water through peat deposits flanking the primary Okavango-Nqoga river system. The Thaoge River flows southwards down the western margin of the Delta and the Maunachira River flows eastwards along the northern margin of the Delta. Both of these river systems eventually disappear as they lose water. The Jao and the Boro Rivers flow south-eastwards to the south of Chief's Island and the Mboroga River arises from the Maunachira River via diffuse flow and drains south-eastwards to the north of Chief's Island. During wet periods the Mboroga and Boro Rivers flow into the Thamalakane River, which flows south-westwards along the Thamalakane Fault, mainly into the Boteti River, which is the only river to flow out of the Delta. The Boteti River terminates in Ntwetwe Pan of the Makgadikgadi Pans, 200 km to the east.

The upper reaches of the Okavango Delta are permanently flooded in a region known as the permanent swamps and the lower reaches are seasonally flooded in a region known as the seasonal swamps. Extending into the alluvial fan are a number of sandveld tongues dominated by species of *Acacia*, while areas with clay-rich soils are dominated by *Colophospermum mopane* (Ellery and Ellery 1997).

The water balance of the Okavango Delta is characterised by a significant surface inflow of water from the catchment in eastern Angola via the Okavango River, which contributes 9.2×10^9 m^3 a^{-1} (McCarthy and Ellery 1998; McCarthy et al. 2003). Local summer rainfall (mainly November to March) contributes a further 6.0×10^9 m^3 a^{-1}, which amounts to about 35% of the water input. Despite January being the month of the highest rainfall in the Delta region, the peak flood wave that has travelled over 1000 km from central Angola, reaches Mohembo at the top of the Panhandle in April, with an average monthly flow in April of about 15×10^9 m^3. Flow in the Okavango River at Mohembo is lowest in the month of November, with an average monthly flow of about 4×10^8 m^3. This variation in inflow contributes to considerable seasonal variation in the extent of inundation in the Okavango Delta, with the greatest extent being in the dry season in July to August while the minimum extent of inundation is generally in the wet season in January to February (McCarthy et al. 2003).

Flow in the Okavango Delta has varied spatially for millennia. The first written records of flow in 1854 describe flow down the Thaoge River into Lake Ngami (Fig. 3.1, Andersson 1856). Today, the Thaoge River no longer flows into Lake Ngami, with its course restricted to about a quarter of its original length. According to oral accounts provided by Indigenous people, the Thaoge River dried progressively during the late 1800s, but during this time a series of hippo trails leading eastwards from the Thaoge River were enlarged by erosion to divert flow into the Nqoga and Mboroga Rivers to the north and east of Chief's Island, respectively (Wilson and Dincer 1976). In the early twentieth century, the Mboroga River via the Thamalakane River was the main supplier of water to the town of Maun (Stigand 1923). In the 1930s the lower reaches of the Nqoga River started failing and this was associated with an increase in flow along the more northerly Maunachira River (Wilson and Dincer 1976). At first glance, such a dynamic environment appears an unlikely setting for the development of extensive peatlands.

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[1] Although the Okavango has a triangular shape, deltas form where rivers enter standing bodies of water, whereas alluvial fans are subaerial features. The Okavango is an alluvial fan and is more correctly referred to as the Okavango Fan.

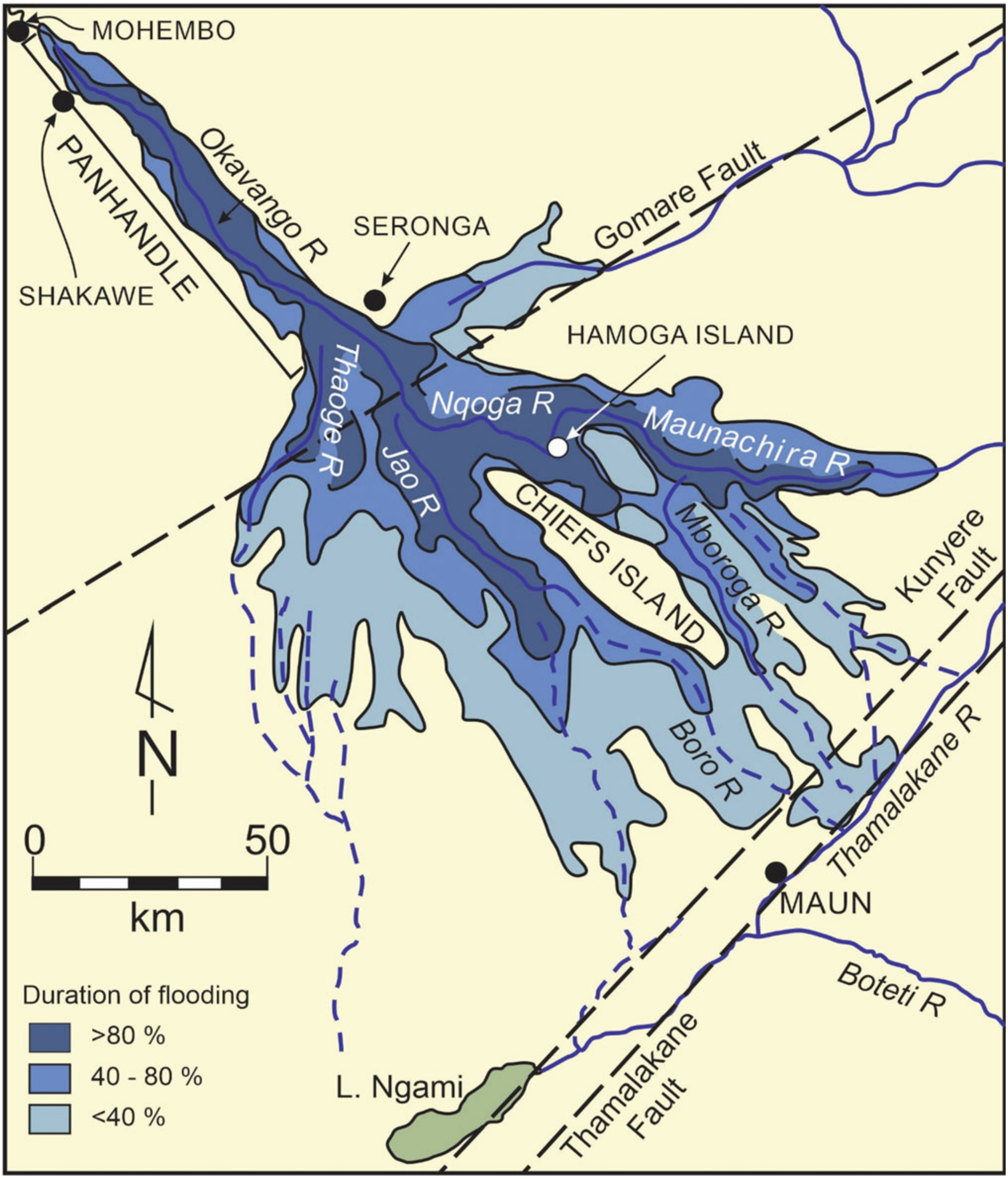


Fig. 3.1 Physiographic features and duration of flooding of the Okavango Delta (modified after McCarthy et al. 2003; Gumbricht et al. 2004)

3.3 Development of Peat in the Okavango Delta

Peat is an organic deposit that forms as a result of the partial decomposition of plants. In general, peat develops in calm, permanently inundated, freshwater environments where the rate of accumulation of organic matter, at or near the surface of a water body, is greater than the rate of decomposition (Clymo 1984). Organic material at or near the surface of a peat body, referred to as the acrotelm, decomposes relatively rapidly due to the presence of predominantly aerobic conditions. However, as organic material is progressively buried, it enters the catotelm, which is anaerobic such that decomposition is slowed considerably. Hydrology is considered the primary determinant of peat formation, particularly the presence of anaerobic conditions caused by permanent flooding, but other factors reported to influence peat formation are many and include low temperature, limited nutrient availability and low pH (Clymo 1984; Craft 2016).

Given that permanent flooding is required for peat to form, the area of the Okavango Delta where peat exists is much smaller than the area of the wetland as a whole. If it is assumed that flooding must be present more than 80% of the time for peat to form, it is likely that the area of peat accumulation in the Okavango Delta matches the area of near-permanent flooding as mapped by J McCarthy et al. (2003) and Gumbricht et al. (2004), as shown in Fig. 3.1. It is estimated to cover approximately 2000 km^2. However, the channel switching processes that alter flow patterns over relatively short time periods of centuries would to some degree serve to reduce the extent of such deposits. Nonetheless, they are widespread in the upper Delta reaches and have been well studied along the Okavango-Nqoga-Maunachira river systems. Because of their differing locations and functioning in the ecosystem, the three main peat-forming areas of backswamps, channel margins and lake inlets are described in turn below.

3.3.1 Backswamp Peatlands and Vegetation Development Along the Maunachira River System

Following channel abandonment of the Thaoge River and later of the lower Nqoga River, the Maunachira river system benefitted from significantly increased flows over the last century (Smith 1976). A small portion of the Maunachira river system consists of lakes, channels and islands, and the rest consists of the permanently inundated backswamps that experience very low water flow rates of generally much less than 0.03 m.s^{-1}. These backswamps have experienced peat accumulation associated with a number of vegetation successional processes (Ellery 1986).

Given that different wetland plant species have particular ranges of tolerance to variation in water depth, species composition generally varies spatially depending on the depth and duration of inundation. Areas of deep water are typically dominated by submerged plant species. As water depth declines towards terrestrial habitats, vegetation is typically dominated sequentially by floating-leaved species, emergent species, seasonally flooded species, and then terrestrial species. This zonation of vegetation is visible spatially in places where water depth decreases from a shallow lake bed to the lake edge (Fig. 3.2). This heterogeneity in plant distribution can also represent temporal vegetation successional changes that occur in response to a gradual decline in water depth through, for example, organic peat accumulation on the bed of a lake. Such successional change in species composition over time with gradually decreasing water depth has been described in many shallow water bodies and wetlands around the world and is known as "hydrarch succession" (Gleason 1926).

Classification of the Maunachira River wetland plant communities resulted in eight communities being identified that vary in their species composition and habitat

Fig. 3.2 Typical spatial zonation of wetland vegetation in the seasonal swamps of the Okavango Delta. In the foreground are floating-leaved species in the deepest water, which give way to emergent wetland species as the depth declines, and ultimately to grasses (not visible) and trees on dry land

characteristics. One of the communities is restricted to channel and lake margins, being dominated by *Miscanthus junceus* or *Cyperus papyrus* (Community G; Fig. 3.3a). A second community is dominated by the floating-leaved plant *Trapa natans*, which occurs in monospecific stands in localised areas where channels enter lakes (Community H; Fig. 3.3a). Neither of these communities play a significant role in backswamp community development, but the channel margin community is key in influencing channel dynamics and is considered in detail in the following section.

The remaining communities are distributed in relation to variation in water depth and the thickness of the substrate in which plants are rooted (Communities A to F; Fig. 3.3a and b). In areas where water depth is greater than about 1.8 m, the plant community is submerged (generally as monospecific stands of *Najas pectinata*; Community A). Where water depth is between 1.6 and 1.8 m deep, a floating-leaved community (Community B) is present (Fig. 3.3b), usually rooted in a benthic mat of organic detritus 0.3–0.4 m thick resting on the sandy bed of an otherwise open water body. Areas dominated by floating-leaved species include *Brasenia schreberi*, *Nymphaea nouchali*, *N. lotus* and *Nymphoides indica*.

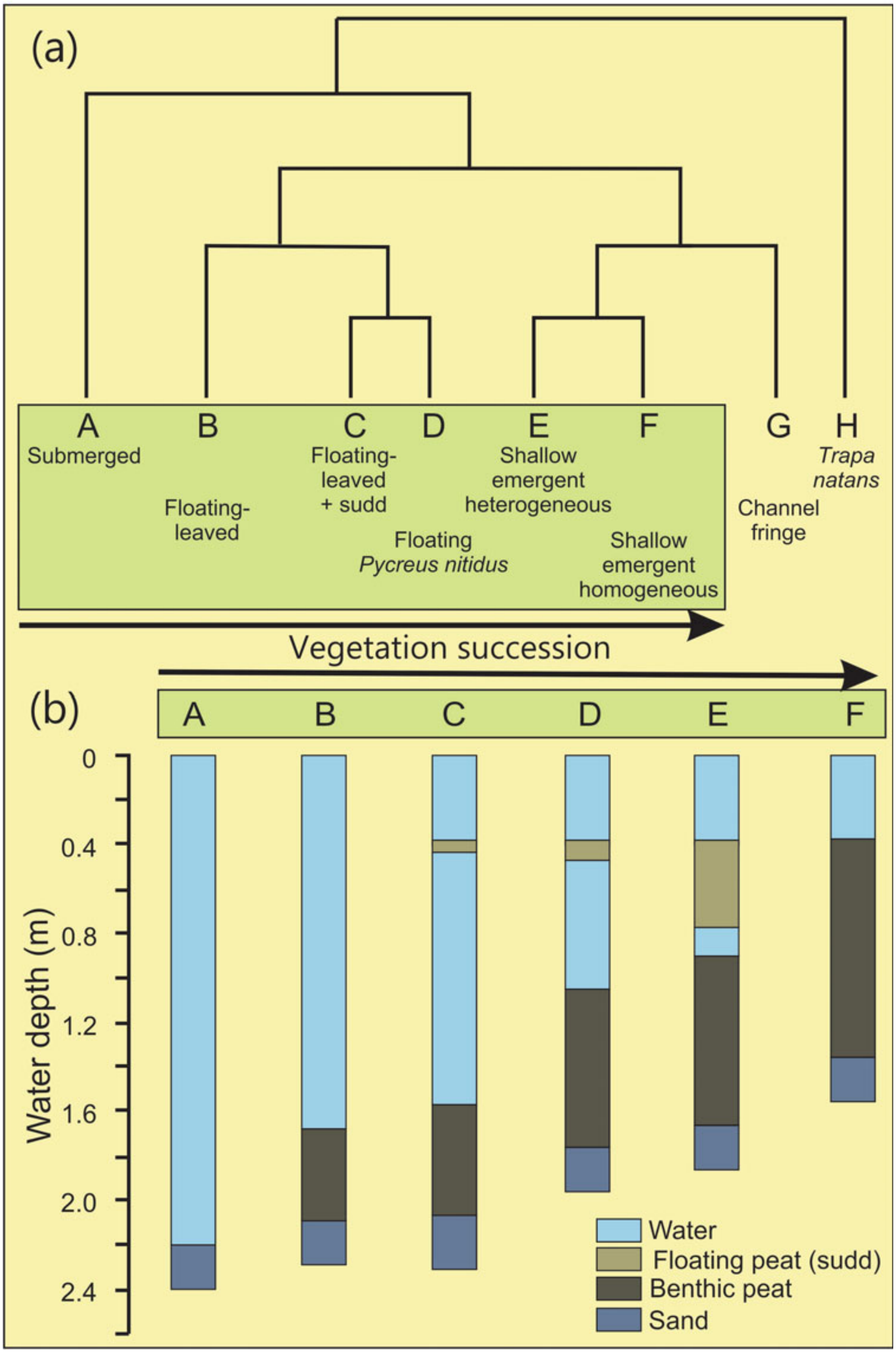
Typically, floating-leaved communities would eventually become emergent communities with the gradual accumulation of benthic detritus and peat—a process that can take millennia. However, an interesting and somewhat unusual phenomenon occurs commonly in the Maunachira floating-leaved communities which considerably speeds up the transition from floating-leaved to emergent backswamp communities: the formation of floating mats or rafts of detritus. The fine organic detritus that is resting on the sandy bed of the floating-leaved communities becomes buoyant, likely through gases being produced in decomposition processes in the benthic mat, which rises to the water surface. Because of the different ways in which such floating mats form, two different plant communities arise. The first is the floating-leaved and sudd community (Community C, Fig. 3.4a and b) which results from the formation of small, isolated mats or sudds of detached organic detritus held together by the root mass of the formerly floating-leaved plants (Fig. 3.4a). The second is the floating *Pycreus nitidus* sedge community (Community D; Figs. 3.3a and b, 3.4b) which forms on extensive floating detrital rafts that cover areas from twenty to hundreds or even thousands of square metres, and therefore remain in a position where they originally form. In contrast, the small isolated floating mats are moved by wind and typically accumulate on the leeward side of open water bodies. The formation of the two “floating” communities is summarised diagrammatically in Fig. 3.5a–c.

Once they occur as floating mats plant community succession is dramatically altered from being driven by gradual rates of benthic detrital accumulation to almost instantaneously being dominated by emergent vegetation. Both the isolated sudds as well as the extensive rafts rapidly become dominated by *Pycreus nitidus* which is able to grow clonally via submerged stolons. Lateral expansion via clonal growth occurs at a rapid rate of between 1 and 1.5 m per annum (Ellery et al. 1990). The succession then also proceeds with colonisation by a diverse array of later successional species such as sedges *Cyperus pectinatus*, *Fuirena pubescens*, and *F. stricta,* the insectivorous *Drosera madagascariensis*, the broad-leafed woody shrub *Ficus verruculosa* and the fern *Thelypteris confluens*, in a small-scale patchy manner (Community E, Fig. 3.3a and b). Over time the substrate becomes more homogeneous and the vegetation is dominated primarily by grasses, sedges and the shrub *Ficus verruclosa* (Community F, Figs. Fig. 3.3a and b, 3.6). As mentioned, the development of such climax backswamp communities from floating communities occurs much more rapidly than would take place from gradual infilling of deeper water communities due to the higher growth rates and biomass production of emergent species, as well as their much coarser nature, which slows decomposition rates.

As succession progresses towards the shallow emergent homogeneous community, the thickness of the floating mat increases, as does the thickness of the organic benthic sediment, due to the gradual raining down of organic material from the floating mat (Fig. 3.3b). As these processes continue, the floating and benthic layers meet forming a relatively uniform layer of peat. The peat deposits associated with each plant community varies from the floating *Pycreus nitidus* community and its precursors, where the organic matter is very fine and unconsolidated (sludgy), held together by fine root material associated with submerged species, to the climax community where the peat is consolidated and contains considerable coarse root material that makes up a large proportion of the volume of the deposit (Fig. 3.7).

Whilst Fig. 3.8 indicates the spatial relationship between the different backswamp plant communities in the Maunachira River landscape, similar communities are found throughout the permanently flooded upper reaches of the Okavango Delta. The submerged and floating-leaved communities are located in the few open water bodies that exist. However, relatively rapid accumulation of peat in this system gives rise to large expanses of relatively stable climax, diverse, emergent backswamp communities. At a landscape level, in a dynamic system such as the Okavango Delta, such stability is not permanent and when this river system loses its permanent supply of water due to channel avulsion further upstream, the drying and burning of peat deposits would then play a key role in the renewal of the landscape. These processes are described later in this chapter.

Fig. 3.3 Vegetation community classification (**a**) and depth to rooting substrate in relation to successional processes (**b**) in the permanent swamps of the Maunachira River wetlands of the Okavango Delta (modified after Ellery et al. 1991)



3.3.2 Channel-margin Peat Deposits and Associated Vegetation

Whilst the backswamp peatlands are an important part of the Okavango Delta landscape due to their extent, the relatively localised channel margin peat deposits and associated vegetation communities (Community G, Fig. 3.3a) play a key role in the landscape-level water delivery and channel-switching events previously alluded to. Channels form in the wetland largely due to the network of hippo trails that are used repeatedly in backswamp areas to get from daytime resting grounds to feeding areas on islands (McCarthy et al. 1998). These channels are generally oriented parallel to the hydraulic slope and promote effective

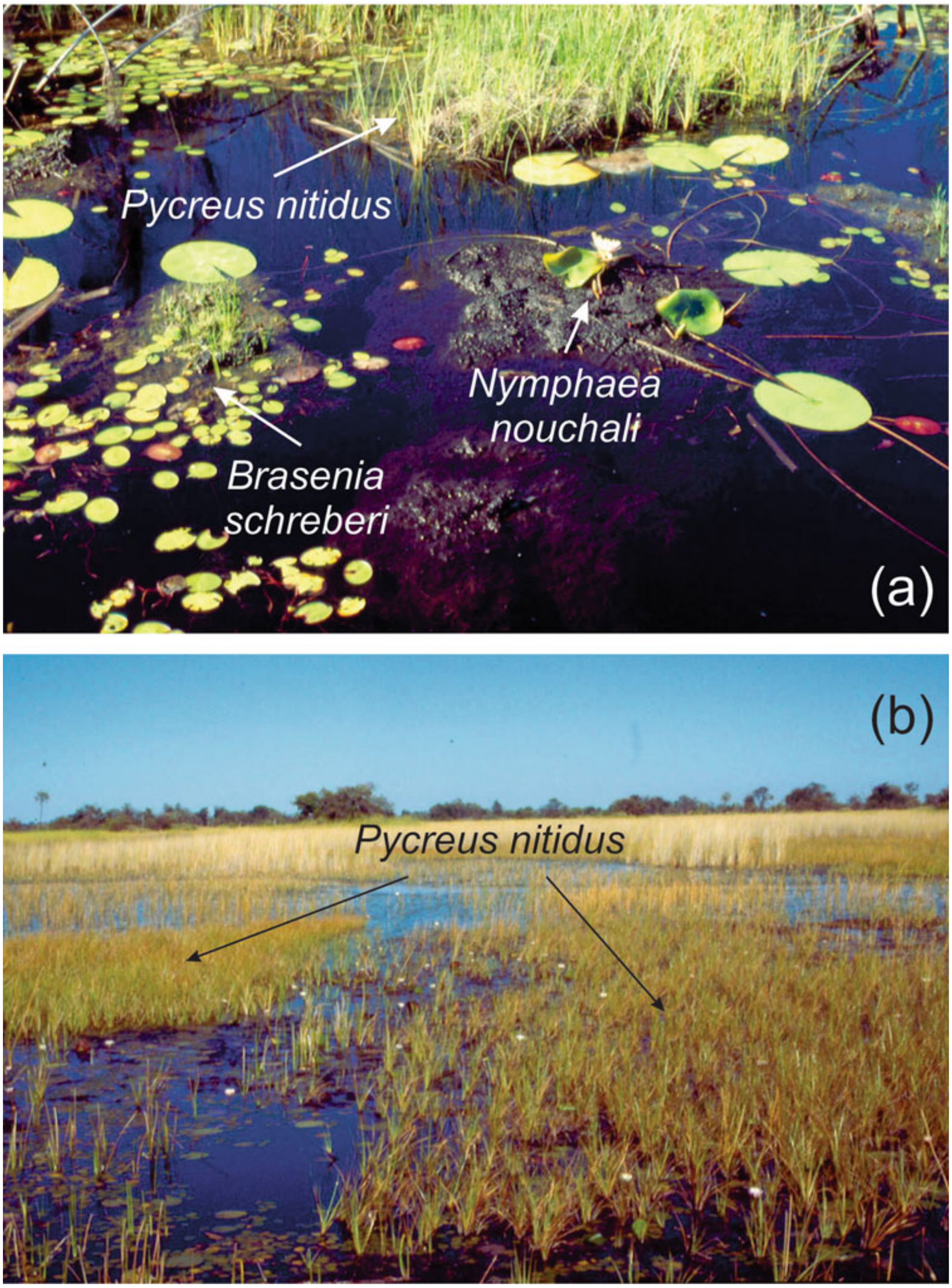


Fig. 3.4 Detached, isolated rafts of floating detritus held together by the root masses of formerly bottom-rooted floating-leaved plants of *Nymphaea nouchali* and *Brasenia schreberi* (**a**), and extensive rafts of detritus floating near the water surface of an open water body, colonised by *Pycreus nitidus* (**b**)

transmission of water through the permanent swamp to sustain water delivery to the distal reaches of the system. However, it is the interaction between the accumulation of clastic and organic sediments within and alongside any channel that is linked directly to the incoming Okavango River, that drives avulsion events that lead to radical changes in flow over timescales of decades to centuries (McCarthy et al. 1986).

Clastic sediment entering the Okavango Delta from the catchment amounts to about 200 000 t a^{-1}, of which 170 000 t is sand transported as bedload, which accumulates on the beds of primary channels (Okavango-Nqoga; McCarthy et al. 1991). Suspended clastic sediment accumulates largely in the peat deposits of the channel margins (McCarthy et al. 1991). This results in a downstream decline in clastic sediments within the channel margin peats, with between 25 and 40% organic matter in the Panhandle and Nqoga River margins, and between 40 and 90% organic matter along the Maunachira River margins (McCarthy et al. 1989). The grass *Pennisetum glaucocladum* dominates where the organic content is lowest, followed by species such as the reed *Phragmites mauritianus* and the sedge

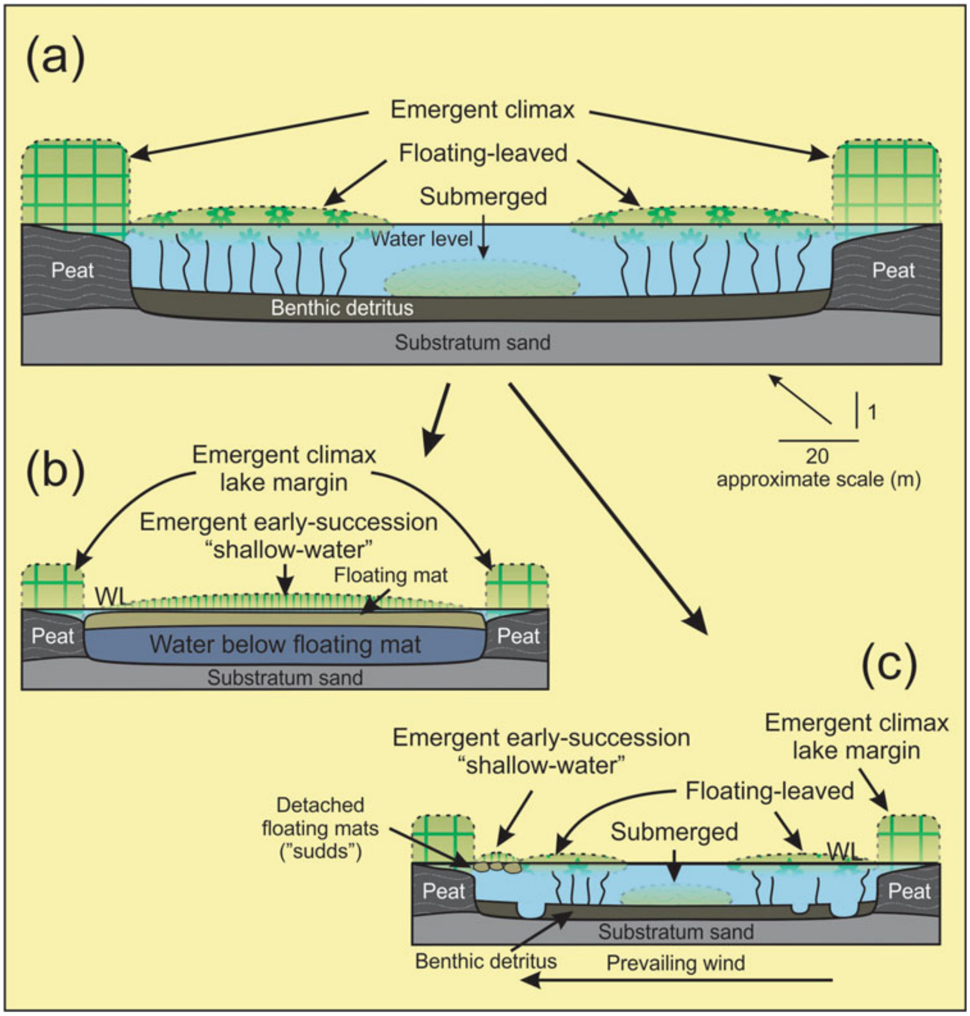


Fig. 3.5 Change in vegetation from an open water body with submerged and floating-leaved communities distributed in relation to water depth (**a**), to an emergent plant community rooted in shallow water (<0.1 m depth) growing on an extensive detrital floating raft (**b**) or small, isolated floating detrital sudds that accumulate on the leeward side of open water bodies (**c**)

Fig. 3.6 The climax community (Community F) that covers large areas of permanently flooded peat (thickness is approximately 2 m), with a diverse range of species present including *Ficus verruculosa* and *Miscanthus junceus*. Isolated patches of woody plants are on termite mounds in the peatland

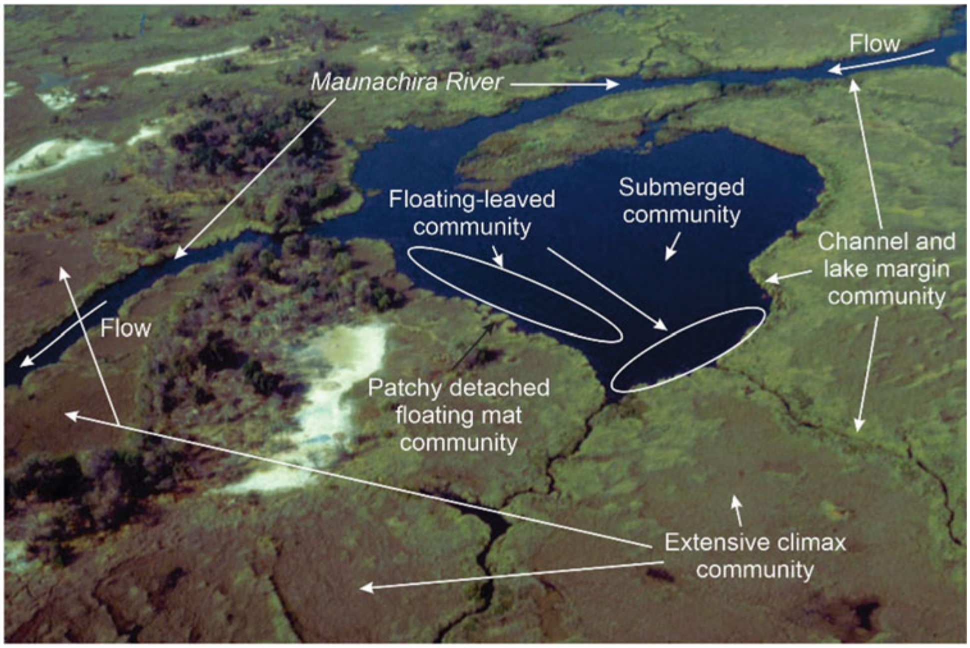
Fig. 3.7 The character of peat deposits of early successional stages dominated by *Brasenia schreberi* and *Pycreus nitidus* (Communities C and D; top) and by climax species such as *Miscanthus junceus* (Community F; bottom)

Cyperus papyrus with increasing organic contents (Ellery et al. 2003). Channel margin communities dominated by *Miscanthus junceus* are characterised by peat deposits that have very high organic contents (Ellery et al. 2003).

There is a sharp transition between the channel and the channel margins, which are made of peat such that channels are roughly rectangular in cross-section (Fig. 3.9). A key feature of peat channel margins is that the channels lose water by overbank flow and flow through the acrotelm of the peat deposits, which means that channels get progressively smaller downstream in respect of their width and discharge such that water entering the ecosystem is dispersed widely across the wetland. The width of the Okavango-Nqoga-Maunachira channel system declines from almost 150 m to 20 m. Equally important is the role of peat banks in confining the bedload sediments to within channels as the sediments are rolled and bounced on the bed of the channel and unable to escape. As channels lose water their ability to transport sediment declines and bedload sediment is deposited on the channel bed, leading to channel bed aggradation, which in the region of the lower Nqoga River near Hamoga Island (see Fig. 3.1) is approximately 0.05 m.a^{-1} (Fig. 3.10). In places where channel bed aggradation is as high as this, the channel margins are dominated by luxuriant, dense stands of papyrus rooted in peat (Ellery et al. 2003). Aggradation of the channel margin takes place largely through extremely rapid growth of papyrus that ultimately forms a coarse and robust peat of partially decomposed and entangled rhizomes, roots and shoots, and can match these high rates of bedload aggradation. Such rapid rates of peat formation have not been reported elsewhere in the region, with reported rates of peat formation elsewhere of 0.002–0.004 m.a^{-1} (Grundling et al. 2013), although rates may be as high as 0.02 m.a^{-1} (Thamm et al. 1996). With bedload and channel margin accumulation rates being similar, channel width and depth are maintained (Ellery et al. 2003). Over time the primary channels are gradually elevated relative to the surrounding backswamp, resulting in substantial loss of water from the channel to the surrounding wetland and ultimately to channel avulsion once sufficient relief has been created.

This set of processes has happened progressively along the lower Nqoga River since the late 1930s. Aggradation of the sandy channel bed and peat margins of the

Fig. 3.8 Plant communities of the backswamp environments of the Maunachira River, Okavango Delta



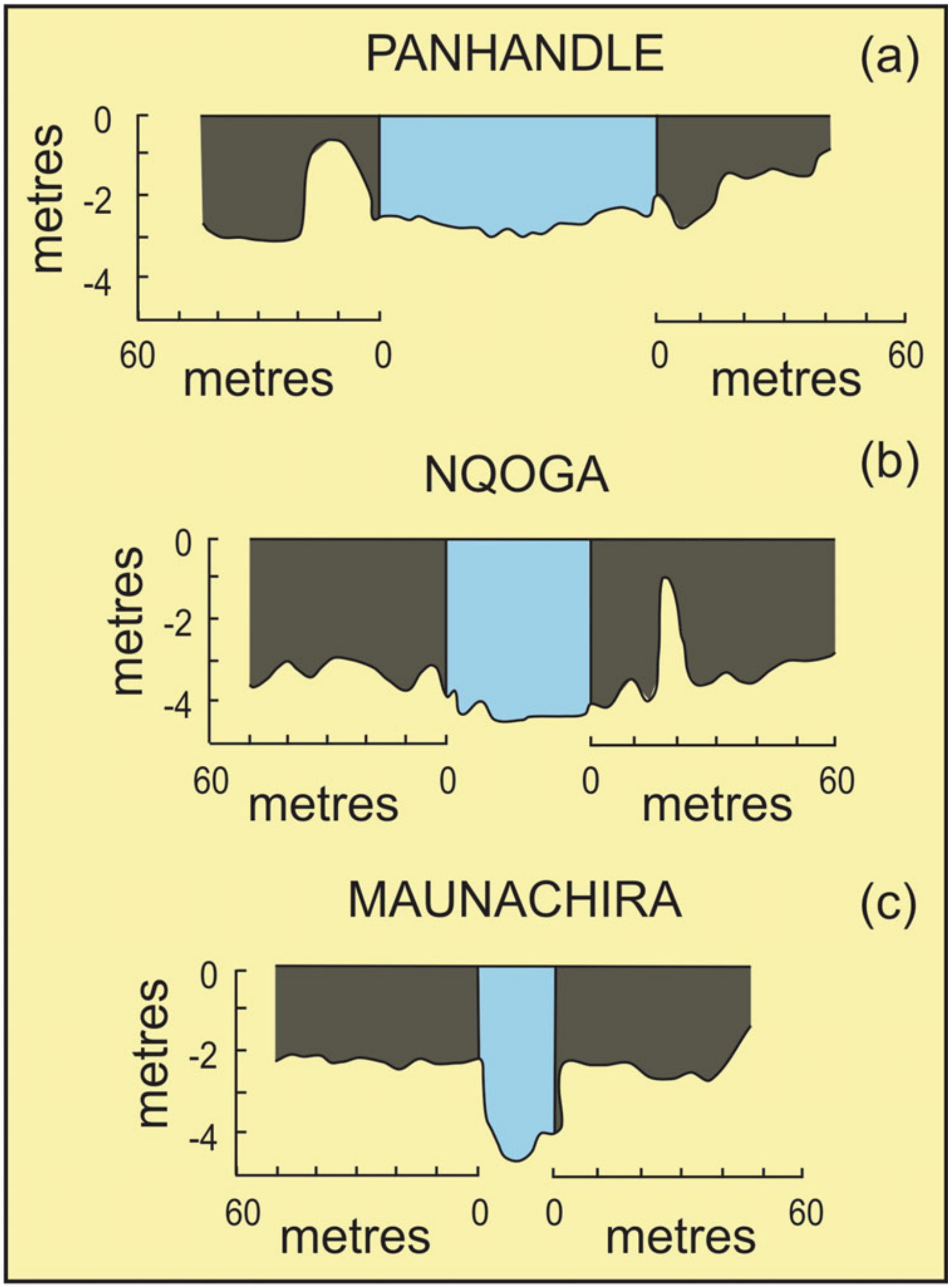


Fig. 3.9 Relationship of channels and channel margins, showing variation in depth and width of channels of the Okavango, Nqoga and Maunachira Rivers over a distance of nearly 250 km arranged sequentially from the town of Shakawe at the top of the Panhandle to the lower Maunachira River

eastward-flowing lower Nqoga River was accompanied by erosion and enlargement of a small hippo trail linking the Nqoga River to Bokoro Lediba (Tswana word for “lake”) to the north (Fig. 3.11a). As flow was increasingly diverted along the hippo trail it became navigable and was given a name: Letenetso Channel (Fig. 3.11b). During this time, the lower Nqoga River started blocking by vegetation encroachment (Ellery et al. 1995). By 1983 all flow from the lower Nqoga River was redirected along the Letenetso Channel into the Maunachira River system (Fig. 3.11c). This was accompanied by, first, lake infilling in Bokoro Lediba and Dxergha Lediba, which is described in the next section, and secondly, peat fires along the abandoned Nqoga River, which is described in the following section.

3.3.3 Lake Inlet Peat Accumulation and Closure

It is inevitable that the first lake situated along a papyrus-lined river course linked to the main Okavango River will ultimately close due to clastic and inorganic sedimentation processes that occur at the lake inlet. *Cyperus*

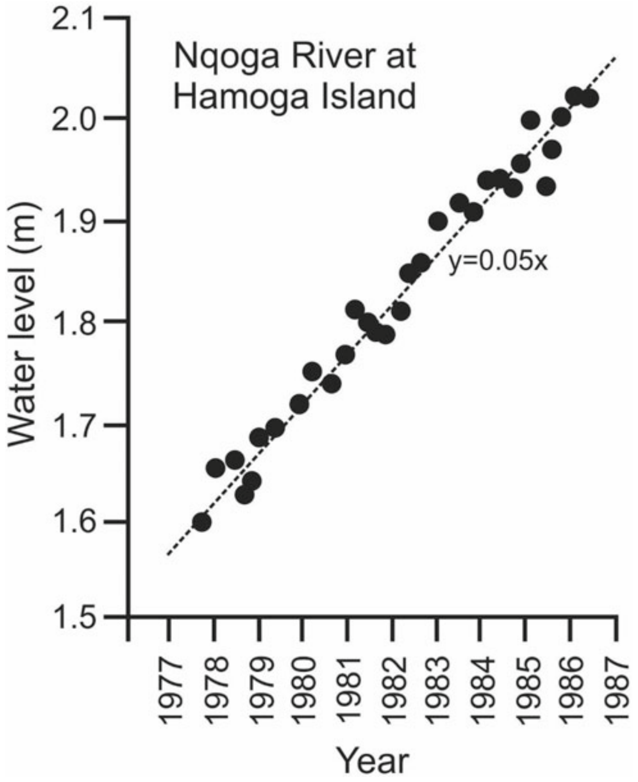


Fig. 3.10 Aggradation rate as reflected by the measured water level at Hamoga Island on the lower Nqoga River

papyrus along channel margins is rooted in peat but it extends from the peat bank into the channel via rhizomes that produce successive shoots. Both older shoots, as well as entire rhizomes, become detached from the parent plant, float downstream on the water surface. These individual floating fragments accumulate in large floating mats on the inner (convex) banks of the sinuous streams, where current velocity is very low compared to the outer (concave) banks. At some point, these floating mats become too large to remain in place and move downstream as large floating rafts. As channels lose water to the surrounding swamp they become progressively narrower downstream such that these rafts eventually are larger than the channel is wide, and a surface blockage forms (Fig. 3.12).

Such blockages tend to undergo a process of consolidation through vegetative growth of papyrus, which tends to strengthen the mat, as well as decomposition where no growth is occurring, which weakens the integrity of the blockage. Ultimately, all of the organic material that temporarily blocks channels ends up in the first lake encountered along the river, which leads to its infilling and the establishment of papyrus swamp.

Such lake infilling processes have been tracked for Dxerega Lediba for over 60 years (Fig. 3.13; see McCarthy et al. 1993) and involve a combination of clastic and organic sedimentation. Lake closure initially involves the formation of a linear sandy bar at the mouth, which propagates out into the lake. The toe end of the delta initially becomes colonised by very dense stands of *Eichhornia natans* which can be submerged or have leaves floating on the water surface (Fig. 3.14). *Eichhornia natans* effectively traps floating rafts of *Vossia cuspidata* debris generated from the channels upstream such that in areas close to the mouth, this species forms dense monospecific stands rooted in the lake bed (Fig. 3.14). This robust emergent species traps rafts of papyrus debris, which rapidly colonise the mouth adjacent to the mouth bar. Once papyrus has been established, peat formation is relatively rapid compared with other species, and the lake is converted to a papyrus marsh with a central channel. In this way, the lake mouth progresses further into the original lake until such time that a single channel passes through papyrus-dominated peatland where the lake used to exist. In the case of Dxerega Lediba, even the channel has almost disappeared (see 2018, Fig. 3.13), as a secondary inlet on the south side of the lake has become the main point of inflow. The small areas of open water at this inlet are rapidly being colonised by emergent plants.

3.4 Channel Abandonment and the Occurrence of Peat Fires

The emphasis up to this point has been on peat formation and the consequences of this at a landscape scale. The focus now changes to processes associated with a failing channel, such as the abandoned lower Nqoga River in Fig. 3.11, where peatlands are destroyed because of desiccation and burning in peat fires.

Channel margin and backswamp peat deposits in the Okavango Delta generally reach thicknesses of between 2 and 5 m. As channel abandonment gradually moves in an upstream direction, peat deposits dry progressively and become susceptible to combustion in peat fires. Peat fires have been observed along the abandoned section of the lower Nqoga River from before the 1970s (probably since the 1950s; Ellery et al. 1989) and were visible in remotely sensed images in 2000, showing that burning of these deposits takes place over periods of several decades. Remarkably, peat fires along the upper Thaoge River were also observed in the same remotely sensed imagery, a channel that was abandoned in the late 1800s, illustrating the prolonged desiccation that takes place in association with

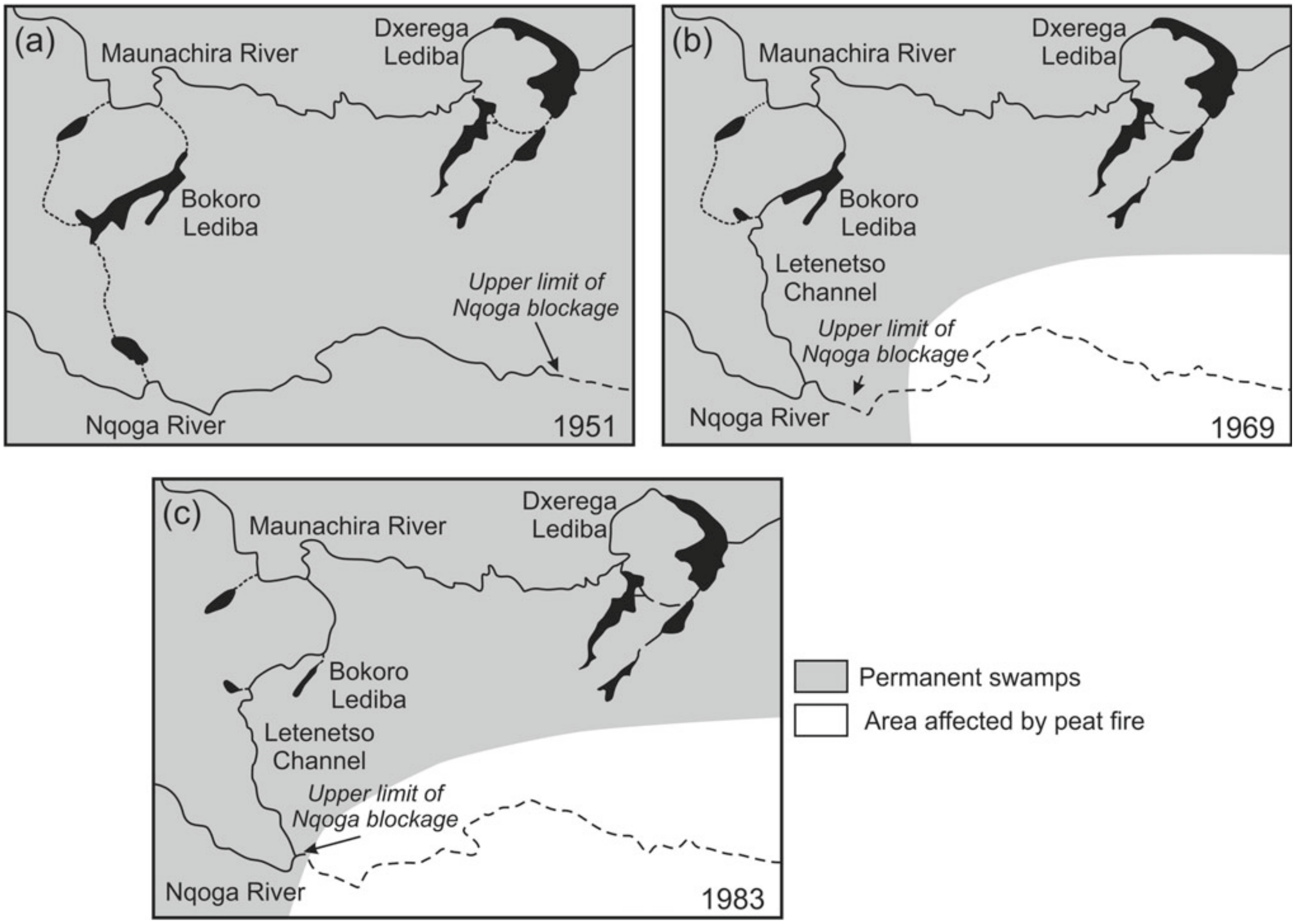


Fig. 3.11 Abandonment of the lower Nqoga River and channel enlargement of the Letenetso Channel based on aerial photography over the period 1951–1983 (modified after McCarthy et al. 1993)

channel abandonment and the equally lengthy time over which peat fires persist following abandonment.

Peat fires on the abandoned lower Nqoga River were observed by the authors in the 1980s (Fig. 3.15a). Generally, the peat fires burn to a depth of less than 1 m at a time due to both oxygen limitations and increasing moisture with increasing depth. But as desiccation proceeds, the peat deposit is burnt to increasing depth in successive fires. In the lower reaches of the abandoned Nqoga River that have been drying for the longest period, burning has destroyed all the peat, thereby exposing the original sandy surface that was beneath the peat (Fig. 3.15b). The former course of the lower Nqoga River is clearly visible from the air as a slightly raised feature (as a result of channel-bed aggradation as described earlier) and is surrounded by a flat and featureless ash-covered plain interrupted occasionally by former hippo trails entering the former watercourse from the adjacent former backswamp (Fig. 3.15b). Since peatlands have the ability to retain nutrients (Ellery et al. 1989), their burning results in the release of these nutrients, which allows these areas to become rapidly colonised by dry land plant species, particularly grasses. As such, these areas are more productive than other areas of the Okavango Delta and support large populations of herbivores including buffalo (*Syncerus*

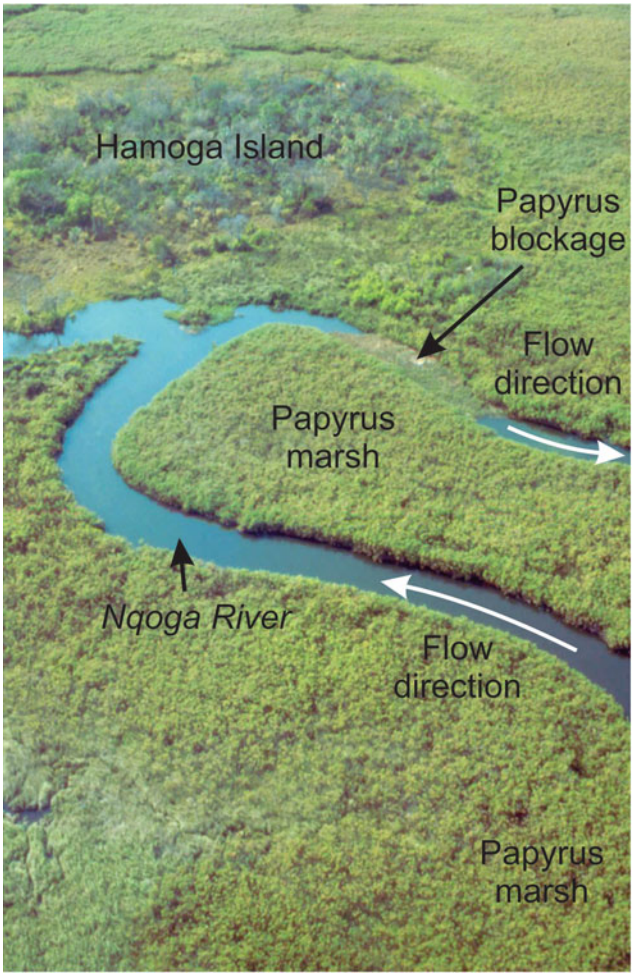


Fig. 3.12 Surface papyrus blockage on the Nqoga River at Hamoga Island

caffer) and red lechwe (*Kobus leche*), which in turn attract large predators. These areas also support a variety of bird species. Should flooding occur at some time in the future, plant and animal diversity would likely decline, and, in time, the cycle is completed by the development of a vegetated peatland dominated by emergent plants.

In summary, peat deposits of up to 5 m thick can be converted to a very thin sedimentary layer of ash, peat and soil with a total thickness of less than 0.5 m, which can be colonised by dryland species (Fig. 3.16). A further feature is the presence of a channel bed that is elevated relative to the adjacent burnt-out plain. The lowering of the basin level through the destruction of peat deposits makes it inevitable that at some point in the future, the area surrounding the abandoned channel will be reflooded. Depending upon the depth of inundation it is, therefore, possible that the former channel will form an island surrounded by permanent swamp (Fig. 3.17). Channel abandonment and the subsequent peat fires are therefore suggested as important processes in the maintenance of habitat diversity in the ecosystem as a whole.

3.5 A Conceptual Model of Peat Formation at a System-wide Scale

We end this chapter on a slightly conjectural note. The localised, relatively short-term, dynamic channel avulsion events that take place as a result of interactions between incoming clastic sediments from the catchment and organic sediments produced in situ, are well documented and understood. However, we suggest that another key process, occurring at a much wider spatial scale and over much longer time spans, is also influencing peatland formation in the Delta. This is the process of chemical sedimentation that influences the longitudinal slope of the system, creating conditions that favour the formation of peat deposits.

As much as 460,000 t of dissolved sediments enter the Okavango Delta system each year (McCarthy and Metcalfe 1990), which is more than twice the clastic sediment input. Of this amount, only about 30,000 t exits via the Boteti River, with possible minor loss of solutes from the system via groundwater outflow (McCarthy and Metcalfe 1990). It is therefore likely that a minimum of 250 000–350 000 t a^{-1} of dissolved sediment accumulates in the Delta each year, with the dominant solutes being SiO_2 and $CaCO_3$ (McCarthy and Metcalfe 1990). The accumulation of these solutes has an appreciable effect on the Okavango Delta landscape and on the morphology of the system as a whole, as these are concentrated in the seasonal floodplains (McCarthy and Ellery 1994). Solute accumulation takes place mainly in the seasonally inundated floodplains (mainly as opalline silica in the form of silcrete) and islands as magnesian calcite and trona beneath and on the surface of islands, leading to aggradation (McCarthy and Ellery 1994).

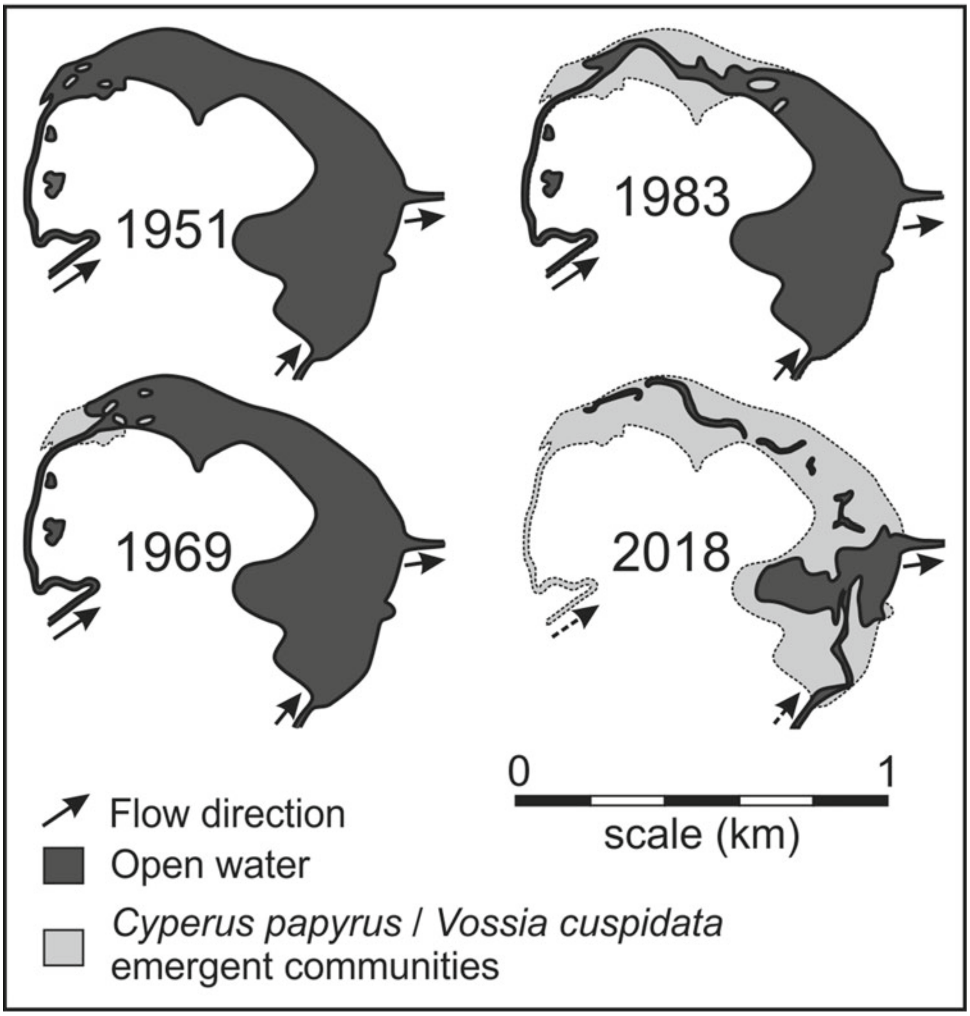


Fig. 3.13 Closure of Dxerega Lediba over the period 1951–2018

With most of the clastic sediment entering the Okavango Delta from the catchment in Angola being deposited in the Panhandle (McCarthy et al. 1991), and most of the dissolved sediment entering the system being deposited on the floodplains and islands of the seasonal swamps (McCarthy and Ellery 1994), accommodation space is created in the mid-reaches of the Delta in which deposition of organic sediment can occur (Fig. 3.18a). Large-scale geomorphic controls such as this, and their influence on peatland formation, are poorly understood. The creation of accommodation space for peat accumulation has been described in the Stillerust, Mfolozi and Mkuze floodplains in KwaZulu-Natal, South Africa as a consequence of aggradation of trunk stream floodplains, which blocks tributary streams (Grenfell et al. 2008, 2010; Ellery et al. 2012). Similarly, the elevation of the base level along trunk streams by tributary sediment input can create accommodation space along trunk streams, which has been documented for the Wakkerstroom and Krom River valley-bottom wetlands in South Africa (Joubert and Ellery 2013; Pulley et al. 2018). We believe these geomorphic processes may by key in many dryland peatlands and are worthy of

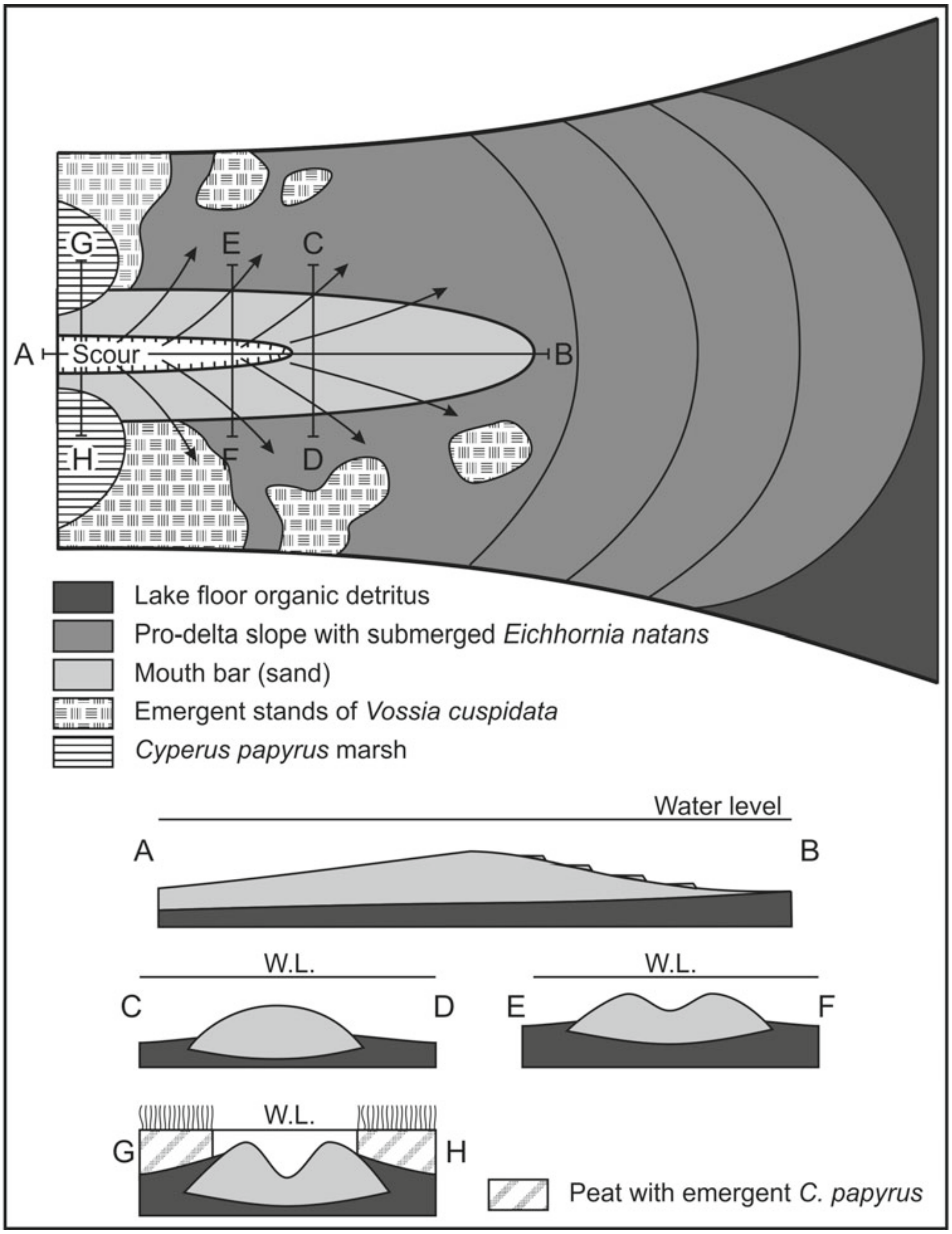


Fig. 3.14 Schematic illustration of the features of the mouth bar and channel at the inlet to Dxerega Lediba (modified after McCarthy et al. 1993)

further study, and in the case of the Okavango, chemical sedimentation in the lower reaches creates accommodation space in an upstream direction that leads to peat formation in the mid-reaches of the system. For this reason, peat formation occurs as a consequence of system-wide landscape processes, and its formation leads to the formation of a system with a remarkably uniform longitudinal slope (Fig. 3.18b, McCarthy et al. 1997).

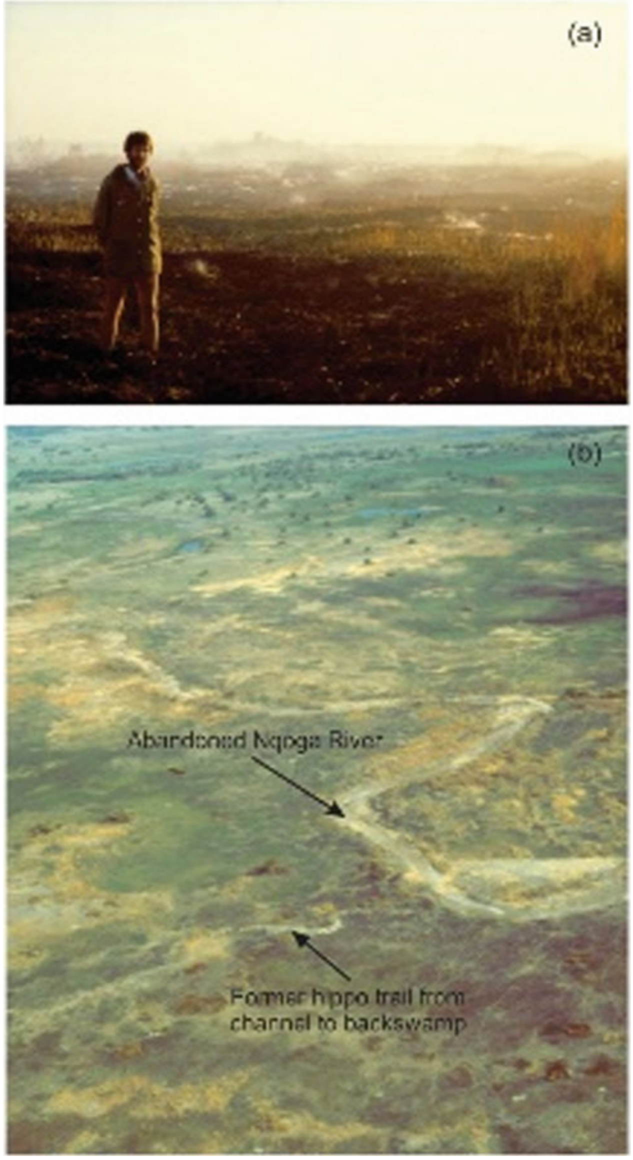


Fig. 3.15 Actively burning peat fires (**a**) and the landscape following decades of combustion of peat deposits along the abandoned lower Nqoga River, revealing a flat and featureless plain surrounding the former channel (**b**)

3.6 Conclusion

Organic sedimentation in the Okavango Delta is characteristic of the permanent swamps. It happens largely due to the presence of extensive organic detritus that rises and floats at or just below the water surface, leading to accelerated succession by emergent wetland plants that have very high rates of primary production compared to submerged and floating-leaved plants, and therefore greatly accelerate organic sedimentation. The closure of lakes by the accumulation of rafts of papyrus is also an important process leading to the formation of large areas with homogeneous surface topography and plant community distribution.

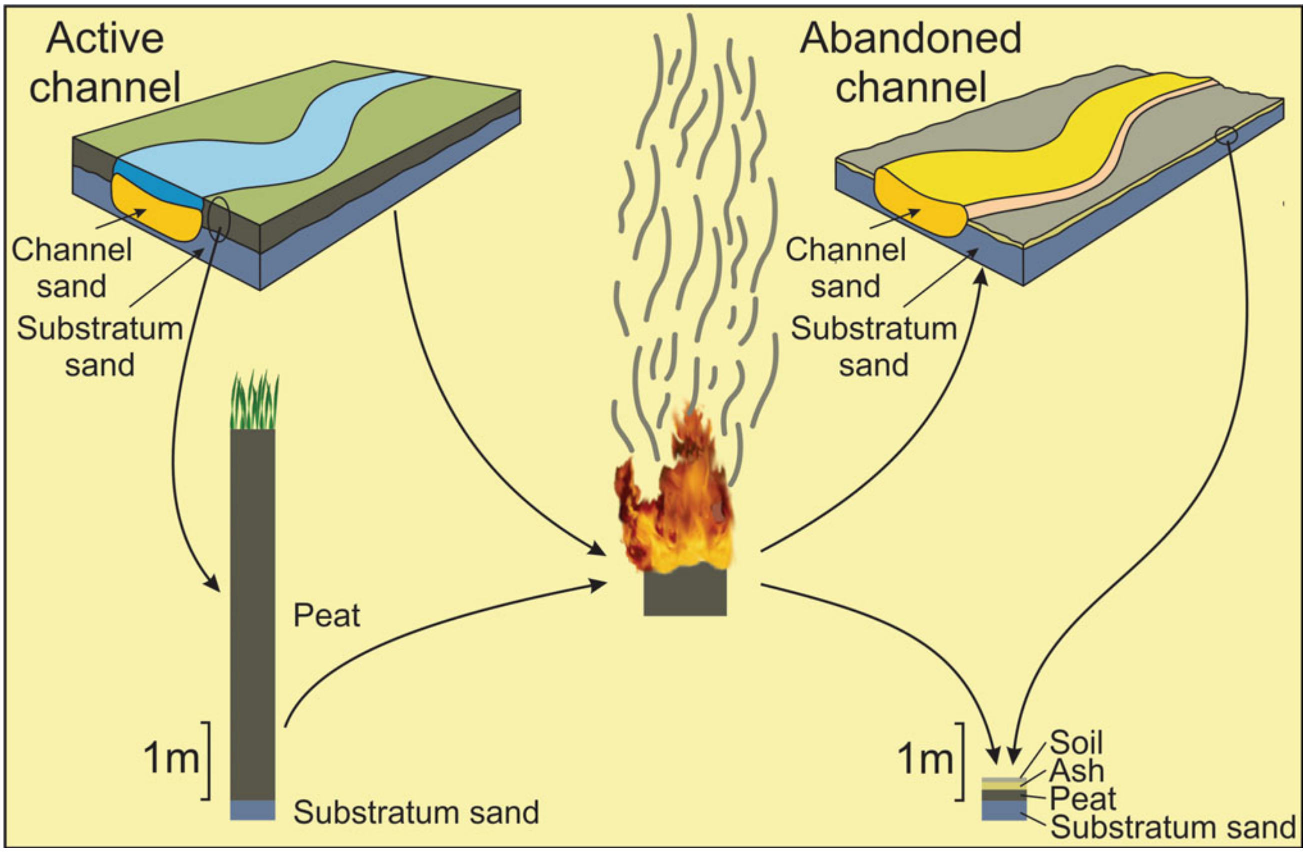


Fig. 3.16 Conceptual model of the destruction of peat deposits following channel abandonment. A 2–5 m peat deposit is converted to a 0.2–0.5 m thick ash/soil deposit and the former channel bed is elevated above the surrounding burnt-out plain

However, aggradation on the beds of primary channels due to the confinement of bedload sediment to in-channel areas, and the simultaneous aggradation of the peat banks, leads to elevation of the channel relative to the surrounding swamps and to channel avulsion. Following avulsion, peat deposits are destroyed such that extant peat deposits in the Okavango Delta are generally only hundreds of years old.

If the average peat thickness in the permanent swamps is between 2 and 4 m, then peat accumulation amounts to 20–40 mm per annum, which is far higher than rates measured elsewhere in the world, including Africa, which are typically two to ten times lower than this.

A key factor in the Okavango Delta is that peat formation may reflect interactions between clastic, dissolved and organic sediment at a system-wide scale such that peat formation is likely to be largely responsible for the overall structure of the alluvial fan.

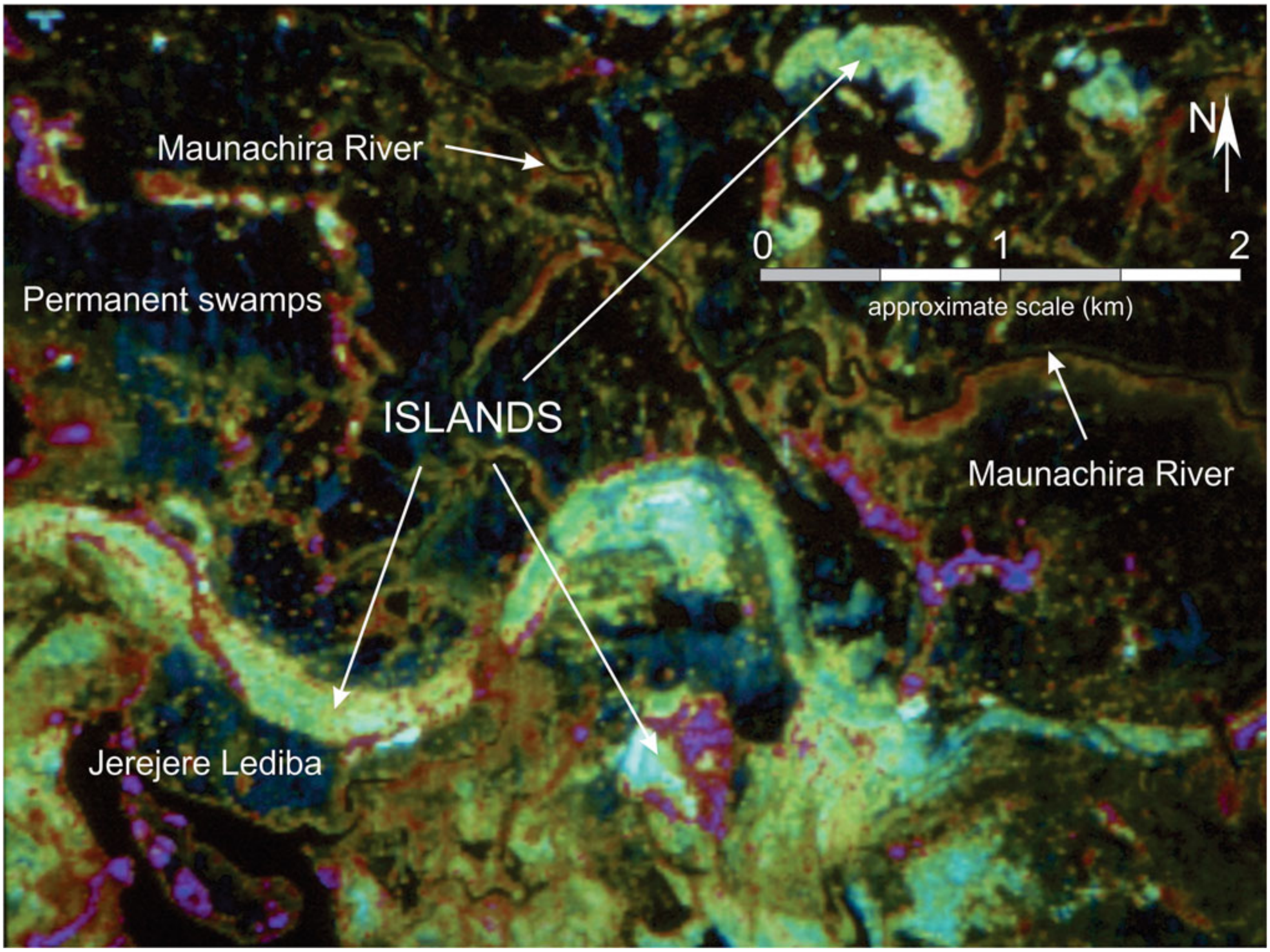


Fig. 3.17 SPOT2 satellite imagery on 8 October 1991 (scene reference number 118.388 and 119.388) of a region of permanent swamp between the abandoned lower Nqoga River and the Maunachira River. The image has been processed to reveal standing phytomass based on a transformed vegetation index (McCarthy et al. 1993). Lakes appear black, permanent backswamp communities are dark colours (charcoal and dark blue), with channel margin communities golden to red, while islands appear yellow to light green. The sinuous island feature must have been formed by a meandering channel in a previous (much larger than at present) flood cycle

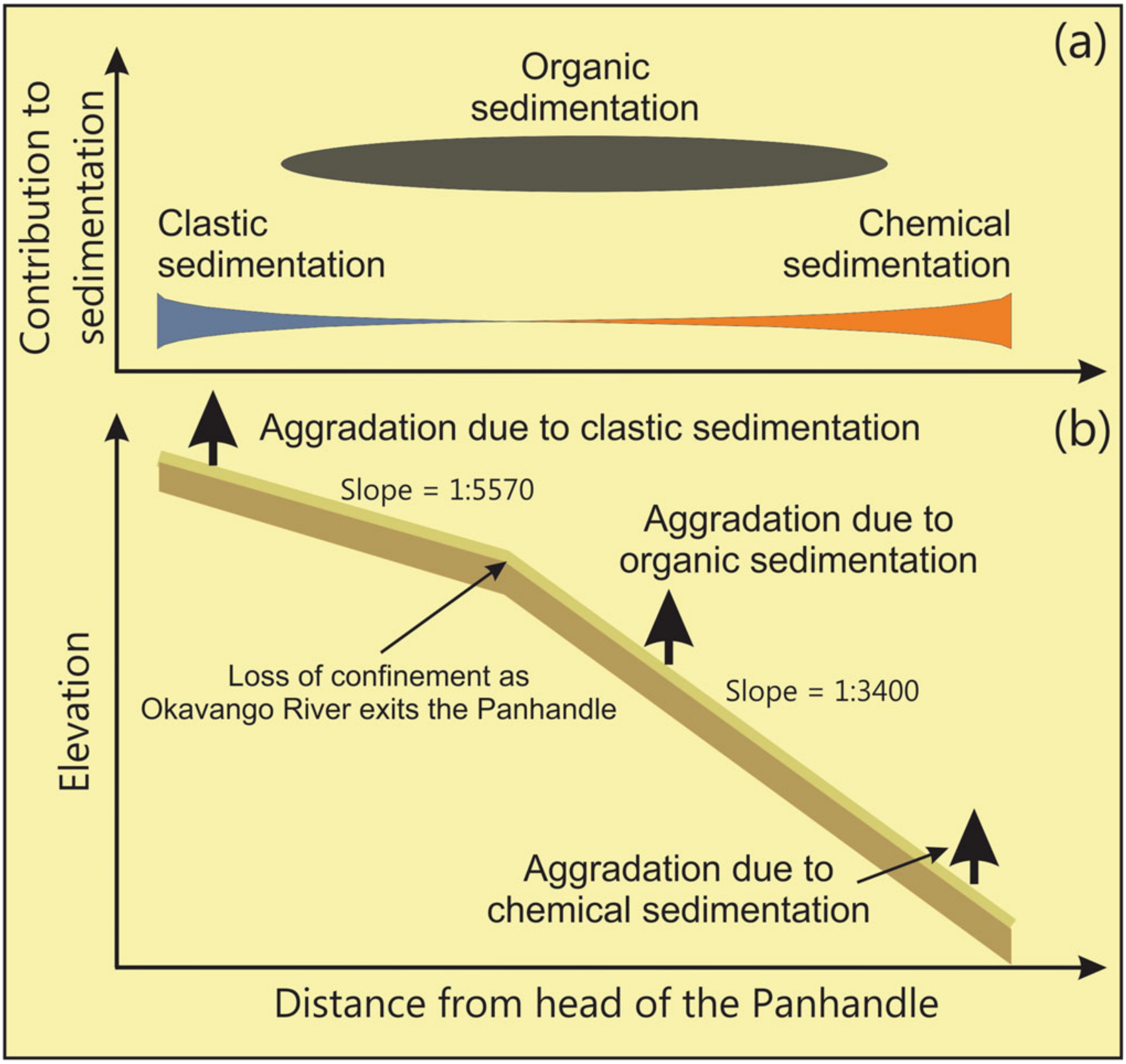


Fig. 3.18 A conceptual model of organic sedimentation in the Okavango Delta as a consequence of lowering the longitudinal slope in an upstream direction of the locus of chemical sedimentation in the floodplains and islands of the seasonal swamps

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William N. Ellery is a wetland scientist who worked in the Okavango Delta for over 20 years as part of a team trying to understand the structure and dynamics of this remarkable wetland. His work focussed on interactions of hydrology, clastic and dissolved sediment deposition, plants and animals, as factors that contribute to the creation of a large freshwater peatland in the drylands of the Kalahari.

Karen Ellery is currently a science educator but worked for a number of years with a multidisciplinary team in the Okavango Delta. Her own work in the area focussed on plant successional processes in the permanent swamps, which included aspects of peat development.