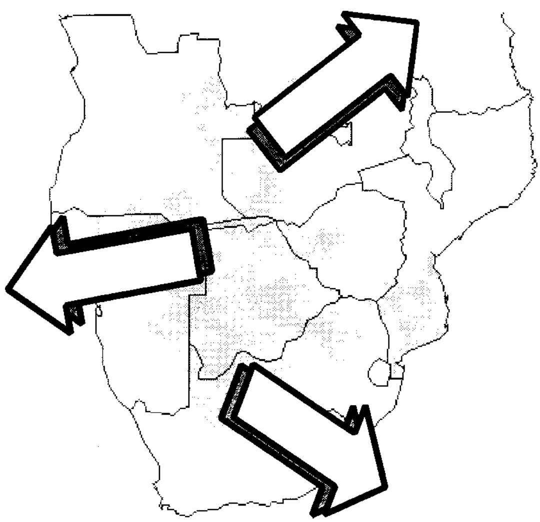
IGBP REPORT 42

International Geosphere–Biosphere Programme (IGBP)



The Kalahari Transect: Research on Global Change and Sustainable Development in Southern Africa

The International Geosphere-Biosphere Programme: A Study of Global Change (IGBP) of the International Council of Scientific Unions (ICSU)
Stockholm, Sweden

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The Kalahari Transect: Research on Global Change and Sustainable Development in Southern Africa

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Cover Photographs:

"Closed canopy forest"	Wet season view of *Cryptosepalum exfoliatum - Brachystegia longifolia* forest. 988mm annum-1 rainfall, 89% canopy cover, 15m tall. (photo. P. Dowty, Lukulu, Zambia).
"Open woodland"	Wet season view of *Diospyrus batocana -Brachystegia spiciformis* open woodland. 690mm annum-1 rainfall, 65% canopy cover, 12m tall. (photo. D. Parsons, Katima Mullilo, Zambia).
"Shrubland"	Dry season view of *Rhigozum trichotomum* shrubland. 100mm annum-1, 2% canopy cover, 0.5m tall. (photo. R.J. Scholes, Upington, South Africa).

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Executive Summary

The Kalahari Transect is proposed as one of IGBPs Transects (see Koch *et al.* 1995 [IGBP Report 36]). It is located so as to span the gradient between the arid subtropics and the moist tropics in southern Africa, a zone potentially susceptible to changes in the global precipitation pattern. Its focus is the relationships between the structure and function of ecosystems and their large-scale biophysical and human drivers (climate, atmosphere and land use). The Kalahari Transect spans a strong climatic gradient in southern Africa, from the arid south to the humid north, while remaining on a single broad soil type, the deep sands of the Kalahari basin. The vegetation ranges over the length of the transect from shrubland through savannas and woodlands to closed evergreen tropical forest, with land uses ranging from migratory wildlife systems, through pastoralism, subsistence cropping to forestry.

Two-and-a-half million square kilometres (a third of the land area of southern Africa) is occupied by these and closely-related ecosystems. Historically they have been sparsely populated, but are now coming under increased human pressure, as a result of population growth, human and animal disease control, increased infrastructure and improved agricultural technology. There is a dearth of information and skilled human resources to address the issue of sustainable use of the grazing, woodland and biodiversity resources on these deep, sandy soils. This information is a priority for national governments and local communities.

The international importance of the Kalahari Transect is related to its large extent, and the opportunity which it presents to study climate-vegetation-human interactions under ideal conditions. The topography is flat and the soil variation is minimal, providing a simplified model system for addressing issues of scaling. Human induced land cover change is just beginning, permitting longitudinal studies of the processes involved.

The objectives of the Kalahari Transect activity are to:

- Build an active network of regional and international researchers around the issue of ecosystem structure and function in savanna woodlands undergoing climatic and land use change
- Quantify the current and future role of southern African savanna woodlands in the global carbon, water and trace gas budgets and the degree of dependence of these budgets on climate and land use change

- Develop a predictive understanding of future changes in southern African savannas and woodlands on sandy soils, including their capacity to deliver forage, timber and other products.

The goal is to develop shared, spatially-explicit models of savanna ecosystem structure and function on Kalahari sands in southern Africa. Achieving this goal will require a coordinated collaborative effort between researchers from the five countries in the region and international partners, as well as significant human resource capacity building. The mechanism of implementation includes workshops, communication, fieldwork at shared research sites, and integration and analysis of comparative data from different sites.

A five year project is proposed, commencing in 1997. The project revolves around four themes: vegetation structure, composition and dynamics; biogeochemistry, trace gas emissions and productivity; resource use and management and water and energy balance. These themes define the minimum set of processes necessary for understanding of the Kalahari system, but do not represent the total sum of work which could be carried out along the transect. Modelling exercises will provide the link between patch, landscape and ecosystem scale research and regionally useful policy and resource management products. Preliminary meetings of the potential collaborators, and some pilot studies, have already taken place. Funding proposals have been prepared and are currently under consideration.

Introduction

The Kalahari is a vast sand-filled basin which occupies a third of southern Africa (Figure 1). The lack of surface water has caused parts of it to be called a ‘desert’, although the rainfall is adequate to support plant cover in most places. Due to its location astride the Inter Tropical Convergence Zone (ITCZ) the rainfall ranges from 160 mm per year in the south to 1000 mm in the north. The rainfall is seasonal and highly variable between years and is believed to be sensitive to changes in the global climate induced by the greenhouse effect. The sands are aeolian and are not completely uniform either regionally or within the landscape, but they are all deep, well-drained and low in plant available nutrients. The lack of water, low fertility and presence of tsetse fly in the north have kept the Kalahari relatively unpopulated until recently. The Kalahari was one of the last remaining migratory wildlife systems in Africa. Deep borehole technology, tsetse control and mineral fertilizers are rapidly changing that situation, leading to concerns that development in the Kalahari should be placed on a sustainable path.

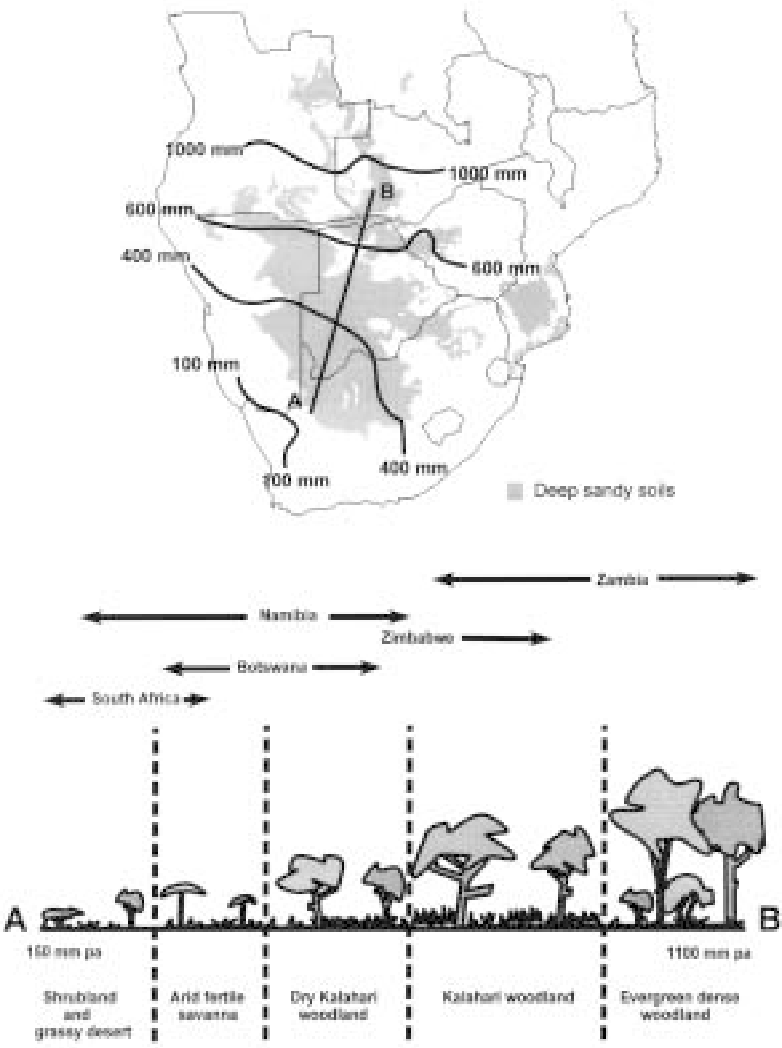
Ecologists have often taken advantage of the natural variation which occurs along environmental gradients to understand the controls on ecosystem composition, structure and function. The IGBP has expanded this concept to the global scale with the idea of ´transects´. They have proposed a global system of about twelve transects, each thousands of kilometres long and spanning a major gradient believed to be susceptible to human induced change. The Kalahari Transect is one of three proposed transects spanning the precipitation gradient between the humid tropics and the subtropical deserts.

The transects (Koch *et al.* 1995):

- Allow the consequences of future changes to be inferred from patterns currently exhibited along the gradient
- Allow thresholds to be located along a continuous gradient
- Provide a mechanism for extrapolation that links the site-based work of ecologists to the regional scale of climatologists and policy-makers.

Figure 1

The Kalahari sand basin occupies 2.5 million km^2 in Angola, Botswana, Namibia, South Africa, Republic of Congo, Zambia, and Zimbabwe. There are outlying deposits of deep aeolian sands in neighbouring countries. A strong rainfall gradient exists between the northern and southern distribution of the sands which has profound influences on vegetation structure.



The Kalahari Environment

The Kalahari Desert is an area of scarce surface water straddling Botswana, Namibia and South Africa. This is part of a more extensive area which is physio-graphically and sedimentologically unified, called the Mega Kalahari (Thomas 1984). The Mega Kalahari lies within the territories of eight countries, from north to south; Gabon, Congo, Republic of Congo, Angola, Zambia, Namibia, Botswana, and South Africa.

Geomorphology

The African continent can be viewed as a series of large sedimentary basins separated by broad upwarps, with smaller basins around the coastal margins (Burollet 1984). The development of the interior basins has been a result of several processes that occurred over long periods of time. First, the breakup of Gondwanaland caused the newly formed African continental margin to subside with an associated band of uplift inland, which developed into the great escarpment. The band of inland uplift caused the interior of southern Africa to subside creating a basin prone to sedimentation. This basin is the contiguous Kalahari-Cubango-Congo basin in which the Kalahari Group sediments have accumulated, forming the Mega Kalahari.

The Kalahari is underlain by a thick geological basement of ancient Precambrian granitoid rocks (Reeves and Hutchins 1975). South of the Zambezi river, the granites are overlain by several hundred metres of Carboniferous to Triassic Karoo Sequence sedimentary rocks, with extensive basaltic intrusions (Mallick *et al.* 1981). The rocks have poor surface exposure throughout the Kalahari, as they are covered by a thick blanket of sand.

The surface sediments can be classified according to the following surface features (Passarge 1904, with subsequent modifications).

Alluvium

These deposits are spatially extensive and are associated with the Okavango-Zambezi swamp zone, the lake basins of the middle Kalahari and pans and channels in the sandveld. They are usually comprised of silts and clays, while those of lacustrine origin contain evaporites.

Decksand

Situated above the Kalahari sand surface, this material consists of reworked surface mixed with rock fragments and alluvium.

Kalahari sand

This is the most common surface unit of the Kalahari Group of sediments and covers an area of over 2.5 million km^2. It is generally agreed that Kalahari sand represents the accumulation of material derived from local sources (Baillieul 1975, Thomas 1984, Musonda 1987). The sands can include accumulated *in situ* weathering products of pre-Kalahari lithologies, supplemented by material transported to the interior by ancient endoreic rivers. In Botswana the Kalahari sand has been divided into four subgroups (Baillieul 1975) based on the hypothesized local origin of the sands.

Conglomerate and gravel

These are sporadically found at the base of the Kalahari Group sediments throughout their distribution. The gravel lithologies usually reflect local and regional geology. The deposits are usually thin (1-10 cm), but in certain areas they may reach a thickness of 100 m.

Sandstone

Although sandstones have been described from throughout the distribution of the Kalahari Group sediments they are better considered as duricrusts, especially silcrete (Thomas and Shaw 1991). These silcretes arise as a result of physico-chemical processes in the active zone of weathering rather than deep burial sedimentary processes which would produce proper sandstones.

Duricrusts

There are three types of duricrust found in the Kalahari Group sediments; calcrete, silcrete and ferricrete. In each case the pre-existing rock, soil or weathered material in the weathering zone has been replaced by calcium carbonate, silica or iron, respectively. Duricrust occurrence tends to increase along with increasing rainfall, and is usually associated with pans, drainage lines and valley sides (Goudie 1973). Below-ground duricrusts are able to form good aquifers because of their impermeable nature.

Soils evolved from Kalahari sand are weakly developed. Profile development is almost absent and the soils are characterized by low levels of nutrients and organic matter. In the linear dunefields, nutrient content (Thomas and Shaw 1991) and sand grain size (Lancaster 1986) of the soil vary in a catenal fashion across the dune ridges, with the highest nutrient concentrations and the finest grain sizes being found in the interdune areas. Kalahari sands have a high transmissivity of water which allows for potential recharge but poor storage. Most of the soils formed from Kalahari sands are classified as arenosols (Food and Agricultural Organization [FAO]/United Nations Educational, Scientific and Cultural Organization [UNESCO] nomenclature) or quartzipsamments (United States Department of Agriculture [USDA] nomenclature).

The predominant landform in the Mega Kalahari (85% of the area) is linear dune fields (Thomas and Shaw 1991). The height of the dunes varies as a function of their age, available sand and degree of vegetation cover (Pye and Tsoar 1990). The degree to which dunes in the Mega Kalahari are vegetated increases with increasing rainfall. The dune fields were formed under the influence of easterly winds (Lancaster 1979) during the last glacial maximum (18000 - 13000 years BP) when annual rainfall in the region was < 150 mm - the threshold for sand movement in a vegetation free environment (Heine 1982).

Climate

The Kalahari Desert lies in the southern hemisphere subtropical high pressure belt, and the northern Mega Kalahari lies between this belt and the equator. The seasonal fluctuations in the components of this belt, especially the Inter Tropical Convergence Zone (ITCZ), results in three major near-surface air streams influencing the Mega Kalahari climate: the Indian Ocean tropical easterlies; the north east monsoon; and south Atlantic air (Tyson 1986). These surface winds give the Mega Kalahari its seasonal climate. A change in the global climate would be expected to lead to a shift in the mean position of the ITCZ, resulting in a change in the distribution of climates along the Kalahari Transect.

In the north of the Mega Kalahari, seasonality is expressed more as variation in rainfall than temperature. In the north the onset of rainfall is earlier and the duration longer than in the south. As a consequence, the mean annual precipitation at the northern limit of Kalahari sands is close to 1000 mm, while at the southern limit it is about 150 mm (Figure 1 and Table 1). The whole of the Mega Kalahari is essentially a summer rainfall zone as a consequence of the ITCZ and Zaire Air Boundary moving south, bringing unstable air into the region and causing convective thunderstorms (Thomas and Shaw 1991). In addition to these seasonal patterns there are marked year to year variations (Tyson and Dyer 1975) that influence the occurrence of rainfall. The summer temperatures are high, but due to the low humidity in the south during the winter, the night-time temperatures are low.

Table 1

Summary of climate statistics for the Kalahari region. Values are means derived from World Meteorological Organisation (WMO) rainfall station data for a minimum of ten years.

	South Upington (28°2′S, 21°6′E)		Central Palapye (22°32′S, 27°8′E)		North Kabompo (15°15' S, 23°9′E)	
Month	Rainfall (mm a^{-1})	Mean Temp. (°C daily)	Rainfall (mm a^{-1})	Mean Temp. (°C daily)	Rainfall (mm a^{-1})	Mean Temp. (°C daily)
January	25.5	27.7	65.8	25.2	229.8	21.5
February	34.9	26.9	79.9	24.4	189.1	21.5
March	40.0	24.7	63.1	23.1	165.3	21.3
April	23.6	20.2	25.3	19.9	46.4	20.7
May	10.9	15.7	3.6	16.2	4.8	18.0
June	2.8	12.1	1.6	13.2	0.7	15.8
July	2.8	11.9	1.5	12.8	0.0	17.0
August	3.6	13.9	0.0	15.4	0.3	19.0
September	3.9	18.0	4.0	19.8	2.7	23.1
October	10.8	21.4	34.1	23.3	39.6	24.1
November	15.5	24.6	30.8	24.8	140.4	22.1
December	18.8	26.9	51.4	25.1	215.2	21.2
Annual	169.9	20.3	361.4	20.3	1034.7	20.4

Vegetation Structure, Composition and Dynamics

The diversity and biomass of vegetation in the Mega Kalahari tracks increases in precipitation along a gradient in a north-easterly direction. Little recent vegetation classification work has been carried out on vegetation growing on Kalahari sands save in the south western area of Botswana (Kalikawa 1990, Thomas and Shaw 1991, Skarpe 1991), western Zimbabwe (Chilides and Walker 1987) and the Western Province of Zambia (Jeans and Baars 1991). However, the broad vegetation types occurring within Botswana, Zambia and Africa south of 10^{o} S, have been mapped by Wild and Fernandes 1968, Weare and Yalala 1971, Edmonds 1976, and Werger 1986.

The vegetation of the Kalahari falls into both the Karoo-Namib region (covering the north western portion of South Africa and south eastern portion of Botswana) and the Zambezian domain (covering the rest of Kalahari sand distribution) of the Sudano-Zambezian phytochorological unit (Werger 1978, Menaut 1983). At a regional scale the vegetation communities are dominated by savanna complexes. The structure of these complexes is closely related to rainfall, with open shrublands occurring in the southern low rainfall areas (150 mm a^{-1}), savannas occurring in the intermediate rainfall areas and deciduous broadleaf forests occurring in the high rainfall areas in the north (>1000 mm a^{-1}). Moving northwards from the southern Kalahari (Figure 1), the shrub and savanna complexes undergo gradual transition from fine-leafed, deciduous *Acacia* species in southern and central Botswana to broad-leafed, deciduous *Baikiea plurijuga* woody savanna in the north of Botswana to *Julbernadia spp*. deciduous forest and *Cryptosepalum spp*. evergreen broad-leafed forest in the northwest of Zambia. These transitions represent the fundamental division in savannas between nutrient rich, fine-leafed savanna and nutrient poor, broad-leafed savannas (Huntley 1982). The exploration of the functional effects of these differing vegetation structures on biogeochemical cycles forms a major part of the research proposed for the Kalahari Transect.

The field layer in the savanna complexes generally consists of tufted perennial grasses. Owing to the low levels of nutrients present in the Kalahari sands, both grasses and trees form associations with both vesicular-arbuscular and arbuscular mycorrhizas (Alexander and Hogberg 1986, Hogberg and Piearce 1986, Veenendaal *et al.* 1992). The importance of these associations for nutrient cycling and plant community structure remains largely unknown in the Kalahari sand systems. In addition, many of the grasses have rhizosheaths which facilitate phosphorous and water uptake (Bailey and Scholes 1997).

Vegetation structure on Kalahari sands has been shown to depend strongly on sand depth, soil moisture and disturbance regime (Chilides and Walker 1987). Poor or changing land use practice affects these determinants of vegetation structure and can lead to vegetation change. Changes in land use practice can be a result of expanding populations, new technology or intensification of land use techniques as well as changing climate (Ellis and Galvin 1994). Types of changes occurring in the Mega Kalahari include clear-felling of closed canopy forest in the northern regions, ash fertilization agriculture, increased numbers of animals in grazing areas through provision of permanent watering points and expansion of areas under crop cultivation. The majority of work carried out regarding these vegetation changes concerns the effects of heavy grazing by animals in grazing areas in Botswana (Skarpe 1986

1990 and 1991, Perkins and Thomas 1993). In these studies it is shown that heavy grazing leads to increases in shrub abundance in shrub savanna and increases in tree abundance in tree savanna complexes. The consequences of the above changes for the sustainable use of natural resources is an issue that demands urgent attention and is tackled by the Kalahari Transect research agenda on several levels ranging from the biogeochemical to the social.

The permanence of these vegetation structural changes has been debated for some time. Recent modelling initiatives (Westoby *et al.* 1989, Law and Morton 1993, Milton *et al.* 1994) and field studies (Archeret *et al.* 1987) have indicated that the changes may be reversible. However, the amount of time needed for a reversal is often very long and, should faster change be required, considerable sums of money would be necessary to facilitate it.

Fire is an important determinant of vegetation structure in African savannas. Its effects are most often cited as being directly responsible for observed tree grass ratios in savannas in which human induced fires have long been a feature of the system. Fire is also a major mechanism for trace gas emissions from savannas. Significant quantities of CO, NO_x , NO_2, CH_4, aerosols and volatile organic compounds are released into the atmosphere during savanna fires. Strong convection columns which develop above fires allow for injection of these substances into the troposphere where they are involved in complex chemical reactions, the products of which are transported outside the region. The influence of such transport has been seen in the development of an ozone maximum over the Atlantic ocean during the African dry season when large volumes of trace gases are exported from the continent by tropospheric circulation systems. Modification of the soil environment by fire through the conversion of nutrients present in biomass and necromass from microbial-unavailable organic forms to microbial-available inorganic forms also leads to a stimulation of biogenic trace gas emission. This influence is particularly noticeable when nutrient release by fires occurs prior to the onset of the rainy season. The timing, frequency and intensity of fires is not uniform across all savanna types. This is due to the lower levels of herbivory in broad-leafed savannas, then in turn to the low nutrient content of their vegetation.

Human Population and Development

The Kalahari was initially peopled by the San, whose modern descendants include the !Kung, the !Ko and the Khoi groups (Main 1987, Thomas and Shaw 1991). Presently, there are in excess of 55 000 San people located principally in Botswana and Namibia.

Approximately 3500 years ago, the Bantu-speaking peoples began moving southwards from a point which is probably modern day Cameroon. This movement culminated in the arrival of these people in South Africa approximately 1600 years ago (Cockcroft 1990). The Bantu people formed groupings which have become the present day Ndebele and Shona in Zimbabwe, the Lozi, Lovale, Lunda and Bemba in Zambia, the Ovambanderu in Namibia, the Ovimbundu and Lunda in Angola, the Lundu and Luba in the Republic of Congo and the Tswana, Sotho, Zulu, and Nguni in South Africa (Cockroft 1990).

Historically, the countries in which the Kalahari sands occur are characterized by low density populations of peoples practising both sedentary and shifting agriculture and pastoralism. Fully developed pastoralism was established in the Mega Kalahari from 500 AD (Denbow and Wilmsen 1986), with cattle and sheep first being introduced into the southern distribution of the Kalahari sands *circa* 2000 years BP (Smith 1992).

Pastoralism has been restricted in the northern distribution of the Kalahari sands by the presence of the trypanosomiasis vector, the tsetse fly (Nash 1969). Similarly, it has been restricted in the southern distribution by the lack of permanent surface water. Recently these restrictions have been reduced through the use of insecticides and drilling of boreholes.

Both the traditional agricultural and pastoral systems practised in this region are adapted to prevalent climatic conditions (Smith 1992) as long as people have freedom to move on to new grazing and virgin or fallow land. However, increasing pressure is being brought to bear both on land previously ill suited to agricultural or pastoral use, and readily utilizable land through rising human populations (Table 2) and the steady removal of water and disease restrictions.

Fencing, tenure systems and permanent water supplies have restricted both peoples´ and animals´ freedom to move, resulting in sustained high use pressures in areas where previously the pressure was intermittent. Effects of increased pressure from domestic animals include overgrazing, bush encroachment and erosion (Van Der Meulen and Van Gils 1983, Ellis and Galvin 1994).

Removal of wood for commercial sale and as fuelwood is also proceeding at an increasing rate (Anderson 1986, van Gils and Aongola 1988). Increasing demand for land has sped up the rotation cycle of ash fertilization agriculture (known as *chitemene*, Stromgaard 1985), resulting in decreased soil fertility and insufficient time for woodland regeneration. There has been a general decline in both the absolute numbers and diversity of wildlife throughout the region, despite its high potential for ecotourism.

The above mentioned forms of land degradation, as a result of present land use patterns and practice, are likely to be exacerbated by global climate change and associated changes in rainfall and vegetation productivity (Ellis and Galvin 1994, Koch, *et al.* 1995). Research focused on determining the social and political causes and consequences for ecosystem structure and function of this changing tapestry of natural resource use and management, against a climate change backdrop, demands immediate attention if future development is to be placed on a sustainable path. Integrating the understanding of different points of interaction between ecosystem structure, function and management within the wider regional political context forms the central core of the scientific questions posed for the Kalahari Transect.

Table 2

Population status for countries in which Kalahari sands are found (Main 1987, World Resources Institute 1992). Year 1990.

Country	Population (millions)	Population density (people km^{-2})	Population growth rate (% a^{-1})	Land surface occupied by Kalahari sands (%)
Angola	10.0	7.5	2.7	55.0
Botswana	1.3	2.2	3.5	75.1
Namibia	1.8	2.1	3.2	30.3
South Africa	35.3	24.2	2.2	4.1
Republic of Congo	35.6	14.3	3.1	3.6
Zambia	8.5	10.0	3.8	25.2
Zimbabwe	9.7	22.7	3.2	6.4

The Scientific Questions

The conceptual model underlying research on the Kalahari Transect is depicted in Figure 2. It represents what we believe to be the minimum set of processes that need to be addressed if the Kalahari system is to be understood, but not the sum of all research possible along the Kalahari Transect. It breaks naturally into four themes. The research questions we have posed deliberately focus on links between scientific disciplines rather than on the discipline themselves. Overlying these themes is the need for data integration through spatially explicit mechanistic and correlative models, as well as emphasis on the intercomparison of modelling products derived for different scales. The linkages between these themes and the IGBP Core Projects and Framework Activities is explored in a later section.

Theme 1 Vegetation Structure, Composition and Dynamics

The main determinants of savanna structure and composition are believed to be water and nutrient availability, fire and herbivory. The quantitative limits and mechanisms of this conceptual model have yet to be established (Figure 3). The gradient in relative availability of water and nutrients offered by the transect, overlaid by differences in herbivory and fire due to land use, provide an opportunity to do so without the confounding influence of differences in soil type. The gradient straddles a wide range of vegetation structures and compositions, including a transition from fine-leafed to broad-leafed savanna. This theme aims at determining these limits and providing predictive understanding of the vegetation structural types in relation to their environment. Results from this theme will be used in Themes 3 and 4 in conjunction with those from Theme 2. These limits would then form the basis for improving Dynamic Global Vegetation Models (DGVM), which are currently poorly calibrated for tropical regions.

Key Question 1.1 How Does Tree Cover, Height and Biomass Relate to Plant Water Availability?

The Workshop hypothesized that aridity is the underlying control on tree biomass along the transect, although the mechanism may be indirect, *via* fire frequency and intensity. Establishment of the broad relationship will allow the reasons for local deviations from the norm to be explored.

Key Question 1.2 How do Grass Cover, Fire Frequency and Intensity Control Woody Plant Recruitment and Mortality?

Fires seldom kill mature savanna trees, except in conjunction with other factors, but they do restrict the rate at which saplings can become mature trees. A competitive grass cover could restrict the number of tree seedlings which become established. Monitoring of tree populations in environments with different fire regimes and grass covers can quantify the relationship between fire intensity, topkill and outright mortality.

Key Question 1.3 What are the Climatic and Edaphic Thresholds at Which Dominance Switches Between the Mimosaceae, Combretaceae and Caesalpinaceae?

The major contrast in African savannas is between the fine-leafed and broad-leafed forms, which exhibit many ecological differences. There are also other transitions related to the dominant tree families and grass tribes. It has been proposed that the transitions are related to water and nutrient availability. The fundamental and realized niches of key species will be explored with a combination of *in situ* and transplant experiments.

Figure 2

The area of interest within the Kalahari Transect programme. These constitute the minimum set of factors and interactions needed to understand changes in the Kalahari environment and their impact on human well-being. They will form the framework around which other projects, not covered in this document, will accrete.

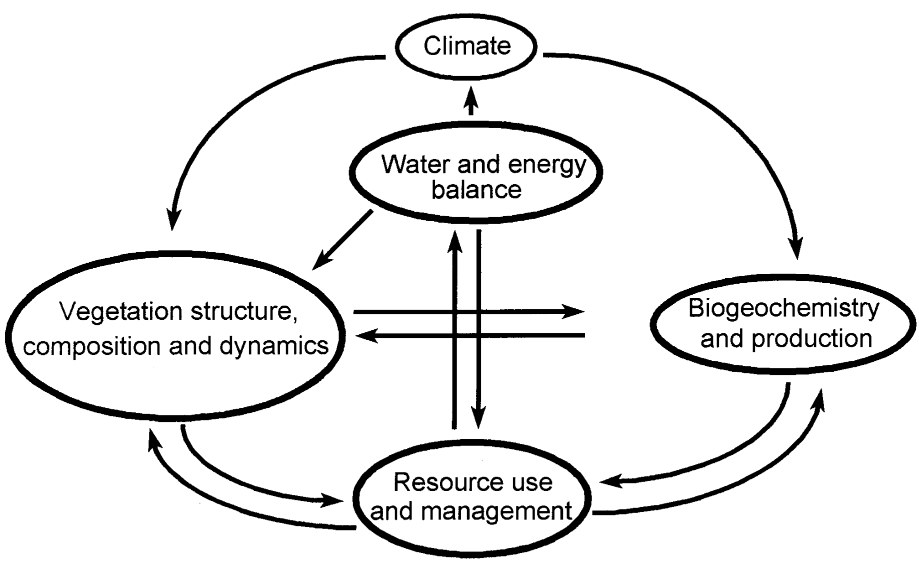
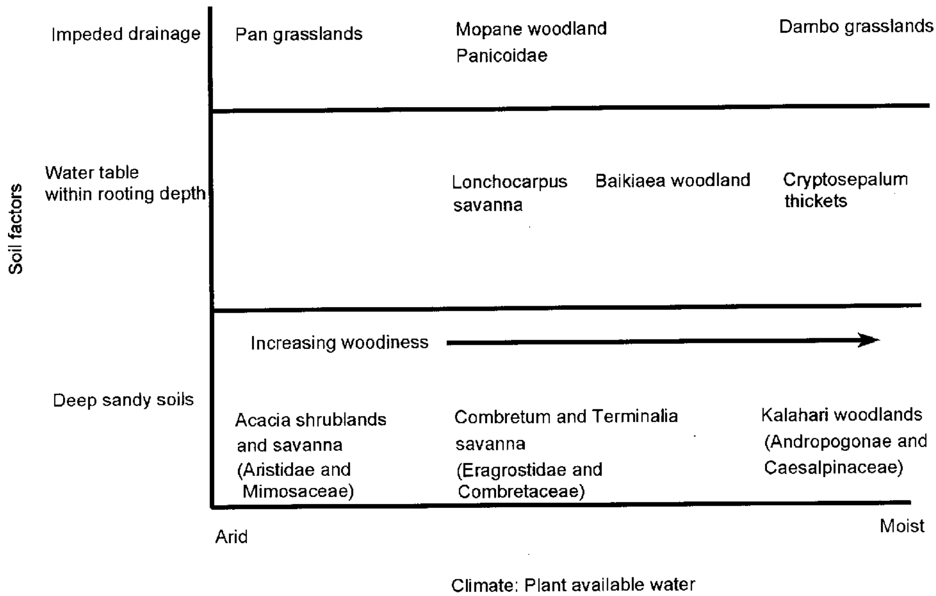


Figure 3

The trends in savanna ecosystem composition and structure in relation to water and nutrient availability.



Theme 2 Biogeochemistry and Production

This theme investigates the processes that link the carbon cycle to other cycles, in particular, those of nitrogen, phosphorus and water, and how these processes are affected by climate and land use. The conceptual model on which the theme is built is shown in Figure 4. The Kalahari Transect is an ideal location for exploring this model, since it offers a large and continuous climate gradient over a remarkably uniform parent material. The Key Questions will be addressed by quantifying the carbon and nitrogen cycle at the research sites (wet and dry deposition, N mineralization and fixation, carbon assimilation, plant tissue and soil C and N contents) and by manipulative experiments, including N and P fertilization and cross-transect litter exchange. This theme underpins research in Themes 3 and 4 as it provides quantitative process based information which feeds explicitly into the higher order interactions between ecosystem structure and function, resource use and management, and ecosystem water and energy use.

Key Question 2.1 How does Ecosystem Structure Control Carbon Stocks and Their Turnover?

The workshop hypothesized that the amount of carbon stored in the Kalahari ecosystems is largely a function of the biomass of trees, although it is not primarily stored in the tree biomass. The interaction between tree cover, grass production, the frequency and intensity of fires and soil carbon stocks can result in carbon sequestration if fires are excluded, but the most stable form of sequestered carbon is elemental carbon left by fires. Quantification of patch scale carbon pools, above and below ground vegetation and soil carbon pools and turnover times (determined from stable isotope studies), allied with carbon and water flux micrometerological studies of Theme 4 at sites along the transect will provide the necessary data for scale-explicit upscaling studies. These studies may then be further utilized to address Key Questions outlined in Themes 1, 3 and 4.

Key Question 2.2 What Controls Nitrogen Availability, and to What Degree does it Control Carbon Assimilation?

Most of the available nitrogen results from mineralization of organic matter, the rate-limiting step in the nitrogen cycle. There are two major inputs of available nitrogen (atmospheric deposition and biological N fixation) and two major avenues of loss (aerobic denitrification and pyrodenitrification). We suggest that the extra-regional export of nitrogen as trace gases and the limitation on fixation imposed by low phosphorus and water lead to a general nitrogen limitation of primary production in the Kalahari. Primary production should therefore be predictable from nitrogen mineralization, which is in turn related to the level and fractionation of soil organic matter. Eddy covariance studies of carbon fluxes would provide a valuable source of data for linking this Key Question to those posed in Theme 4.

Key Question 2.3 How does the Balance of Carbon to Nitrogen Assimilation Control Plant Tissue Digestibility and Decomposition Rate?

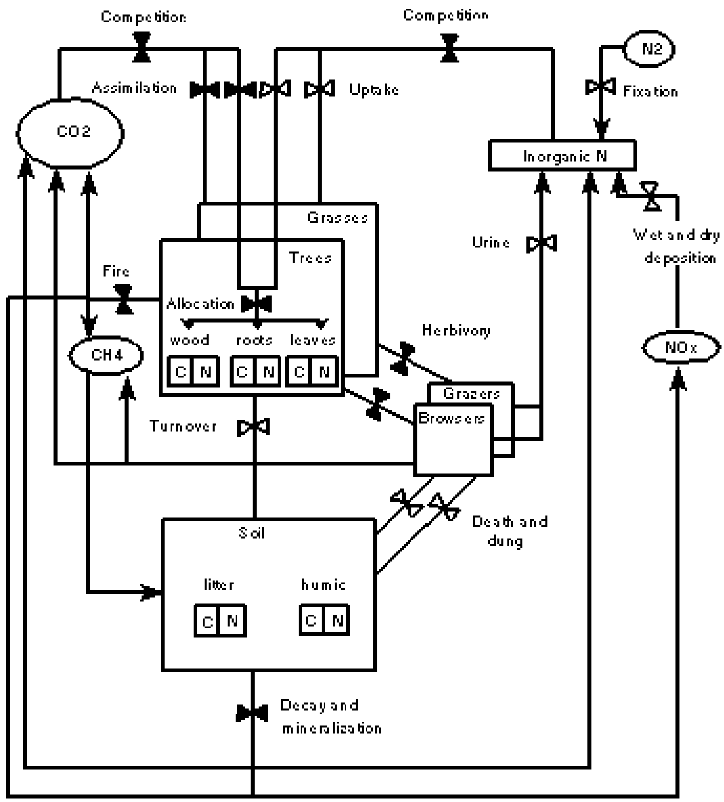
Animal production in the Kalahari is controlled by forage digestibility rather than forage production. Digestibility, and the related concept of decomposability, is directly and indirectly (through secondary compounds) related to the balance between plant nitrogen assimilation and carbon assimilation. Therefore animal production and carrying capacity should be predictable from this relationship, providing mechanistic and correlative information required by Key Questions 3.1 and 3.2.

Key Question 2.4 How Does Ecosystem Structure and Land Management Affect Trace Gas Emissions?

Most radiatively-active and ozone-forming trace gas emissions are related to the carbon cycle (CO, CH_4, hydrocarbons) or nitrogen cycle (N_2O, NO_x). An understanding of these two cycles and how they interact, derived from Key Question 2.2, will allow prediction of the trace gas emission rates as well as strategies for reducing them. This extends further to the influence of savanna type, broad-leafed or fine-leafed, on the nitrogen and carbon cycles and consequently the emissions of the different trace gas species from these savanna types. Information regarding fire regimes and extents gained from Key Question 1.2 will be invaluable in further describing, quantifying and modelling trace gas emissions as a result of managed and wild fires as well as determining modifications to biogenic emissions brought about by fire.

Figure 4

The linkages between the carbon and nitrogen cycle which constrain the quantity and quality of plant production.



Theme 3 Resource Use and Management

This theme focuses on the inter-relationships between ecosystem change and resource use. Changes in the nature, location or intensity of human activity in the Kalahari have repercussions for the structure and function of ecosystems examined in Themes 1 and 2; conversely the state of the ecosystem determines what human activities are possible. This reciprocal linkage can lead to a downward spiral of increasing degradation and poverty. Indigenous communities have usually developed the knowledge and resource management systems to ensure that it does not. However, changes in human activity are also driven by external policy decisions, economic conditions, infra-structural development, new technology and population growth and spread.

Some of the changes currently taking place in the Kalahari are fairly well documented, for instance the decline in wildlife and vegetation changes due to cattle grazing, while others, such as the increased exploitation of ground water, are not. The transect offers a unique opportunity to study the people-environment interaction, because it spans a wide variety of land use-environment combinations; a variety of different national policies; and different levels of community participation in natural resource management. The reference points provided by the research sites allow quantitative expression of the sometimes vague concept of 'resource degradation'. The Kalahari has just begun a process of major human-induced change, which offers both research opportunities and the potential for meaningful interventions.

Key Question 3.1 What are the Qualitative and Quantitative Environmental Effects of the Main Agents of Resource Use and Management in the Kalahari?

The 'main agents' include land uses such as cropping, grazing, tree harvesting, tourism and wildlife conservation, mineral and ground water exploitation, and actions such as the application of fire, provision of water, implementation of permanent grazing schemes, change in erection of fences and the construction of roads.

Key Question 3.2 What are the Socio-Economic Consequences of, and Human Responses to, Resource Degradation in the Kalahari?

Poverty and socio-economic inequalities (especially unequal access to resources) are both causes and consequences of resource degradation. The opportunity to study past and present land use changes will help to understand the feedback between environmental state and land use practice and why it is sometimes dysfunctional.

Key Question 3.3 What are the Driving Forces of Change in Resource Use and Management in the Kalahari?

Potential driving forces include population growth, migration, new technology and opportunities offered by infrastructural development, changes to traditional forms of land tenure and use-systems, produce and input prices, perceptions, loss of indigenous knowledge and changes in the relative power of local and central authorities. Understanding the relationships between driving forces and resource use practices will help to formulate policies which promote sustainable use. Policy exploration, evaluation and justification will be aided by the understanding gained from Themes 2 and 4.

The methods used to address these questions are:

- Baseline characterization of land uses at a regional scale using ground surveys and satellite images
- Development of chronological sequences of land cover change in selected areas undergoing change using historical maps, aerial photographs and satellite images
- Comparative socioeconomic surveys along gradients of land use and intensity, covering population growth, origin and composition, economic activities, resource access and use, poverty, local structures and government policies
- In depth follow-up surveys of land use, socioeconomic characteristics, land use policy impacts and local perceptions.

Theme 4 Water and Energy Balance

The principal climatic gradient in the Kalahari is between the arid southwest and the humid northeast. The porous sands permit almost no surface runoff; thus the pathways of water loss from the ecosystem are deep drainage to aquifers and evaporation from plants and soil. Evaporative loss controls the partitioning of intercepted radiant energy at the land surface between latent and sensible heat, which is climatically important, and is directly related to the vegetation's capacity to assimilate carbon. Deep drainage recharges the aquifers on which sustained human occupation of the Kalahari depends.

Key Question 4.1 How do Vegetation Structure and Composition Control Energy and Water Balance at the Land Atmosphere Interface, and how is this Altered by Land Use?

Many factors are involved in determining the partitioning of water and energy by terrestrial ecosystems. A key issue is the fraction of radiant energy reflected by the surface (albedo), which is mainly a function of plant cover and its greenness. Large-scale albedo changes, for instance by tree clearing and overgrazing, have the potential to alter local climate. A second key issue is the vegetation bulk conductance to water, which is a function of leaf area, its distribution in space and time, and its stomatal conductivity in relation to plant water availability. Allied to this issue is the investigation of the influence of soil nitrogen status and supply rates on canopy stomatal conductivity.

This Key Question could be addressed by conducting detailed energy and water balance studies at a range of sites along the transect. At each site, continuous water and energy flux data would be collected using micro-meteorological techniques (eddy correlation, which also lends itself to gas exchange studies) for a period sufficient to cover the intra and interannual climate and phenological variations. Linking this data to the eddy covariance measurements of carbon fluxes of Theme 2 would provide a means to place patch scale observations within larger scale ecosystem processes. This data would be supported by vegetation characterization including rooting depth studies and determination of the depths at which plants aquire water, phenological observations, and leaf- and branch-level observations. The relative flatness, large scale and simplicity of the Kalahari system lends itself to upscaling studies, in which the site measurements are related to aircraft measurements in the boundary layer. These data are of great interest to climate (World Climate Research Programme [WCRP]) and hydrological modellers (Biospheric Aspects of Hydrological Cycling [BAHC]).

Key Question 4.2 How Does the Depth to the Water Table Control Community Composition, Structure and Water Use?

In general the water table in the Kalahari is very deep (100 m or more). It is not known to what degree plants depend on this water, or even if they have access to it. In places the water table is closer to the surface, usually due to the presence of drainage-impeding layers in the sand blanket. These locations are believed to be marked by distinctive changes in the vegetation (for instance, *Baikaea* forest or *Cryptosepalum* thicket) consequently creating linkage to Key Question 1.3. A drop in the water table due to extraction from boreholes would have unknown but possibly serious consequences to be explored within Theme 3. The relationships between climate, aquifer depth and vegetation could be established if a systematic survey were done of water depth in boreholes, plant cover and rooting depth of dominant woody species. Satellite observations of dry-season greenness would provide supporting evidence. Isotopic analysis of rainwater, transpired water and ground water would allow determination of the degree of dependence of plants on deep water sources. Together with Key Question 4.1 it would improve the understanding of aquifer recharge, a matter of vital concern to development authorities in the Kalahari.

Key Question 4.3 What Controls Phenology in the Kalahari?

Little is known about cues for leaf development and loss in tropical savannas: are they based on day length, temperature or water stress? What role does nutrient scarcity play in leaf longevity and the degree of evergreeness? These questions are fundamental for modelling the vegetation, especially in relation to climate change. The data resulting from long-term observations of phenology at sites needed to address this question would be complemented by the 20-year daily Advanced Very High Resolution Radiometer (AVHRR) coverage, and would in turn provide a valuable resource for the interpretation of satellite data. A predictive understanding of phenology will greatly assist the development of vegetation structural and functional models mentioned under Themes 1 and 2.

Implementation

A key feature of the Kalahari Transect regional programme is a high degree of flexibility with regard to the level of involvement by participating countries. Despite having a focused set of research themes, tackling of all of these themes is not mandatory for participation. The level of participation as well as the specifics of individual research projects is a matter for the participating countries and institutions to determine. Against this backdrop, a transparent and open style of programme implementation and management is suggested as detailed below.

Management

The Kalahari Transect regional programme will be guided by a Task Team (TT) consisting of a representative from each participating country in the region, appointed by the researchers in that country, plus representatives from the following IGBP Programme Elements: Global Change and Terrestrial Ecosystems (GCTE), Biospheric Aspects of the Hydrological Cycle (BAHC), International Global Atmospheric Chemistry (IGAC), Global Change System for Analysis Research and Training (START), and the jointly sponsored IGBP/IHDP project Land Use and Cover Change (LUCC). Some of these representative may fill dual roles, and other members may be co-opted if the need arises. The TT will meet annually, in conjunction with the researchers' annual meeting. It will be responsible for promoting the programme at international and national levels, obtaining funding for joint regional projects and supervising its expenditure, initiating and monitoring the implementation of joint projects, reviewing applications of projects to become affiliated with the Transect and overseeing the work of the Transect Officer.

A Kalahari Transect office will be established in one of the participating organizations, with good communications and secretarial support. A Transect Officer will be appointed for five years with the responsibility of coordinating the programme. Funding for coordination activities on the transect will be sought collectively; funding for individual projects will be the responsibility of their participants.

Sites

Six major research sites are proposed on the transect (Figure 5 and Table 3). In addition, there will be numerous locations at which data are collected once or periodically. These locations will be chosen so as to represent landscape facets and associated vegetation types typical of regional spatial heterogeneity. Sites at which human induced change has occurred or topography has noticeable influences on vegetation composition are examples of such locations.

The main sites have been selected on the basis of:

- Representing a major vegetation type
- Having security of access for the foreseeable future
- Potential for long term research
- On-site or nearby facilities for visiting scientists
- Linkage to existing or proposed research programmes.

A core set of mandatory data will be collected at each site on a routine basis for an initial period of three years (Table 4). These data will be owned jointly by transect participants, with a one-year first-publication right by the site principal investigators. The sites will be the major locations of manipulative experiments such as fertilization trials and transplant experiments. They will serve as bases for a network of periodically monitored plots covering the range in variation of landscape, vegetation and land use in their vicinity.

Coordination

Coordination is the responsibility of the Transect Officer. The coordination activities will include:

- A biannual newsletter, supplemented by ongoing Fax and E-mail links
- An annual research workshop for all Transect participants lasting for one week and located on the Transect. The workshops will initially address methods and training and will progress to research results and integration
- Travelling workshops aimed at making research results and their implications available to local resource managers and associated government structures
- Standardization of measurements, using shared protocols, training and equipment
- Maintenance and support of shared databases and models.

Figure 5

Proposed sites within countries which have expressed interest in the Kalahari Transect. In addition there will be a large number of sample locations which are periodically monitored, whose purpose is to cover the range in variation of land-scapes and land uses.

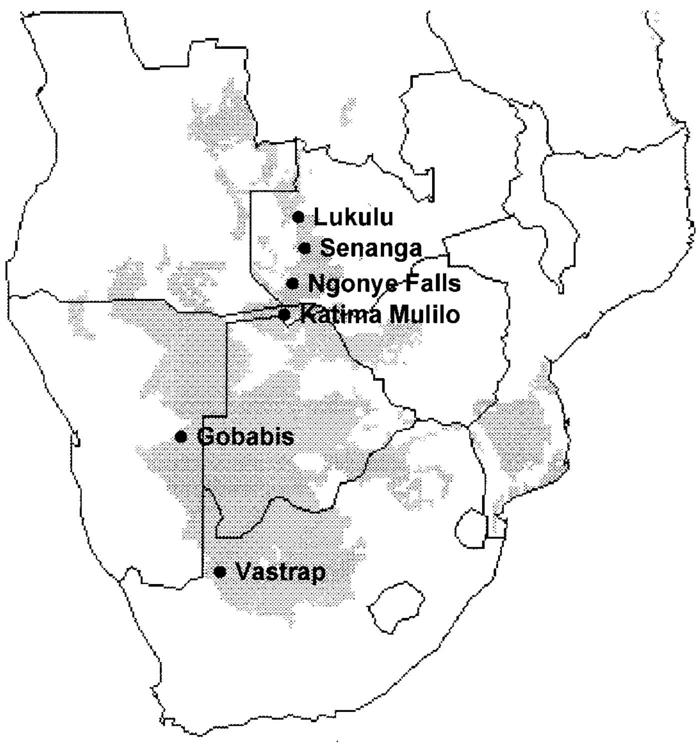


Table 3

Proposed site locations and their vegetation properties.

Lukulu, Zambia (14˚50′S, 24˚48′E)	Evergreen dense woodland (*Cryptosepalum exfoliatum, Brachystegia longifolia*). >85% cover, 12 m tall
Senanga, Zambia (15˚09′S, 23˚16′E)	Kalahari woodland (*Erythrophleum africanum, Brachystegia spiciformis, Diospyrus batocana*). 60% cover, 10 m tall
Ngonye Falls, Zambia (17˚20′S, 27˚30′E)	Dry Kalahari woodland (*Brachystegia spiciformis, Diospyrus batocana, Pterocarpus angolensis, Burkea africana*). 50% cover, 8 m tall
Katima Mulilo, Namibia (17˚38′S, 24˚04′E)	*Baikaea plurijuga* woodland. 50% cover, 14 m tall
Gobabis, Namibia (20˚00′S, 23˚25′E)	*Terminalia sericea, Acacia luderitzii* woodland. 25% cover, 8 m tall, 6m tall
Vastrap, South Africa (27˚44′S, 21˚25′E)	*Acacia haemotoxylon* open shrubland. 3% cover, 2 m tall.

Table 4

The minimum core data set to be collected by all sites.

Item	Description	Frequency	Reason
Soil physical & analysis	PSD, Bulk Density, C, N & P fractions, cations, CEC	Initial	Characterization, biogeochemical budgets
Short-term climate data Long-term climate (interpolated from climatic fields)	daily rainfall, temperature, RH monthly rainfall and temperature	5 years Initial	Characterization, modelling Characterization, modelling
Vegetation	Tree cover, species, biomass, grass cover, species, forb species	Initial	Characterization
Land cover	Landsat scene	5 years	Change detection, extrapolation
Tree increment and recruitment	Marked trees Ring counts	Annual	NPP, tree demography
Litterfall	40 0.5 x 0.5 m traps /site	Bimonthly	NPP
Soil respiration	10 CO_2 traps	Monthly	Belowground NPP
Trace gas emission (NO_x, VOC, CH_4, CO, N_2O)	Chamber and, tower measurements	Seasonal	Trace gas budgets - local to regional
Herbaceous layer production	10 m^2 clipping	Bimonthly	NPP, fuel load
Energy, water and CO_2 flux	Eddy correlation	Hourly	NEP, energy and water balance
Soil moisture modelling, phenology studies	Wet season/ Daily	Biogeochemical and soil moisture	
Solar radiation	Radiometers	Hourly	RS corrections, aerosol thickness, energy balance

CEC = Cation Exchange Capacity
NEP = Net Ecosystem Production
NPP = Net Primary Production
PSD = Particle Size Distribution
RH = Relative Humidity
RS = Remote Sensing

Integration

Three types of integration need to be achieved: spatial integration between sites, landscapes and regions; functional integration between different climatic, ecological and social processes; and integration between human component and ecological data at all scales.

Spatial integration from patch to landscape to regional scale will be achieved using Geographic Information System (GIS) modelling, relying partly on remotely-sensed data to drive a range of canopy spectral, tree/grass demographic and biophysical-geochemical models which will use the site data for calibration and validation purposes. Coarse-resolution (1 km) daily AVHRR data (10 day composites) will be used to drive phenology at a regional scale, and single-date coverage with high resolution (20 m) multispectral data will be used to map land cover and land cover change. The minimum set of data (Table 4) to be collected at the potential research sites also lends itself to a wide range of model validation and intercomparison studies. These studies and the design of the research along the Kalahari Transect feed explicitly into comparison of models operating at different scales, patch through to region.

Functional integration has been promoted by the deliberate selection of key questions which are interdisciplinary, and the focus on shared sites. It will be implemented in a suite of shared numerical models of ecosystem structure, function and change.

Human component and ecological data integration presents a challenge which is only recently being explored. Cognizance of the differences between the two types of data is fundamental to this level of integration with the emphasis being placed on recognition that shifting social and political mosaics have profound consequences for ecological processes and natural resource management, as well as *vice versa*. This level of integration provides an opportunity for the use and evaluation of new methods which have only been used in a handful of studies.

In addition to scientific integration, it is important that the findings of the Kalahari Transect research are integrated and disseminated in a manner appropriate for use by policy makers in the countries in which research is carried out. Integration in this sense could be achieved either by providing presentations or reports to relevant policy makers within the countries involved in research. Resource management policy makers from national through to local level would be the focus of such integration.

Capacity Building

Physical research capacity will be provided by the Transect sites, which will need to be equipped with a standard set of instruments and a minimum level of infrastructure. Work conducted temporarily in remote areas will require off-road vehicles. Shared models and data will require computers and software in participating institutions and adequate communications. Chemical and isotopic analysis will rely on existing centralized laboratory facilities. The capacity for advanced remote sensing and GIS exists in several institutes in the region.

Human capacity will be built in four ways:

- Training courses for Transect participants, especially with respect to data collection, analysis and reporting
- Short-term exchange of individuals between sites and institutions, regionally and internationally, to benefit from particular strengths and promote mentoring relationships
- Establishment of a GCTE Impact Center in the region, specifically tasked with making the linkage to policy
- Bursary support for students registered for degrees with their research based on the Transect.

Linkages to IGBP Programme Elements and Regional Research

The idea for the Kalahari Transect has arisen from a combination of international and regional initiatives. It is strongly oriented towards finding the area of common interest between global and local concerns. The central themes, of vegetation productivity and management and water resources are all high priorities in national research programmes. The tools available in the international research arena - such as models, advanced measurement technology and remote sensing - will complement the detailed local knowledge, providing benefits to both partners. The integration with national research agendas is achieved by having national representatives of the Kalahari Transect steering group, by working through national research institutions, and by locating research sites at stations linked to national research.

The Kalahari Transect, like other IGBP transect studies, is an Inter-Programme Element activity with relevance to several different IGBP Programme Elements and Famework Activities. It had its conceptual origin in the GCTE Programme Element, focused on terrestrial ecosystem - climate linkages, and has been administered through that project to date. The interests of GCTE are strongly embedded in Themes 1, 2 and 3 of the Transect.

The Southern African Fire Atmosphere Research Initiative (SAFARI) experiment, coordinated by IGAC, showed the importance of southern Africa for global trace gas and aerosol budgets, and particularly those related to pyrogenic and biogenic emissions. There is thus an ongoing interest within IGAC in experiments and monitoring in the region, linking to Theme 2 and 3 of the Transect. BAHC is concerned with water and energy balance at the land-atmosphere interface, with obvious linkages to Theme 4 of the Kalahari Transect as well as the delineation of plant functional types explored within Theme 1. The LUCC (IGBP/IHDP) is focused on understanding the causes and consequences of land cover and land use changes, in the context of global change. It has interests in Theme 3 of the Transect with additional support being given through Theme 2.

The Kalahari Transect will rely on the IGBP Data Information Systems (IGBP-DIS) for assistance in data collation, management and dissemination (in particular, for remotely sensed data), and the Global Analysis, Integration and Modelling (GAIM) Focus Activity for linking models developed on the transect to global models, and *vice versa*.

The Kalahari Transect is one of three global tropical aridity gradient transects: the other two are the Savannas in the Long Term (SALT) transect in West Africa, and the Northern Australian Tropical Transect (NATT) in Australia. These three act loosely as 'replicates' in a global experiment. They are part of a wider family of about twelve transects covering the major axes of potential global change (Koch *et al.* 1995). The formal structures for interaction will arise in due course.

The Kalahari Transect has been planned under the umbrella of the southern African START activities (a joint IGBP, IHDP and WCRP initiative to make global change research globally representative). It has been designed to compliment the Miombo Network, a similar regional IGBP Transect, based in the woodlands of south central Africa, and will share a site with the Miombo Network. A third regional IGBP activity, the subsistence pastoralism network of GCTE focus 3, will use the opportunities provided by the Kalahari Transect and Miombo Network to conduct its studies and experiments.

These are the most obvious and explicit linkages to other IGBP activities, but do not exclude the possibility of unforeseen linkages to other IGBP Programme Elements, such as Past Global Changes (PAGES) and Joint Global Ocean Flux Study (JGOFS). Good coordination with the IGBP Programme Elements is to be achieved by having members of the Kalahari Transect Steering Group who are also participants of the affected Programme Elements.

Expected Benefits

Benefits will be accrued at four scales: local, national, regional and global.

At the local scale, the fundamental measurements of tree growth rate, grass production and ground water recharge will assist with resource management in the vicinity of the research sites. The mode of research at the sites will be participatory, improving the bilateral transfer of knowledge between the local community and researchers.

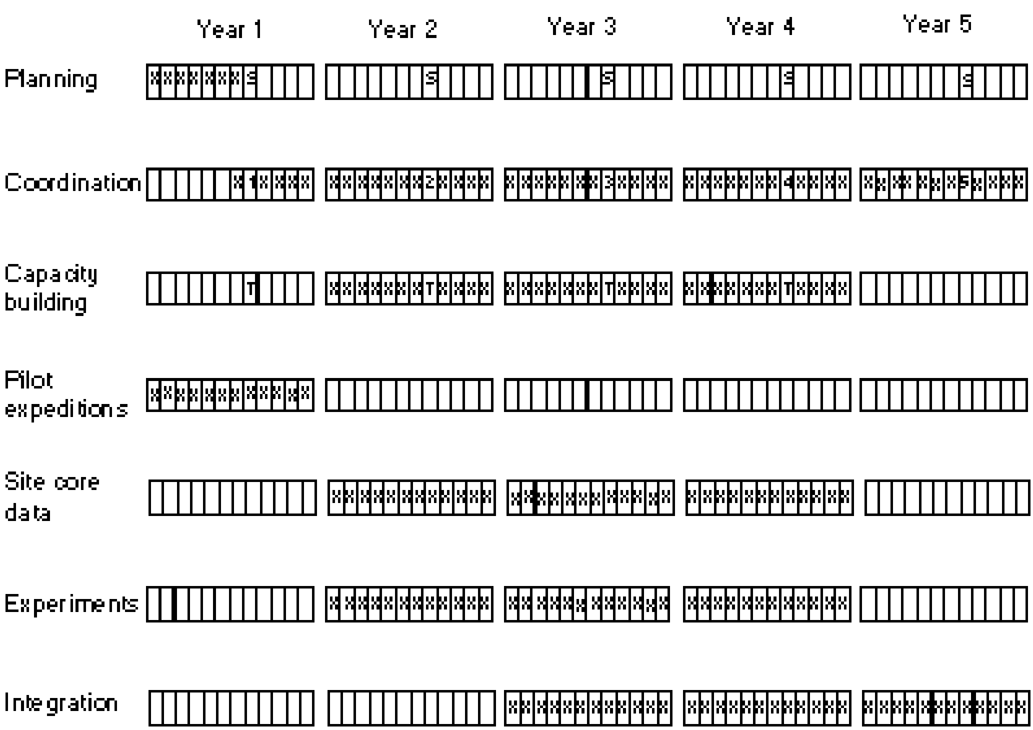
Land cover maps and resource dynamics models generated by the programme will assist national level planning and policy. They will help to establish, for instance, the sustainable levels of resource exploitation, the scope and nature of desertification and the sizes of trace gas sources and sinks required by the Framework Convention on Climate Change. A major benefit at the national scale will be research capacity building, both in terms of human resources and equipment.

The region will benefit from the synergy resulting from pooling the efforts of the sparse regional research community and attracting developed nation scientists to work on the Transect. Some of the processes under investigation, such as the impact on climate, may have regional implications. Understanding of these processes will facilitate cross border management of ecosystems as a whole and not as a vegetation type within a country. The sharing of remotely-sensed images, GIS databases and models regionally will increase their cost-effectiveness. The high level of co-operation and data interchange between scientists from countries within the subregion will enable significant bridging between the paradigms of scientists, resource managers and policy makers in different countries who until now have been operating semi-independently of one another.

The global benefits come from the improved understanding of an extensive but poorly-understood ecosystem. The Kalahari Transect is one of three savanna transects identified as research priorities by the IGBP. The benefits include improved calibration of satellite derived land cover products, better quantification of tropical carbon sequestration and trace gas emissions and improved land surface parameterizations for global climate models.

Schedule

Scheduling of activities for the Kalahari Transect research initiative.



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Acronyms and Abbreviations

AVHRR	Advanced Very High Resolution Radiometer
BAHC	Biospheric Aspects of the Hydrological Cycle (IGBP)
CEC	Cation Exchange Capacity
DGVM	Dynamic Global Vegetation Model (GCTE)
DIS	Data and Information System (IGBP)
FAO	Food and Agriculture Organization (UN)
GAIM	Global Analysis, Interpretation, and Modelling (IGBP)
GCTE	Global Change and Terrestrial Ecosystems (IGBP)
GIS	Geographic Information System
ICSU	International Council of Scientific Unions
IGAC	International Global Atmospheric Chemistry Project (ICAGP/IGBP)
IGBP	International Geosphere-Biosphere Programme (ICSU)
IHDP	International Human Dimensions Programme on Global Environmental Change
ITCZ	Inter Tropical Convergence Zone
JGOFS	Joint Global Ocean Flux Study (IGBP/SCOR)
LOICZ	Land-Ocean Interactions in the Coastal Zone (IGBP)
LUCC	Land-Use/Cover Change (IGBP/IHDP)
NATT	Northern Australian Tropical Transect
NEP	Net Ecosystem Production
NPP	Net Primary Production
PAGES	Past Global Changes (IGBP)
PSD	Particle Size Distribution

RH	Relative Humidity
RS	Remote Sensing
SALT	Savannahs in the Long Term
SC	Scientific Committee
SCOR	Scientific Committee on Oceanic Research
SSC	Scientific Steering Committee
START	Global Change System for Analysis, Research and Training (IGBP)
TT	Task Team
UN	United Nations
UNESCO	United Nations Educational, Scientific and Cultural Organisation
USDA	United States Department of Agriculture
WCRP	World Climate Research Programme
WMO	World Meteorological Organization

Appendix I

Members of the Kalahari Transect Planning Team

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List of IGBP Publications

IGBP Report Series. List with Short Summary

IGBP Reports are available free of charge from:
IGBP Secretariat, Royal Swedish Academy of Sciences, Box 50005, S-104 05 Stockholm, Sweden.

*Report Nos. 1-11 and reports marked * are no longer available.*

No. 12
The International Geosphere-Biosphere Programme: A Study of Global Change (IGBP). The Initial Core Projects (1990). IGBP Secretariat, Stockholm, 330 pp.
The IGBP science plan is composed of research projects aimed at answering a number of key questions related to global change, through the establishment of Core Projects on the distinct sub-components of the Earth system, and related activities on data systems and research centres. An implementation strategy provides for its fulfilment.

No. 13
Terrestrial Biosphere Exchange with Global Atmospheric Chemistry. Terrestrial Biosphere Perspective of the IGAC Project: Companion to the Dookie Report. Report on the Recommendations from the SCOPE/IGBP Workshop on Trace-Gas Exchange in a Global Perspective. Sigtuna, Sweden, 19-23 February, 1990. Edited by P.A. Matson and D.S. Ojima (1990). IGBP Secretariat, Stockholm, 103 pp.
The Sigtuna workshop contributed to the development of a scientific action plan on terrestrial ecosystem gas exchange, complementing the International Global Atmospheric Chemistry Project (an IGBP Core Project) in areas of natural variability, boreal regions, global integration and modelling of fluxes, and trace gas fluxes in mid-latitude ecosystems.

No. 14
Coastal Ocean Fluxes and Resources. Report of a CP2 Ad Hoc Workshop, Tokyo, Japan, 19-22 September 1989. Edited by P. Holligan (1990). IGBP Secretariat, Stockholm, 53 pp.
The focus of IGBP Coordinating Panel 2 on Marine Biosphere-Atmosphere Interactions is the elucidation and prediction of the feedback loops between climate and ocean biogeochemistry under conditions of significant anthropogenic changes to the trace gas composition of the atmosphere. The workshop concentrated on global change and the coastal oceans.

No. 15
Global Change System for Analysis, Research and Training (START). Report of a Meeting at Bellagio, December 3-7, 1990. Edited by J.A. Eddy, T.F. Malone, J.J. McCarthy and T. Rosswall (1991). IGBP Secretariat, Stockholm, 40 pp. Also available in Spanish and French.
START is a plan for the development of an international network of regional research centres and sites to gather data and study global change problems in their regional contexts. These regions are identified. Issues to be addressed are: How changes in land use and industrial practices alter the water cycles, atmospheric chemistry and ecosystems dynamics; how regional changes affect global biogeochemical cycles and climate; and how global change leads to further regional change in the biospheric life support system.

No. 16
Report from the IGBP Regional Meeting for South America. São José dos Campos, SP, Brazil, 5-9 March 1990 (1991). IGBP Secretariat, Stockholm, 58 pp.
The workshop discussed, in a South American context, past global changes, the effects of climate change on terrestrial ecosystems, the role of ocean processes in global change, land transformation and global change processes, the importance of the Andes for general circulation models, and regional research centres. Recommendations promote the role of South American science in global change research.

No. 17
Plant-Water Interactions in Large-Scale Hydrological Modelling. Report of a Workshop, Vadstena, Sweden, 5-8 June 1990 (1991). IGBP Secretariat, Stockholm, 44 pp.
The workshop addressed plant-water interrelationships at landscape to continental scales: the spatial pattern at landscape level of the dynamics of water flows and waterborne fluxes of dissolved and suspended mater; plant/vegetation characteristics and properties affecting return flow to the atmosphere; methodological issues of large-scale modelling; research in humid tropical, semi-arid and temperate zones.

No. 18:1
The Recommendations of the Asian Workshop, New Delhi, India, February 11-15, 1991. Edited by R.R. Daniel (1991). IGBP Secretariat, Stockholm, 36 pp.
Recommendations of the Workshop address issues of prime concern to Asian countries, with reports and recommendations from Working Groups on IGBP Core Projects and key activities.

No. 18:2

Proceedings of the Asian Workshop, New Delhi, India, 11-15 February 1991. Edited by R.R. Daniel and B. Babuji. Madras, Committee on Science and Technology in Developing Countries (COSTED) and the Indian National Committee for the IGBP (1992). Madras, COSTED, Asia Regional Office, 152 pp.
The Proceedings include 19 papers on Earth system research and global environmental change in Asia, and national reports on global change programmes.

No. 19*

PAGES Past Global Changes Project: Proposed Implementation Plans for Research Activities. Edited by J.A. Eddy (1992). IGBP Secretariat, Stockholm, 112 pp.
The Past Global Changes (PAGES) project will secure better understanding of the natural and human-induced variations of the Earth system in the past, through studies of both natural and written records. Focus is on changes within two temporal streams: global changes for the period 2000 BP, and changes through a full glacial cycle. Implementation plans address: solar and orbital forcing and response, Earth system processes, rapid and abrupt global changes, multi-proxy mapping, palaeoclimatic and palaeoenvironmental modelling, advances in technology, management of palaeodata, and improved chronologies for palaeoenvironmental research.

No. 20*

Improved Global Data for Land Applications: A Proposal for a New High Resolution Data Set, Report of the Land Cover Working Group of IGBP-DIS. Edited by J.R. Townshend (1992). IGBP Secretariat, Stockholm, 75 pp.
This report outlines a proposal to produce a global data set at a spatial resolution of 1 km derived from the Advanced Very High Resolution Radiometer primarily for land applications. It defines the characteristics of the data set to meet a number of requirements of IGBP's science plan and outlines how it could be created. It presents the scientific requirements for a 1 km data set, the types and uses of AVHRR data, characteristics of a global 1 km data set, procedures, availability of current AVHRR 1 km data, and the management needs.

No. 21*

Global Change and Terrestrial Ecosystems: The Operational Plan. Edited by W.L. Steffen, B.H. Walker, J.I. Ingram and G.W. Koch (1992). IGBP Secretariat, Stockholm, 97 pp.
The objectives of GCTE are: to predict the effects of changes in climate, atmospheric composition, and land use on terrestrial ecosystems, including agricultural and production forest systems, and to determine how these effects lead to feedbacks to the atmosphere and the physical climate system. The research plan is divided into four foci: ecosystem physiology, change in ecosystem structure, global change impact on agriculture and forestry, and global change and ecological complexity. Research strategies are presented.

No. 22
Report from the START Regional Meeting for Southeast Asia. Arranged by the International Geosphere-Biosphere Programme: A Study of Global Change (IGBP), in collaboration with Human Dimensions of Global Environmental Change (HDGEC) Programme (1992). IGBP Secretariat, Stockholm, 114 pp.
The report presents general recommendations on global change research in the region, thematic studies relating to IGBP Core Project science programmes, global change research in studies of eight countries in the area, and conclusions from working groups on the participation of the region in research under the five established IGBP Core Projects and the related HDGEC programme.

No. 23
Joint Global Ocean Flux Study: Implementation Plan. Jointly published with the Scientific Committee on Oceanic Research (SCOR) (1992). IGBP Secretariat, Stockholm, 78 pp. (JGOFS Report No. 9)
The Report describes how the aims of JGOFS are being, and will be, achieved through global synthesis, large scale surveys, process studies, time series studies, investigations of the sedimentary record and continental margin boundary fluxes, and the JGOFS data management system.

No. 24
Relating Land use and Global Land-Cover Change: A Proposal for an IGBP-HDP Core Project. A report from the IGBP/HDP Working Group on Land-Use/Land-Cover Change. Edited by B. L. Turner, R. H. Moss, and D. L. Skole (1993. IGBP Secretariat, Stockholm, 65 pp. (Human Dimensions of Global Environmental Change Programme, HDP Report No. 5)
The report presents the main findings of the joint Working Group of the IGBP and the International Social Science Council on Land-Use/Land-Cover Change; it describes the research questions defined by the group and identifies the next steps needed to address the human causes of global land-cover change and to understand its overall importance. It calls for the development of a system to classify land-cover changes according to the socioeconomic driving forces. The knowledge gained will be used to develop a global land-use and land-cover change model that can be linked to other global environmental models.

No. 25
Land-Ocean Interactions in the Coastal Zone (LOICZ) Science Plan. Edited by P.M. Holligan and H. de Boois, with the assistance of members of the LOICZ Core Project Planning Committee (1993). IGBP Secretariat, Stockholm, 50 pp.
The report describes the new IGBP Core Project, giving the scientific background and objectives, and the four research foci. These are: the effects of global change (land and freshwater use, climate) on fluxes of materials in the coastal zone; coastal biogeomorphology and sea-level rise; carbon fluxes and trace gas emissions on the coastal zone; economic and social impacts of global change on coastal systems. The LOICZ project framework includes data synthesis and modelling, and implementation plans cover research priorities and the establishment of a Core Project office in the Netherlands.

No. 26

Towards a Global Terrestrial Observing System (GTOS): Detecting and Monitoring Change in Terrestrial Ecosystems. Report of the Fontainebleau Workshop. Edited by O. W. Heal, J.-C. Menaut and W. L. Steffen (1993). Paris: MAB, 71 pp. (UNESCO Man and the Biosphere Digest 14)

The Fontainebleau Workshop, July 1992, defined a strategy to initiate a global terrestrial monitoring system for the IGBP project on Global Change and Terrestrial Ecosystems, the French Observatory for the Sahara and the Sahel, and the UNESCO Man and the Biosphere programme, in combination with other existing and planned monitoring programmes. The report reviews existing organisations and networks, and drafts an operational plan.

No. 27*

Biospheric Aspects of the Hydrological Cycle. The Operational Plan. 1993. Edited by BAHC Core Project Office, Berlin (1993). IGBP Secretariat, Stockholm, 103 pp.

A presentation of the mandate, scope, principal subjects and structure of the BAHC research plan is followed by a full description of the four BAHC Foci: 1) Development, testing and validation of 1-dimensional soil-vegetation-atmosphere transfer (SVAT) models; 2) Regional-scale studies of land-surface properties and fluxes; 3) Diversity of biosphere-hydrosphere interactions; 4) The Weather Generator Project.

No. 28*

The IGBP in Action: The Work Plan 1994-1998. 1994. IGBP Secretariat, Stockholm, 151 pp.

This Report provides an overview of the global change research to be carried out under the aegis of the International Geosphere-Biosphere Programme over the next five years. It represents a follow-up to IGBP Report No. 12 (1990) that described the basic structure of the global change research programme, the scientific rationale for its component Core Projects and proposals for their development. The IGBP Core Projects and Framework Activities present their aims and work programme in an up-to-date synthesis of their science, operational and implementation plans.

No. 29

Africa and Global Change. A Report from a Meeting at Niamey, Niger, 23-27 November, 1992. (1994). IGBP Secretariat, Stockholm. (English and French under the same cover)55 pp.

A summary is given of the conference arranged by the Global Change System for Analysis, Research and Training (START) on behalf of the IGBP, the Human Dimensions of Global Environmental Change Programme (HDP), and the Joint Research Centre of the Commission of the European Communities (CEC) that describe the global change scientific research situation in Africa today.

No. 30

IGBP Global Modelling and Data Activities, 1994-1998. 1994. Strategy and Implementation Plans for Global Analysis, Interpretation and Modelling (GAIM) and the IGBP Data and Information System (IGBP-DIS). IGBP Secretariat, Stockholm, 86 pp.
This report sets out the goals and directions for GAIM and IGBP-DIS over the next five years, expanding on the recent overview of their activities within IGBP Report 28 (1994). It describes the work within IGBP-DIS directed at the assembly of global databases of land surface characteristics, and within GAIM, directed at modelling the global carbon cycle and climate-vegetation interaction.

No. 31

African Savannas and the Global Atmosphere. Research Agenda. 1994. Report of a joint IGBP/START/IGAC/GCTE/GAIM/DIS Workshop on African Savannas, Land use and Global Change: Interactions of Climate, Productivity and Emissions, 1-5 June 1993, Victoria Falls, Zimbabwe. Edited by C. Justice, B. Scholes and P. Frost. IGBP Secretariat, Stockholm, 53 pp.
The workshop focused on interactions between African savannas and the global atmosphere, specifically addressing land-atmosphere interactions, with emphasis on sources and sinks of trace gases and aerosol particles. The report discusses the ecology of African savannas, the research issues related to carbon sequestration, ongoing and proposed activities, and gives a research agenda.

No. 32

International Global Atmospheric Chemistry (IGAC) Project. The Operational Plan. 1994. IGBP Secretariat, Stockholm, 134 pp.
The goals of IGAC are to: develop a fundamental understanding of the processes that determine atmospheric composition; understand the interactions between atmospheric chemical composition and biospheric and climatic processes, and predict the impact of natural and anthropogenic forcings on the chemical composition of the atmosphere. The Operational Plan outlines the organisation of the project. The plan describes the seven Foci, their related Activities and Tasks, including for each the scientific rationale, the goals, strategies.

No. 33

Land-Ocean Interactions in the Coastal Zone. Implementation Plan. 1995. Edited by J.C. Pernetta and J.D. Milliman. IGBP Secretariat, Stockholm, 215 pp.
LOICZ is that component of the IGBP which focuses on the area of the Earth's surface where land, ocean and atmosphere meet and interact. The implementation plan describes the research , its activities and tasks, and the management and implementation requirements to achieve LOICZ 's science goals. These are, to determine at regional and global scales: the nature of these dynamic interactions, how changes in various compartments of the Earth system are affecting coastal zones and altering their role in global cycles, to assess how future changes in these areas will affect their use by people, and to provide a sound scientific basis for future integrated management of coastal areas on a sustainable basis.

No. 34

BAHC-IGAC-GCTE Science Task Team. Report of First Meeting. Massachusetts Institute of Technology, Cambridge, Massachusetts, USA, 10-12 January, 1994. 1995. IGBP Secretariat, Stockholm, 45 pp.

The Science Task Team discussed and developed recommendations for multi-Core Project collaboration within the IGBP under three headings: process studies in terrestrial environments, integrated modelling efforts, and partnership with developing country scientists. Three interrelated themes considered under process studies are: transects and large-scale land surface experiments, fire, and wetlands. Methods for implementation and projects are identified.

No. 35

Land-Use and Land-Cover Change. Science/Research Plan. 1995. Edited by B. L. Turner II, D. Skole, S. Sanderson, G. Fischer, L. Fresco and R. Leemans. IGBP Secretariat, Stockholm, HDP Secretariat, Geneva, (IGBP Report 35/HDP Report 7) 132 pp.

The Science/Research Plan presents land-use and land-cover change and ties it to the overarching themes of global change. It briefly outlines what is currently known and what knowledge will be necessary to address the problem in the context of the broad agendas of IGBP and HDP. The three foci address by the plan are: (i) land-use dynamics, land-cover dynamics - comparative case study analysis, (ii) land-cover dynamics - direct observation and diagnostic models, and (iii) regional and global models - framework for integrative assessments.

No. 36

The IGBP Terrestrial Transects: Science Plan. 1995. Edited by G.W. Koch, R.J. Scholes, W.L. Steffen, P.M. Vitousek and B.H. Walker. IGBP Secretariat, Stockholm, 53. pp. Also available in Chinese.

The IGBP Terrestrial Transects are a set of integrated global change studies consisting of distributed observational studies and manipulative experiments coupled with modelling and synthesis activities. The transects are organised geographically, along existing gradients of underlying global change parameters, such as temperature, precipitation, and land use. The initial transects are located in four key regions, where the proposed transects contribute to the global change studies planned in each region.

No. 37

IGBP Northern Eurasia Study: Prospectus for an Integrated Global Change Research Project. 1996. Edited by W.L. Steffen and A.Z. Shvidenko. IGBP Secretariat, Stockholm, 95 pp. Also available in Russian.

This report was prepared by scientists representing BAHC, IGAC, and GCTE. It is a prospectus for an integrated hydrological, atmospheric chemical, biogeochemical and ecological global change study in the tundra/boreal region of Northern Eurasia. The unifying theme of the IGBP Northern Eurasia Study is the terrestrial carbon cycle and its controlling factors. Its most important overall objective is to determine how these will alter under the rapidly changing environmental conditions.

No. 38

Natural Disturbances and Human Land Use in Dynamic Global Vegetation Models. A Report of a Workshop Co-convened by the GAIM, GCTE, LUCC, and IGBP-DIS Programme Elements of the IGBP. 1997. Edited by F.I. Woodward and W.L. Steffen. IGBP Secretariat, Stockholm, 49 pp.

This report summarises the findings and recommendations of an International Geosphere-Biosphere Programme (IGBP) Workshop which aimed to develop an approach to modelling landscape-scale disturbances in the context of global vegetation change.

No. 39

Modelling the Transport and Transformation of Terrestrial Materials to Freshwater and Coastal Ecosystems. A Workshop Report and Recommendations for IGBP Inter-Programme Element Collaboration. 1997. Edited by C.J. Vörosmarty, R. Wasson and J. Richey. IGBP Secretariat, Stockholm, 84 pp.

This report is the major product of a three-day workshop entitled: "Modelling the Delivery of Terrestrial Materials to Freshwater and Coastal Ecosystems" held in Durham, NH, USA from 5-7 December 1994.

No. 40

Global Ocean Ecosystem Dynamics. Science Plan. 1997. Final editing by: R. Harris and the members of the GLOBEC Scientific Steering Committee (SSC). IGBP Secretariat, Stockholm, 83 pp.

Based on a draft plan written by the SCOR/IOC SSC for GLOBEC in 1994. That plan was itself based on a number of scientific reports generated by GLOBEC working groups and on discussions at the GLOBEC Strategic Planning Conference (Paris, July 1994). This document was presented to the Executive Committee of the Scientific Committee on Ocean Research (SC-SCOR) for approval (Cape Town, November 14-16 1995), and was approved by the SC-IGBP at their meeting in Beijing in October 1995. The members of the SCOR/IGBP CPPC were: B.J. Rothschild (Chair), R. Muench (Chief Editor), J. Field, B. Moore, J. Steele, J.-O. Strömberg, and T. Sugimoto.

No. 41

The Miombo Network: Framework for a Terrestrial Transect Study of Land-Use and Land-Cover Change in the Miombo Ecosystems of Central Africa. Conclusions of a meeting of the Miombo Network Workshop held in Zomba, Malawi, December 1995. Edited by P.V. Desanker, P.G.H. Frost, C.O. Justice, and R.J. Scholes. 1997. IGBP Secretariat, Stockholm, 109 pp.

This report describes the strategy for the Miombo Network Initiative, developed at an IGBP intercore-project workshop in Malawi in December 1995 and further refined during the Land Use and Cover Change (LUCC) Open Science Meeting in January 1996 and through consultation and review by the LUCC Scientific Steering Committee (SSC).

No. 42

The Kalahari Transects: Research on Global Change and Sustainable Development in Southern Africa. Edited by R.J. Scholes and D.A.B. Parsons. IGBP Secretariat, Stockholm, 61 pp.
The Kalahari Transect is proposed as one of IGBPs Transects. It is located so as to span the gradient between the arid subtropics and the moist tropics in southern Africa, a zone potentially susceptible to changes in the global precipitation pattern.

Book of Abstracts

Book of Abstracts. Natural and Anthropogenic Changes: Impacts on Global Biogeochemical Cycles. Asian Change in the Context of Global Change. Beijing, 23-25 October, 1995. IGBP Secretariat, Stockholm, 107 pp.
This book of abstracts is a result of materials presented at the scientific symposium held in conjunction with the Fourth Scientific Advisory Council for the IGBP (SAC) held in Beijing, 23-25 October, 1995.

IGBP Booklet*

A Study of Global Change. 1989. Edited by IGBP Secretariat, Stockholm, 9pp.

Global Change: Reducing Uncertainties

Prepared by P. Williamson, with editorial assistance from the Scientific Committee for the IGBP (June, 1992; reprint August 1993), IGBP Secretariat, Stockholm, 40 pp.

IGBP Directory

IGBP Directory. No. 1, February 1994
IGBP Directory. No. 2, October 1995
IGBP Directory Update: 1996, April 1996
IGBP Directory 1997, February 1997

IGBP NewsLetter

Global Change NewsLetter. Quarterly, No. 1, 1989 (latest issue No. 30, June 1997)