

# **Preliminary Land-Use and Land-Cover Mapping in the Upper Okavango Basin and Implications for the Okavango Delta**

*By Cornelis VanderPost<sup>1</sup>, Susan Ringrose<sup>1</sup> and Mary Seely<sup>2</sup>*

## **Abstract**

Image processing in the upper Okavango catchment resulted in ten generalised classes which may be used as base line data for monitoring future overall land-use/cover change assessments over the entire upper catchment. Specific work was undertaken using single images for more detailed land-use/cover mapping in a 10 km buffer along all tributaries of the upper Okavango in Angola and Namibia. In terms of the under-developed Angolan upper catchment there is relatively little land clearing at present, and impacts on water use and quality are expected to be minimal in the near future. This is a consequence of 20 years of civil war, while the return of refugees is being inhibited by the prevalence of land-mines. Much more extensive development is taking place in Namibia along the southern bank of the Kavango river. This area is likely to become more intensively used as Namibia attempts to develop greater food security. Further work is required to monitor the impacts from Namibian agricultural expansion. These are likely to be pervasive in terms of the ecology of both the Mahango Game Reserve in Namibia and the Okavango Delta in Botswana.

## **Introduction**

Land-cover change is related to natural causes such as short or long term climate shifts, vegetation changes and geologic/tectonic events, and is influenced by man-made changes to the natural environment such as land clearing for crop cultivation, infrastructure and settlement development (Dube and Pickup, 2001). Land-cover change over time can be neutral, negative (reduced cover or reduced quality of cover) or positive (more cover or improved quality of cover) and is often taken as an indicator of overall environmental change, especially over relatively short time periods (5 to 25 years). In relation to wetlands, land-cover characteristics in the contiguous drainage basin area can be significant determinants of drainage and flow conditions, influencing interception, run-off and thus sediment load and transportation, and consequently the speed of flow (Andersson *et al*, 2003). Change in land cover characteristics adjacent to river channels and wetland environments is thus important to the study of the ecological health of wetlands, as changes may impact ecological conditions downstream (Mitsch and Gosselink, 1993).

Poverty contributes to land cover change, especially when increasing numbers of poor people need access to subsistence resources. In developing countries these include land for cultivation, land for grazing domestic stock (including goats), and surface and groundwater resources. Frequently, rural settlement spreads and more land will be cleared and even over-grazed, contributing to land cover change (cf. Olsen *et al*, 2004). As formerly sparsely populated rural areas become more densely settled, land degradation and desertification issues come to the foreground. Land degradation and desertification are linked to global environmental change through climate variables such as rainfall, temperature and surface albedo, and are also linked to biodiversity loss (e.g. Ringrose *et al*, 1995). The United Nations established

1. Harry Oppenheimer Okavango Research Centre, University of Botswana, Private Bag 285, Maun, Botswana.

2. The Desert Research Foundation of Namibia.

the Convention to Combat Desertification to 'target poverty, drought and food insecurity in dryland countries experiencing desertification, particularly those in Africa' (Reynolds *et al*, 2003). It is recognised in the context of this convention that desertification can only be tackled when due simultaneous consideration is given to the roles of 1. climate/meteorology; 2. ecology; and 3. human dimensions at relevant scales. An integrated approach that simultaneously considers both biophysical and socio-economic attributes is essential to the understanding of land degradation.

In recent decades, considerable attention has been focused on the use of satellite imagery and GIS analysis techniques and their role in providing data to help resolve resource use/land-use conflicts in developing countries and elsewhere (Hellden, 1991). This includes the investigation of land-use related environmental problems. Attention worldwide has focused on the need to assess the appropriateness of land management strategies, especially where these occur near sensitive areas of wildlife habitat such as the Okavango Delta. Data derived from satellite imagery has been used in this context to show the extent of human induced degradation as opposed to that driven by droughts or seasonal effects (Otterman, 1974; Matheson and Ringrose, 1994). High resolution imagery has shown that the effects of degradation in southern Africa tend to be either localized expanding areas of bare soil around discrete locations or are manifested as areas of woody weed formation (bush encroachment) (e.g. Perkins and Thomas, 1993, Ringrose *et al*, 1996). Throughout southern Africa problems arise from human and livestock population pressure and general development activities which include increasing demands for arable land, grazing lands and water usage.

The Okavango Delta and its peripheral areas in northwest Botswana are among the more pristine wetland-wilderness regions of the world and a major habitat for many African wildlife species. Input to the Okavango Delta is estimated to be 66% from stream flow originating in Angola and 33% from rainfall over the Botswana portion of the Okavango basin, resulting in flow variations that make the Okavango Delta a highly dynamic alluvial fan with wetted extents varying from 6,000 to 12,000 km<sup>2</sup> in any given year (Andersson *et al*, 2003). The Delta has in recent decades become a major tourism destination for the more adventurous western tourist, attracting 50,000 tourists per year to the Moremi Game Reserve alone (Mbaiwa, 2003).

Human activity has been an integral part of the Delta wetland system since archaeological times but has accelerated in recent decades (VanderPost, 2004) as the resident population of the district surrounding the Okavango Delta trebled between 1960 and 2001 (CSO, 2002). Population growth has also been substantial in the Namibia portion of the Okavango, while rapid growth is expected in Angola as increasing numbers of refugees return. These developments have resulted in potential conflicts of interest between the aims of environmental protection and conservation and the commercial and subsistence interests of the resident population, in a mosaic of protected parks, reserves, conservancies and other land uses with diverse management practices. While much of the pristine, productive character of the Okavango wetlands remains intact, the time has come to initiate efforts aimed at monitoring environmental conditions in and around the Delta with the aim to work toward sustainable human activity based upon the natural resources of the wetland system. One step in initiating such efforts is to compile relevant base line information about land-cover, land-use and resource use details, and to establish trends over time. From such an established baseline, a monitoring system can be set up with or without the use of river basin planning tools.

This work aims to establish baseline data which can assist in the assessment of land-use/cover change in the Okavango Basin by contributing land-cover data. This may be used as an input into monitoring river and wetland conditions in both the upper and the lower Okavango

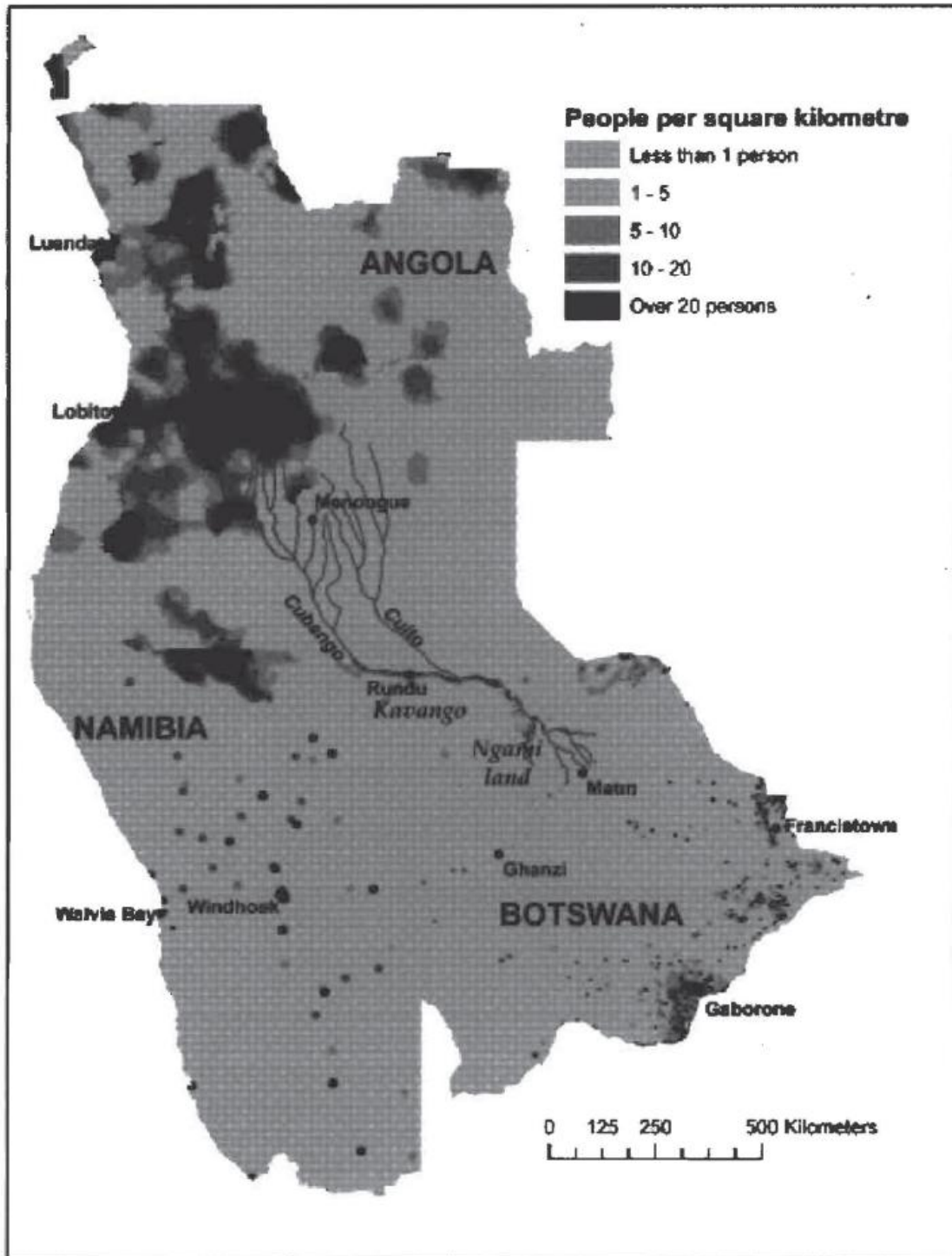


Figure 1. The Location of the Okavango Basin and the Population Density in the Basin Countries of Angola, Namibia and Botswana.

basin and Delta. Future work will determine trends of land-cover change in the recent past (10 years) and establish relationships between land-cover change and variables such as population increase, settlement sprawl and economic development on the one hand, and water quality on the other.

### **Study Area**

The present work emphasizes the use of satellite image interpretation and the development of user-friendly techniques for the future regular monitoring of land-use/cover change in the upper Okavango catchment (cf. Ringrose *et al*, 2003a). This is supplemented by selective field visits, historical records and aerial photography. The location of the Okavango Basin study area in southern Africa is shown in Figure 1. The river rises in Angola where the rainfall averages 1,300 mm/yr and takes at least four months to reach the distal portion of the Delta in Botswana. The upper distributaries are numerous but converge on the Cuito and Cubango major headstreams. The Cubango becomes the Kavango in Namibia and converges with the Cuito east of Rundu before entering Botswana as the Okavango. The study looks at different aspects of the upper Okavango catchment mainly in Namibia and Angola, concentrating on strips of land 10 km on either side of the main rivers.

### **Methodology**

Land-cover classification can be undertaken according to a variety of existing techniques. The most significant recent contribution has been the development of the FAO land-cover classification system (Di Gregorio and Jansen, 2000). This hierarchical system may become a world standard for land-cover mapping and analysis work. Its applicability to Okavango conditions needs to be established in view of the lack of statistical and other corroborative data. It is as yet not evident that the system can be applied to classification efforts that are purely based on satellite image interpretation with limited ground truthing as is the case in this Okavango basin study. In the meantime, the following definitions from the FAO report are employed to allow for alignment with the FAO classification (Di Gregorio and Jansen, 2000):

1. LAND-COVER is defined as the observed (bio) physical cover on the earth's surface.
2. LAND-USE is described as being characterised by the arrangements, activities and inputs people undertake in a certain land cover type to produce, change or maintain it.

#### *Satellite Imagery and Image Processing*

Toward the end of 2003 it was possible to acquire late wet-season Landsat ETM+ imagery from 2003 and to start the baseline assessment. This was an advantage as it reflected the latest possible overview of the land-cover/land-use situation in the basin in view of ongoing post-civil-war resettlement of displaced persons along the Okavango tributaries in Angola. Image classification was begun for the 2003 season to provide a baseline for expected rapid future change in both the Angolan and Namibian portion of the basin (cf. Mosugelo *et al*, 2002). Sixteen images were used; they were mostly in NLAPS format, though with different geographical projections. Image files were imported using Erdas-Imagine software routines and were re-projected to geographic coordinates (Latitude/Longitude) using the Erdas Reproject function to facilitate the bridging of several UTM map projection zones in the basin (Figure 2). Where required to cover the river basin area, neighbouring images were mosaiced together,

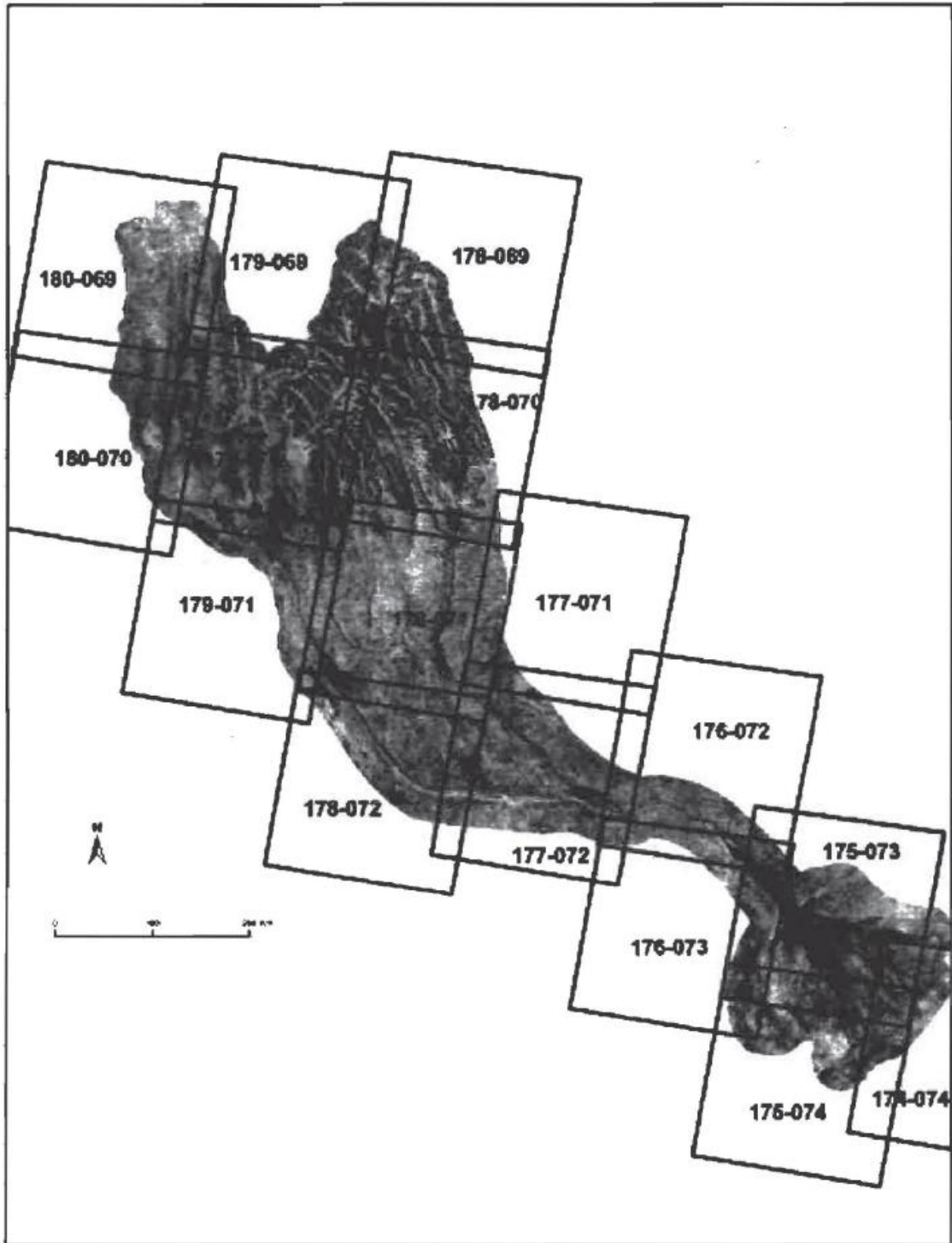


Figure 2. The Okavango Basin with 10 km buffer along streams, showing landsat image scenes (with reference number) as used for land-cover classification.

using the Erdas Mosaic functionality. This took place on subsetted images over a 10 km buffer adjacent to the major rivers and tributaries, using a shapefile of the river created for the Every River project (Mendelsohn and El Obeid, 2004). This was intended to represent the most sensitive continuous area with respect to land-water interactions. The development of classes began for the Namibian section of the river, where more detailed field data were available, and proceeded to Angola. Initial unsupervised classification using 30 classes and applying standard Erdas Imagine automated routines, applying eight iterations, resulted in sufficient differentiation to allow subsequent manual interpretation of broad land-cover classes into 10 distinct land-cover types. However, the floodplains and related areas were not adequately differentiated because mixtures occurred of various categories of water surfaces (e.g. deep, shallow, very shallow) and riverine vegetation such as reeds and papyrus

After experimenting with both unsupervised and supervised classification routines in Erdas Imagine, it was decided to perform classification on single images (as opposed to mosaics) to avoid inter-image reflectance contrasts and resulting misclassification (cf. Ringrose *et al*, 1988). Subsets of single images were extracted to cover the same 10 kilometers zone along the rivers and tributaries thereby focusing the classification on key elements in the immediate river zone. The images were subjected to unsupervised classification and subsequently interpreted manually (repeated over 16 individual images) making use of the details of the Namibian fieldwork data and estimates based on similarities for the Angola portion of the catchment. Preliminary statistical data in terms of prevalent cover percentages were developed for three land-cover classes (riparian zones, cleared areas and irrigated farms) regarded as being of paramount importance in terms of their potential effects on river hydrology. Previous work has shown that the riparian trees are often deep rooted thereby protecting the banks from erosion (cf. Ringrose, 2003b). Procedures were thus carried out to determine the relative proportions of cleared land, irrigated land and riparian forest cover in the 10 km buffer zones in the respective image scenes.

#### *Fieldwork in the Namibian Section of the Kavango River Zone*

During the period December 2003-January 2004, fieldwork took place in the Namibian section of the Kavango river, covering the area from the Botswana border to Nkurenkuru in the west. Along this route, land-cover and vegetation characteristics were recorded at 110 sites, well distributed along the river margin using techniques developed by Ringrose *et al* (1996). For each site the GPS location was recorded using a Garmin 12X GPS. At each site, one 100 m transect was paced along a compass bearing. The unit area of the transects comprising one field site is 100 m by 3 m wide. Data from the 110 sites included the recording of all species types, canopy extent and tree and shrub height. Species identification resulted in species lists being systematically developed. Tree height of all major species was calculated using geometrical procedures while shrub height was measured using a vertically held tape. The differentiation of trees and shrubs is taken here at the 4.0 m limit. Canopy cover per cent is the total measured canopy per site area. Additional observations were added regarding modifying agents (e.g. evidence of recent land clearing), structural information as well as locational details such as proximity to roads. Additional land-use data from a further 80 locations, including the documentation of specific field crops, size and condition of fields, presence of fencing and extent of irrigation, were obtained. A few informal interviews were also conducted with irrigation farmers who have tended to clear large areas of land on the river terraces.

### *Fieldwork in the Angolan Upper Catchment*

A field-visit to the upper Okavango basin in Angola lasted only one day as the terrain was unsuitable for 'fieldwork' due to unsafe conditions (land-mines). However, valuable impressions about the situation on the ground were obtained from the region along one of the major tributaries of the Cubango. Travel was limited to the cleared road between Menongue and Caiundo, along the Cueba tributary of the Cubango river. Observations and photographic data were taken during the stops on the 100 km journey.

## **Results**

### *Field-Visit to Upper Okavango Basin*

Observations were recorded along the landmine-safe road which passes through Miombo woodland between Menongue and Caiundo in south central Angola. This included noting the condition of mainly interfluves and intervening dambos (small swamps), in addition to providing first-hand evidence of the impacts of ongoing resettlement and associated land clearing which comprise mainly slash-and-burn methods (Figure 3). The overall impression created was that, although there is a great need for resettlement and agricultural production, progress will be slow in view of the magnitude of logistical problems. Much of the catchment area either lacks infrastructure or there is considerable damage (e.g. roads with bomb craters, no electricity, poor telephones) such that the development of an organised economy will take



**Figure 3. Mixed Miombo woodland in Angola with evidence of slash and burn clearing for cultivation.**

time. Also apparent is the low level of training of the local population as, because of the duration of the war, a complete generation has grown up without any education. Many areas are also still unsafe due to the prevalence of landmines in large numbers. These conditions imply that land-cover changes will be gradual and may take some 5-10 years to have a serious impact on the landscape. Most of the land clearing that was already ongoing appeared to be concentrated on the higher interfluvies at some distance from the rivers and streams on weathered granitic terrain composed mainly of ferrasols. While these are subject to erosion, the distance from the main watercourse precludes this being a large-scale problem in the immediate future. Land closer to streams tends to be swampy, especially near the numerous dambos which form part of the fossil drainage network. However, according to local informants, ideas are afloat to begin to utilize these lower lands for rice cultivation and some of this swamp stabilisation has started near Menongue. If this were to happen on a large scale, it could have significant impacts upon the flow regimes of the small tributary streams that feed the Cubango's main tributaries by controlling the flow and thereby contributing to the reduction of flooding downstream.

A further observation on the environment in the Menongue-Caiundo region concerns the total absence of wildlife, including birds, in spite of the prevailing low human population density and relatively dense bush cover. According to informants interviewed informally during the field visit, all wildlife and birdlife were killed during the war years. Available suitable habitat appears less of a problem as over many areas the natural vegetation cover is intact and well developed. In many locations, former areas with fields and villages have reverted back to 'bush' as people had abandoned them. It was possible to confirm this from earlier satellite imagery. This provides for the possibility of baseline land cover information against which to monitor future change, particularly with respect to land clearing, and to assess the nature of change in the past.

#### *Fieldwork and Image Interpretation*

The results of vegetation data gathering in the Namibian portion of the river are shown on Table 1. The terrain here comprises about seven river terraces, all of which are composed of sandy soil. Beyond the terraces lies a series of sand dunes. Occasionally the dune topography intersects the terraces, causing areas of lower land where nutrients have accumulated leading to extensive cultivation. A similar pattern arises where ephemeral streams enter the main river system. Mostly, however, cultivation takes place on the lower terraces initially and is encroaching further into the upper terraces and occasionally into the dunes. The dune areas have some bush cover intact and are used as a source of fuelwood, timber for construction purposes and an area in which to graze livestock. Results indicate that there are extensive areas of cleared land, much of which extends to the river. The topography is however low and therefore, except locally, there is relatively little erosion. Most of the cleared land is used for subsistence agriculture as there are villages approximately every 5 or 10 kilometers along the riverside road. Most of the crops grown are maize and sorghum but the yields appear patchy, probably because of the uncertainty of rain. Interestingly, none of the fields are fenced, although a number of the farmers own livestock. It appears that the livestock are always herded as they transit from the settlements by the river to the wooded dune areas, around 2-3 km away. An ongoing issue appears to be the ever increasing extent of clearance into the dune hinterland. If this continues it will inevitably increase the distance covered for grazing and essential resource procurement. While this occurs, some fields in localized areas on the lower terraces are reverting back to secondary vegetation cover (Figure 4).

A major phenomenon which appears to be increasing along the Kavango is the irrigated



Table 1 Vegetation data resulting from Namibian fieldwork (first 21 sites).

Site number	Primary Species	Primary Species	Primary Species	Primary Species	Optional Modifier-notes	Height
Nam 1	L. nelsii	G. flava	G. retinervis		Interdune	to 1m
Nam 2	G. flava	Combretum sp.	G. bicolor	A. mellifera	Thorny lower dune slope	0.5-4m
Nam 3	C. mopane	G. retinervis	G. bicolor	G. flava	Just below FeO ridge	2-4m
Nam 4	T. sericea	B. africana	O. pulchra		Dune crest	to 7m
Nam 5	B. massaiensis	T. sericea			Interdune	to 2m
Nam 6	C. mopane					6-8m
Nam 7	C. mopane	B. albitrunca			Dune crest	6-8m
Nam 8	C. angolensis	G. flava	G. senegalensis	Combretum sp.	Interdune	0.5-1m
Nam 9	T. prunioides				Dune crest (washed)	10-12m
Nam 10	C. mopane	Combretum sp.	G. flava	G. retinervis	Dunes	1-3m
Nam 11	T. prunioides	Combretum sp.	G. bicolor		Dunes	1-4m
Nam 11A	Grapple plant					
Nam 12	T. sericea	B. massaiensis	C. molle	Combretum sp.	Dune crest	1-2m
Nam 13	C. mopane					2m
Nam 14	B. massaiensis	C. molle	T. sericea		FeO layer	2-4m
Nam 15	A. arenaria	Asparagus spp.	M. angolensis	A. mellifera	Interdune	0.5-3m
Nam 16	R. brevispinosum	L. nelsii	B. albitrunca	G. flava	Interdune	0.5-4m
Nam 17	B. africana	B. petersiana	T. sericea		Dune	1-4m
Nam 18	C. hereroense	G. senegalensis	A. mellifera	G. bicolor	Interdune	0.4-4m
Nam 19	Combretum molle	C. collinum	B. petersiana	T. sericea	Fe dune crest	0.5
Nam 20	B. petersiana	S. rautanenii			Dune slope	to 3m

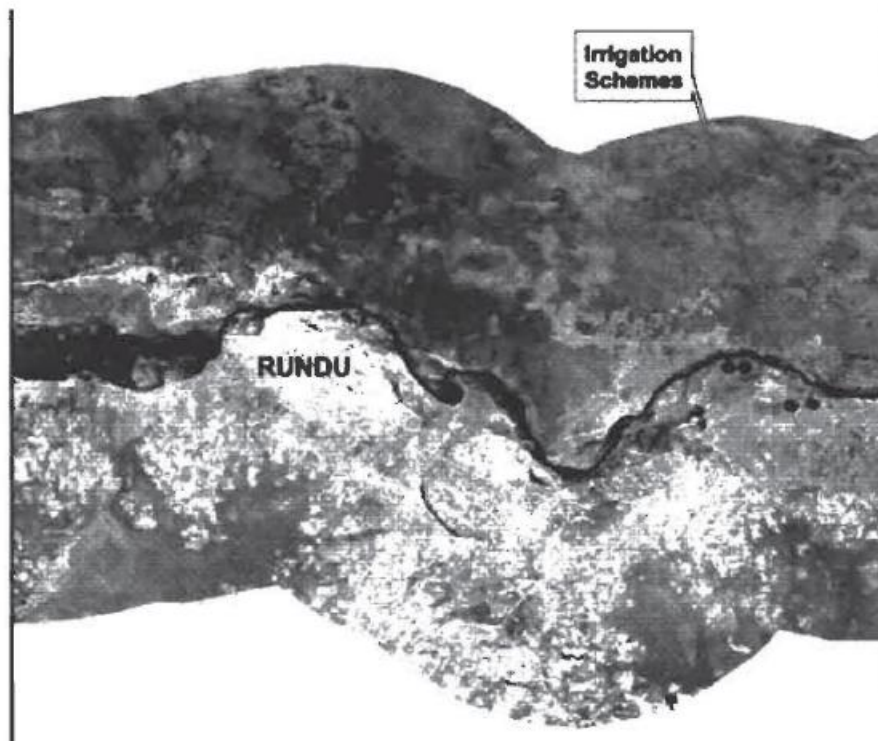
duced by Sabinet Gateway under licence granted by the Publisher (dated 2009).



Figure 4. Large scale land clearing for irrigated cultivation along the Kavango in Namibia, with bush regrowth in the background.

cropping areas. Two types of irrigated areas were identified during the fieldwork - central pivot and drip irrigation. Discussions with local farmers indicated that much of the central pivot irrigation (some 6-8 farms) was at least in part government owned. According to Mendelsohn and El Obeid (2004), large irrigation projects are found at Musese, Vungu Vungu, Shadikongoro, Shitemo, Bangani and Samochema. These are mainly producing maize, cotton and wheat over about 1,200 ha. Overall, about 22 Mm<sup>3</sup> are currently extracted from the Okavango river annually, of which 74% is taken up by irrigation schemes, 15% for watering livestock, and 11% is used by the people of Rundu, the largest town in the area (Figure 5). However, the intention (according to local newspapers) is to increase the amount of irrigated land in a bid for greater food security. This is called the Green Scheme, which is coming about as a result of government interventions. A further 7,400 ha is planned for irrigation which would lead to the extraction of 134 Mm<sup>3</sup> per year, or 1.4% of the total water flow (Mendelsohn and El Obeid, 2004). A number of local people work on the irrigated farms which produce much more substantial crops than the dryland farms. Alternatively, the one drip irrigated farm that was visited had extensive areas of cleared land on terraces close by the river. This farm grew vegetable crops (e.g. onions and squash) for export to Europe during the northern hemisphere winter. Both types of irrigated areas are likely to deposit unknown quantities of fertilizers, pesticides and insecticide residues into the river (cf. Mendelsohn and El Obeid, 2004). Water quality studies in this stretch of the river have been intermittent but preliminary results suggest that the irrigated areas may not at present be causing major problems (S. Bethune, pers. comm.)

Image processing resulted in ten land cover classes which are now available as baseline data showing generalized land-cover over the entire upper catchment (Figure 6). Classes



**Figure 5. Portion of satellite image for the Rundu area at the Kavango in Namibia, showing extensive land clearing for subsistence dryland cultivation as well as commercial irrigation crop farming (on the right).**

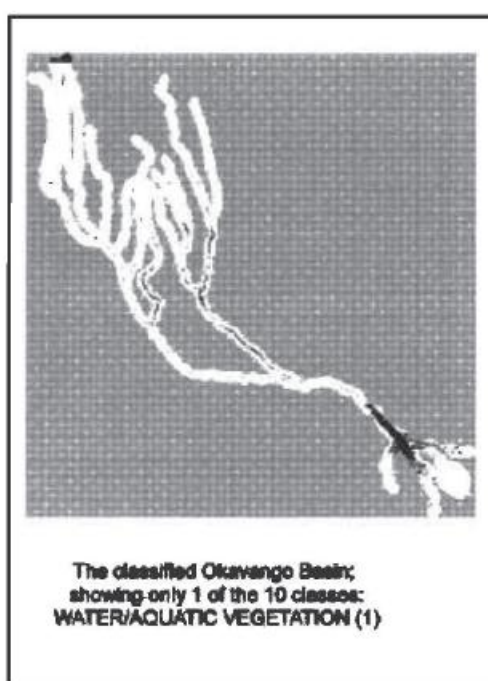
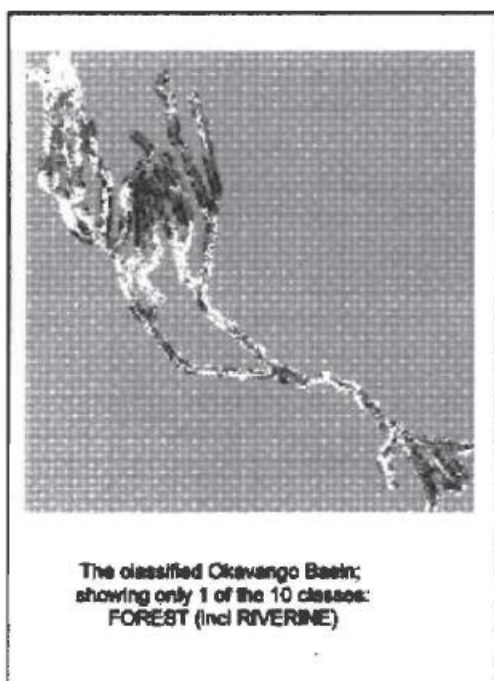
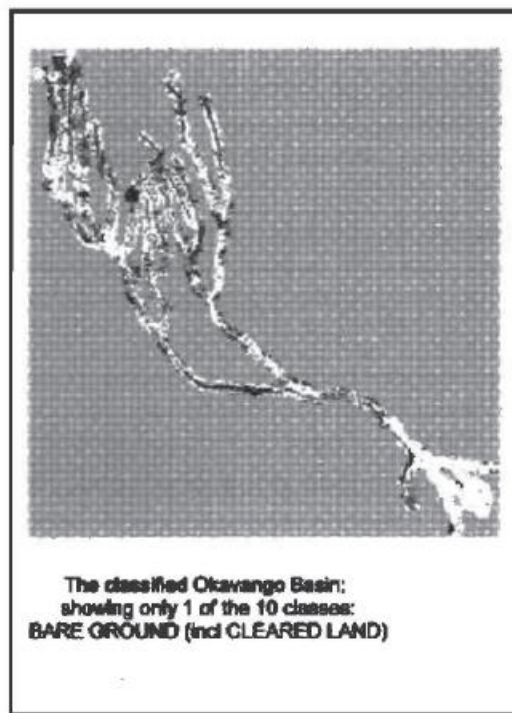
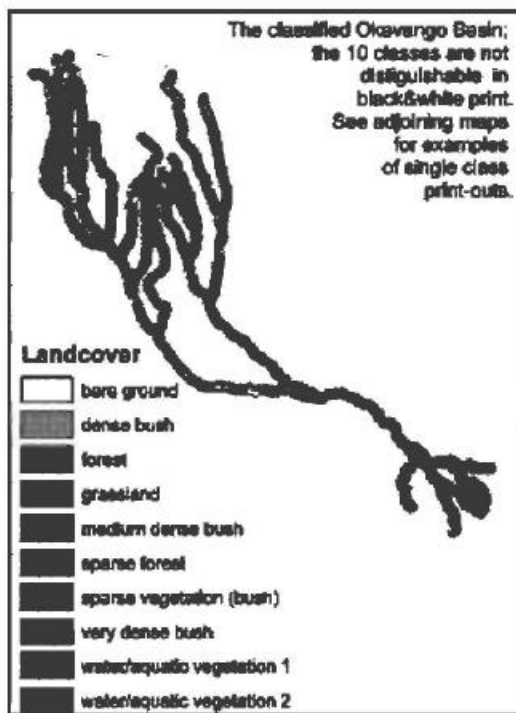


Figure 6. Preliminary 10-class Land-cover Classification of the Okavango Basin (10 km buffer along rivers).

include bare ground incorporating both natural and cleared areas, various densities of bush cover and areas of vegetation regrowth. Because of the preliminary nature of this work it was decided not to quantify the class areas at this time as it might provide misleading results. In order to specify land-use more closely individual sections of the rivers based on single image classifications were considered. Image interpretation over a 10 km river strip indicated that the Namibian Okavango between longitudes 20.25 east and 21.40 east comprises 0.5 % riparian cover, 3.4% cleared areas and 0.8% irrigated area on the Namibian side while the Angola side is almost completely bush covered. This is over a total area of 3,408 km<sup>2</sup>. Notable is the low proportion of riparian cover along the southern Namibian side, as much of the riparian forest has been cleared for farming. Along other sections, flooded and swampy conditions do not promote the growth of such vegetation. Further west, in the section of the Namibia Kavango River between longitudes 18.73 east and 20.46 east, major areas of cleared land were also observed. This section, which includes the town of Rundu, is characterised by 1.3% riparian cover, 17.5% cleared areas and 0.3% irrigated area (e.g. Figure 5), over a total area of 4,138 km<sup>2</sup>. All irrigated land and most cleared land is located along the southern bank in Namibia, with very limited evidence of contemporary agricultural activity on the Angolan bank of the river, although old abandoned and overgrown (former) fields are in evidence.

In general, a sharp contrast was noticeable between the northern (Angolan) and the southern (Namibian) river banks, the river forming the international boundary between the two countries. While the southern bank is densely populated, partly due to the influx of refugees from the north, and exhibits substantial agricultural land, some of which is under irrigation, the northern bank has few people and many of the old agricultural fields have been abandoned and have reverted back to bush. The extensive cleared lands on the Namibian side are a potential source for increased levels of sand deposition into the river channel, while the irrigation schemes, as noted above, have the potential to contribute chemicals deriving from fertilizer usage in addition to pesticides and herbicides in the future as the clearing and irrigated areas increase. This is particularly relevant to the area near Rundu, the largest town in the Kavango region (Figure 5).

The estimates of cleared, irrigated and riparian cover for the Angola portion of the river basin are based on comparative analysis with the Namibia section and known transitions to wetter, more vegetated conditions at lower latitudes in Angola (Table 2). Large stretches of the Cuito river consist of extensive floodplains with the river meandering through these at a very slow pace. These floodplains are swampy and play an important role in regulating the flow of this major tributary of the Okavango. The Cuito is therefore a very balanced water contributor, delivering a more steady flow to the system than the Cubango itself, which is more prone to fluctuations. Along most of the Cuito, there is limited land-clearing, except in the far north of the basin. Along the Cubango, land clearing for agricultural purposes is much more extensive especially around Menongue and Donde where the proportions reach 19.9% and 13.8% respectively (Table 2). The upper headwaters especially occur in a densely populated region with large areas of fields cultivated mostly for subsistence farming, with some evidence of former large-scale plantations also visible on satellite imagery.

### **Discussion**

Land degradation and desertification, once a certain level is reached, are extremely difficult to remedy, especially when the context of a growing rural population, compelled to over-exploit environmental resources for subsistence survival, remains unchanged. In such cases, inter-

Table 2. Preliminary land-cover characteristics of the upper Cuito and Cubango rivers along a 10 km river buffer strip in Angola.

Location and total area in 10 km river buffer strips (with satellite image scene number as per Figure 2)	% Cleared (natural and man made)	% Riparian Forest
Longa and Cuiriri (tributaries to Cuito) Total area = 38106.7 km <sup>2</sup> Satellite image scene: 178 - 070	7.5% of total area: Mostly bare (exposed) sand and minor fields	Very limited riparian
Upper Cuito (Tempe and Cangoya) Total area = 14326.6 km <sup>2</sup> Satellite image scene: 178 - 069	7.9% of total area Mostly bare (exposed) sand and minor fields	Very limited riparian; sandy floodplains grass covered
Caiundo area (mid Cubango) Total area = 6078.9 km <sup>2</sup> Satellite image scene: 179 - 071	1.9% of total area Mostly bare (exposed) sand and minor fields - small scale resettlement)	Very limited riparian
Mid Cubango, south of Menongue Total area = 29808.8 km <sup>2</sup> Satellite image scene: 179 - 070	3.4% of total area Major fields (old plantations evident) and some bare (exposed) sand	Riparian minimal Extensive swamp grasslands along tributaries (acting as sponge)
Nkurenkuru (Namibia) to confluence of Cubango/Cuatir rivers (start of Brachistegia woodlands) Total area = 2578.4 km <sup>2</sup> Satellite image scene: 178 - 072	Major fields along the Cubango up to 4.5% of total area	Riparian varies from 0.33% to 0.9% along Cubango (from south to north) (Cuatir has swamp grassland)
Cubango (from south to north) (Cuatir has swamp grassland) Cubango river north of Cuatir confluence Total area = 31133.3 km <sup>2</sup> Satellite image scene: 178 - 071	0.2% of total area: Scattered major fields	Riparian zones extend into forested uplands, estimated at 0.04% of total area
Uppermost headstreams of Cuito (mostly unsettled) and mid-Cubango (relatively densely populated) Total area = 101 km <sup>2</sup> Satellite image scene: 179 - 069	6.9% of total area:	Very limited riparian zones. extensive areas of swamp grassland
Upper Cubango, Menongue and north Total area = 5199.5km <sup>2</sup> Satellite image scene: 180 - 070	19.9% of total area (mostly in 1300-1400m elevation zone around Menongue)	Riparian cover 4.1% of total area
Cubango Upper Headstreams Total area = 11553.6 km <sup>2</sup> Satellite image scene: 180 - 069	13.8% of total area (most cleared area in north esp. around Donde)	No obvious riparian zone

ventions external to the region concerned are needed to turn the tide and to create new and alternative opportunities for the affected population. In seriously affected regions, local populations do not have sufficient capacity to cope with problems of such magnitude. Changes in land-use and land-cover patterns are among the most pertinent reflections of developments in the socio-economic realm. Typically, growing settlements and associated croplands encroach upon the natural forest/shrub/savanna cover, while the expansion of grazing, made possible by the development of borehole technologies, similarly encroaches upon naturally vegetated areas and competes with wildlife.

This work aims to develop baseline data against which future (and past) land-use/cover change can be monitored in the Okavango catchment. This is undertaken to help minimise conflicts of interest between the aims of environmental protection of the Botswana Delta and commercial and subsistence interests upstream. In the Namibian portion of the river basin so far studied, there is substantial evidence of increased land clearance during recent years for agricultural purposes. This is in sharp contrast to the other, Angolan, side of the river that is mostly characterized by regrown *Burkea* and *Terminalia* shrubland, a result of the abandonment of croplands. A relatively new development appears to be the increasing presence of large-scale irrigation schemes along the river, e.g. near Rundu, clearly discernable from satellite imagery. While some of these are actively used as evident from 'green circles' caused by pivot irrigation, other cleared areas within the central pivot remain unused. Field observations suggested that while most of the irrigation schemes grow maize and wheat for local consumption, others grow a range of vegetables destined for European markets during the northern hemisphere winter. It should be noted that this is one of the more productive areas in Namibia and national plans to become more self sufficient in terms of food security will inevitably put increased pressure on the southern bank of the Namibian Okavango River. Much of the cleared land that increased agricultural production generates (some farms are 30-40 ha) will likely cause increased soil erosion during intense rainfall events. There is also a possibility that fertilizer residue and herbicide/pesticide products may end up in the water, affecting water quality for downstream villages and impacting negatively on ecosystems in the Mahango Game Reserve and the Okavango Delta.

In the Angolan section of the basin, land-cover removal through clearing, typically for subsistence crop-farming, is prevalent mostly in the upper reaches of the Cubango, where the majority of the population is concentrated (locally reaching a density of over 20 persons per km<sup>2</sup>, which is high for rural Africa). The most extensive land-clearing, reaching 20% of the total land area (Table 2), is situated in the interfluves which are somewhat buffered from the main rivers by intervening swamps and floodplains. However, extensive large-scale clearing may well have potential hydrological repercussions, affecting run-off conditions and possibly contributing to flash flooding and high sediment-load levels. By contrast, the lower section of the Cubango in Angola, before the river reaches Namibia, exhibits a more dense natural vegetation cover of *Burkea*/*Terminalia* woodland which mitigates these upstream effects. The Cuito sub-basin on the other hand is hardly affected by land-clearing. Although there is some evidence of land clearing in the upper sections (e.g. near Cuito-Cuanavale) it is less extensive compared to the upper-Cubango headwaters. The middle range of the Cuito, with its extensive floodplains, marshlands and meanders, also filters out any possible adverse effects, delivering pure water to the Kavango in Namibia.

While further work is needed in a number of related areas, ongoing work considering scenarios of change (including climate change) is currently being undertaken. Such work analyses the impact of future water off-take in Angola (through dams) and Namibia (for

Windhoek and irrigation schemes) on Delta ecosystems (Murray-Hudson *et al*, 2005). General conclusions from this work suggest that in terms of water volume, expected future developments in the Okavango basin over the next 5-10 years, with the possible exception of massive expansion of irrigated acreage along the Kavango in Namibia, may generate relatively small impacts.

### **Summary and Conclusions**

Image processing resulted in ten classes which are now available as generalized baseline data for future land-use/cover change assessments over the entire upper Okavango catchment. Classes generated in this work consist of bare ground (including both natural and cleared areas), various densities of bush cover, and areas of vegetation regrowth. To specify land-use and land-cover more closely, individual 10 km sections of river strips were considered. Results indicate that very different conditions prevail in the two countries hence separate conclusions may be ascribed to each. In terms of the relatively under-developed Angolan upper catchment:

1. Most of the rural areas show between 1-8% land clearing, with more clearing in the northern Cubango and relatively little clearing in the Cuito headstreams.
2. The most extensive areas of cleared land are at present occurring around the larger settlements e.g. Menongue (19.9%) and Donde (13.8%) along the Cubango river.
3. Although there is a great need for resettlement and agricultural production, progress will be slow in view of the magnitude of logistical problems such as the lack of trained manpower and the prevalence of landmines.
4. The foregoing implies that land-cover changes in the Angolan catchment will mostly be gradual and may take some 5-10 years to have a serious impact on the environment, as clearing is mainly taking place on adjacent interfluves rather than next to the river itself.
5. While tourist development will be impeded by the lack of wildlife, habitat is available in the upper catchment as previously cleared areas have regenerated as bush.
6. Bush regeneration caused by out migrations resulting from over 20 years of civil war in fact provides for the possibility of good base-line land-cover information against which to monitor future changes.

In terms of the developed Namibian southern bank of the Okavango River:

1. Extensive areas (up to 17.5%) have been cleared for agriculture (rain-fed and irrigated) all along the banks but especially in the vicinity of larger settlements as this area is among the more productive in the entire country. This has the potential of increasing soil erosion during intense rainfall events, raising sediment loads.
2. Expansion is expected because of Namibian aspirations towards food self-sufficiency and the otherwise hyper arid regimes of the country.

3. The clearing is on terraces immediately adjacent or very close to the river. Hence possibilities arise for increased fertilizer, herbicide and insecticide inputs having adverse impacts on human and ecosystem health downstream.

More work needs to be undertaken to monitor all these impacts which are likely the most pervasive in terms of immediate and future impacts on the ecology of the Mahango Game Reserve in Namibia and the Okavango Delta in Botswana.

#### Acknowledgements

This work was made possible through a grant from the University of Botswana Research and Publications Committee (R129). The work was also undertaken in support of the WERRD project, funded by the European Union. Field observation work in Angola was funded through the Sharing Water Project (USAID).

#### References

- Andersson, A., Gumbrecht, T., Hughes, D., Kniveton, D., Ringrose, S., Savenije, H., Todd, M., Wilk, J and Wolski, P. (2003) Water flow dynamics in the Okavango river basin and Delta - a prerequisite for the ecosystems of the Delta, *Physics and Chemistry of the Earth*, 28; 1165-1172.
- CSO (Central Statistics Office) (2002) 2001 *Population and Housing Census: Population of Towns, Villages and associated Localities*, Gaborone.
- Di Gregorio, A. and Jansen, L.J.M. (2000) *Land Cover Classification System*, p. 179. Rome: FAO.
- Dube, O.P., Pickup, G. (2001) Effects of rainfall variability and communal and semi-commercial grazing on land cover in southern African rangelands. *Climate Research*, Vol. 17: 195-208.
- Hellden, U. (1991) Desertification – time for an assessment. *Ambio*, 20, 372-381.
- Matheson, W., and Ringrose, S. (1994) Assessment of degradation features and their development into the post-drought period in the west-central Sahel using Landsat MSS. *Journal of Arid Environments*, 15:12-26.
- Mbaiwa, J.E. (2003) The Socio-Economic and Environmental Impacts of Tourism in the Okavango Delta, Northwestern Botswana. *Journal of Arid Environments*. 54(2): 447-468.
- Mendelsohn, J. and el Obeid, S. (2004) *Okavango River, The Flow of a Lifeline*, p. 176. Cape Town: Struik Publishers.
- Mitsch, T. and Gosselink, V. (1993) *Wetlands*, 2nd ed. New York: Van Nostrand Reinhold.
- Mosugelo, D.K., Stein, M., Ringrose, S. and Nellemann, C. (2002) Vegetation changes during a 36 year period in northern Chobe National Park, Botswana, *African Journal of Ecology*, 42:232-240.
- Murray-Hudson, M., Wolski, P. and Ringrose, S. (2005) Scenarios of the impact of local and upstream changes of climate and water use on water flow in the Okavango Delta, *Journal of Hydrology*, (submitted paper).
- Olsen, J. (2004) The LUCID Project – landuse land-cover change in East Africa. Published on internet web at: <http://www.lucideastafrica.org/>



- Otterman, J. (1974) Baring high albedo soils by overgrazing, a hypothesized desertification mechanism. *Science*, 186, 531-533.
- Perkins, J.S., and Thomas, D.S.G. (1993) Spreading deserts or spatially confined environmental impacts? Land degradation in the Kalahari desert of Botswana. *Land Degradation and Rehabilitation Bulletin*, 4, 179-194.
- Reynolds, J.F., Stafford Smith, D.M. and Lambin, E. (2003) Aridnet: seeking novel approaches to desertification and land degradation. *Global Change Newsletter*, 54, June.
- Ringrose, S., Matheson, W. and Boyle T. (1988) Differentiation of Ecological Zones in the Okavango delta Botswana by classification and contextual analysis of Landsat MSS data, *Photogrammetric Engineering and Remote Sensing*, 54:325-332.
- Ringrose, S., Sefe, F. and Ekosse, G. (1995) Progress towards an evaluation of desertification in Botswana, *The Desertification Bulletin*, 15:2 146-152.
- Ringrose, S., VanderPost, C. and Matheson, W. (1996) The use of remotely sensed and GIS data to determine causes of vegetation cover change in southern Botswana. *Applied Geography*, 15, 2-26.
- Ringrose, S., Vanderpost, C. and Matheson, W. (2003a) Mapping ecological conditions in the Okavango Delta Botswana using fine and coarse resolution systems including simulated SPOT VEGETATION imagery, *International Journal of Remote Sensing*, 24(5): 1029-1052.
- Ringrose, S. (2003b) Techniques for assessing the use of near surface groundwater by riparian trees in the distal Okavango Delta, Botswana, *Applied Geography*, 32(2), 281-302.
- VanderPost, C. (2004) Population growth, development and protected areas in Ngamiland. *Paper presented at the BENRON conference, July 2004, Gaborone.*