10. Pastoral surveillance system and feed inventory in the Sahel

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10.1 INTRODUCTION

The Sahelo-Saharian region is characterized by vast grazing areas and high spatio-temporal rainfall variability. A large fraction of the human population subsists on extensive livestock systems characterized by extensive inter-seasonal movements linked to the availabilities of two natural resources – water and pasture.

The expansiveness of the pastoral spaces, the difficult access to pastoral resources and the very low demographic density require a different mode of food security and population vulnerability monitoring from that in areas where livestock are sedentary. In this setting, GIS and remote-sensing data must be employed because they enable efficient monitoring of pastoral resources. Pastoral food security is dependent on livestock and thus the livestock feed balance in the region.

Over several years, ACF International (Action Contre la Faim), together with the national early warning systems in Mali and Niger, has developed a Pastoral Early Warning System consisting of GIS-based tools that assess pastoral population vulnerability. Recent improvements in the system make it possible to assess pastoral population vulnerability on a regional scale, contributing to early warning systems in Sahelo–Saharian pastoral areas.

10.2 INPUTS

10.2.1 General

The Pastoral Early Warning System developed by ACF has the potential to contribute to livestock feed inventories in the Sahelo-Saharian areas because it is specifically designed to monitor feed availability for pastoral livestock. The system makes extensive use of near real-time satellite imagery, ground data validation and livestock movement maps. Computer-based tools produce user-friendly maps which enable quantitative, dynamically changing feed assessments. The system has proved to be quite efficient in recent years for identifying vulnerable situations for pastoralists, but there is still room for further improvements.

10.2.2 Remote-sensing data

The pastoral early warning system developed by ACF utilizes NDVI (Normalized Difference Vegetation Index) and DMP (Dry Matter Productivity) data products that are distributed by the Flemish Technologic Research Institute (VITO). These products are derived from the moderate-resolution VEGETATION sensors on the SPOT 4 and SPOT 5 satellites launched in 1998 (Table 10.1). Daily imagery is produced on a global scale at 1 km x 1 km resolution. In

TABLE 10.1
SPOT-VEGETATION spectral bands

Bands	Colour	Wavelengths
B0	Blue	0.430–0.740 mm
B2	Red	0.610–0.680 mm
B3	Near Infra-Red (NIR)	0.780–0.890 mm
SWIR	Short Wave Infra-Red (SWIR)	1.580–1.750 mm

order to eliminate the cloud cover, a compositing operation is realized over a 10-day period giving decadal synthesis: three decades per months (1–10, 11–20, 21–end of concerned month) and 36 decades a year.

The algorithm details can be found on the following web pages:

- http://web.vgt.vito.be/documents/BioPar/g2-BP-RP-BP053-ProductUserManual-DMPV0-I1.00.pdf
- http://www.vgt4africa.org/PublicDocuments/S10-NDVI-Product-Sheet.pdf

10.3 METHODOLOGY

10.3.1 General

The ACF's system employs a GIS overlay approach that integrates spatial data which characterize pastoral physical resources and livestock movements. The system assesses gross biomass production as well as the accessibility of the biomass in relationship to water availability and pastoral movements throughout the seasons (Figue 10.1). In the north Sahel, biomass is the primary variable which must be considered when quantifying feed availability, given that forage is directly derived from biomass.

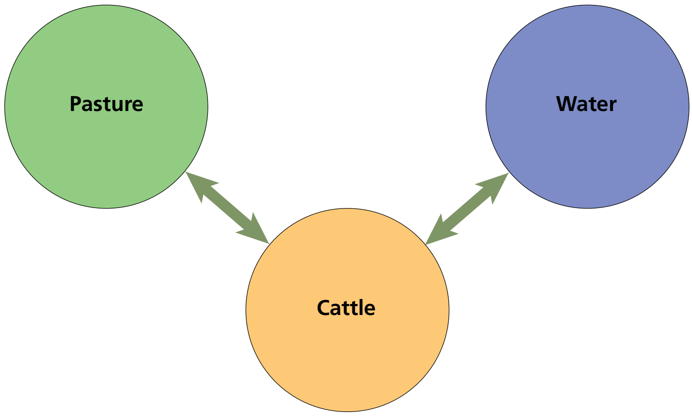
Depending on the area and the season, water may or may not be available within a feasible proximity to the grazing areas. Cattle must move to access water at sufficient frequencies while also accessing pasture. Therefore, monitoring of water availability and livestock movements to pastures are both fundamental to an accurate feed inventory. Biomass and water are integrated with additional variables such as livestock distributions and topography to produce assessments of forage availability.

10.3.2 Two-step process

Two basic steps are required in the feed inventory:

1. Biomass monitoring
2. Map overlaying
   a. Water maps
      i. Surface water
      ii. Wells and boreholes
   b. Concentration areas mapping
   c. Livestock distribution maps
   d. Topography

FIGURE 10.1
Integration of pasture, water and cattle distribution map data



10.3.3 Biomass monitoring and the BioGenerator Tool

In the north Sahelian context, the pasture growing season ends a few weeks after the end of the rainy season, occurring in autumn. After that, it is possible to determine the pasture balance of the area for the current year. A computer-based tool integrating satellite images has been developed by ACF called *BioGenerator*. This tool enables the calculation of available vegetation matter throughout the whole region at the end of the rainy season. The resulting outputs are the total dry matter production of the year, expressed as kg of dry matter per hectare, and the departure from the inter-annual average, called anomaly of dry matter production expressed in percentage.

The following is excerpted from an unpublished user manual written by E. Fillol.

Folder structure

The folder structure of input and output data is shown in Figure 10.2a. The *In* folder contains the input data while the *Out* folder receives output data.

Input data

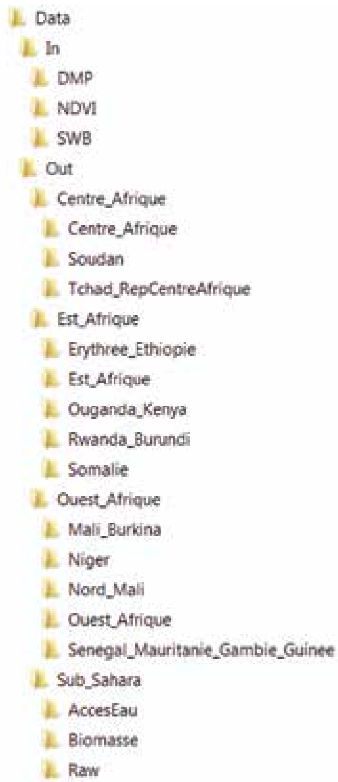
VITO provides ACF-Spain with a specific decadal data product called DMP (Dry Matter Productivity). These data are automatically loaded onto the ACF-Spain server. Access to the data is through the following contacts:

- Alejandro Canet Rodriguez : acanet@achesp.org
- Frédéric Ham : f.ham@achesp.org

The first step consists of loading the data via ftp protocol, unzipping the archives and copying them into the appropriate folder. Two fields are necessary to perform the processing: DMP and NDVI (Table 10.2).

The unzipped DMP and NDVI files are copied respectively into folders *Data/In/DMP/* and *Data/In/NDVI/*. The .img files are the image data in raw format and .hdr files are the header files.

FIGURE 10.2a
Work Folder structure of BioGenerator 2 (v2.1)



BioGenerator 2 (v2.1) can function if one or more decades are missing. In this case, a message identifying the missing decades will warn the user but the calculation will be processed. The value of missing decades will then be linearly interpolated.

BioGenerator parameters

The parameters that can be changed by the user include the following:

- Biomass anomaly spatial filter function parameters. These parameters are the size and the number of passes of this circular filter. The first number gives the number

TABLE 10.2
Zipped and Unzipped folder nomenclature and file size

Products	Zipped archives	Unzipped archives	Destination folder	Image file size .img [bytes]
DMP	DMP_aaaammjj.zip	DMP_aaaammjj.img DMP_aaaammjj.hdr	Data/In/DMP/	56 925 660
NDVI	NDVI_aaaammjj.zip	NDVI_aaaammjj.img NDVI_aaaammjj.hdr	Data/In/NDVI/	28 462 830

of passes of the filter and the second gives the radius in pixels of the filter window. The filter can also be deactivated. This biomass anomaly map filtering quickly shows local anomaly variations.

- The integration period is defined by the first and last decades. The input values are the decade's position between 1 and 36 (see Table 10.3). In the event that the last decade's value is higher than the first decade's value, the integration goes until the next year's decade. For example, default values 7 and 6 mean the integration calculated for year x is done from decade 01/03 of year x until decade 21/02 of year x+1 (as in Table 10.3). The integration period must be equal to or higher than two decades.

These parameters are accessible by the user and can be modified. Otherwise, default values will be used along with the decade's start date.

Program execution

The program is executed and an execution window opens showing the used parameters, the used decades and the number of years that are considered from this series (Figure 10.2b).

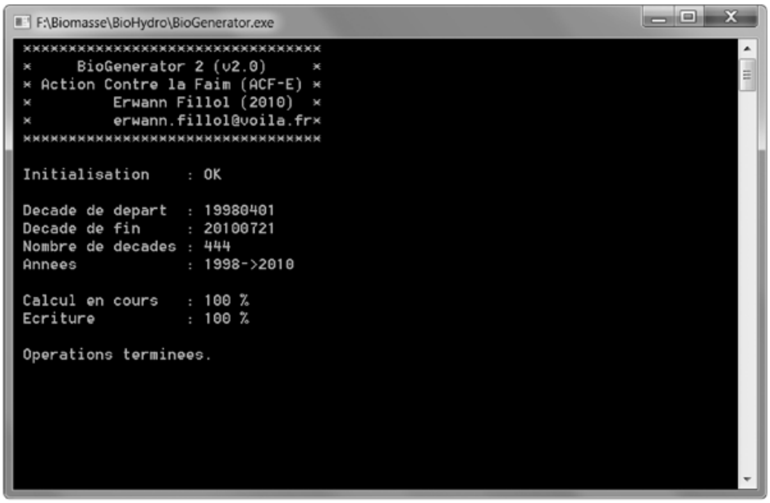
A counter shows the progress of the calculation in percent. Two calculation phases follow one another: the first phase is the calculation on the global sub-Saharan window. The second phase processes the output windows and sub-windows and performs output file writing.

Depending on the number of decades, the processor and hard disk speed, the calculation can take two to three hours on a standard PC. The minimum required configuration mainly concerns the RAM available with a minimum of 1 GB and also disk space with a minimum of 3 GB per years considered.

TABLE 10.3
Matching between decade number and decade start date

Decade number	Date	Decade number	Date	Decade number	Date
1	01/01	13	01/05	25	01/09
2	11/01	14	11/05	26	11/09
3	21/01	15	21/05	27	21/09
4	01/02	16	01/06	28	01/10
5	11/02	17	11/06	29	11/10
6	21/02	18	21/06	30	21/10
7	01/03	19	01/07	31	01/11
8	11/03	20	11/07	32	11/11
9	21/03	21	21/07	33	21/11
10	01/04	22	01/08	34	01/12
11	11/04	23	11/08	35	11/12
12	21/04	24	21/08	36	21/12

FIGURE 10.2b
BioGenerator 2 (v2.1) execution window



Output data

BioGenerator produces biomass quantity, expressed in kg of dry matter per hectare [kg.ha^{-1}] for each year and also for the mean value of the calculation period. It also produces annual anomalies [percent] on 13 different geographic windows. The output data are in GEOTIFF (.tif) format in geographic coordinates Lat/Lon WGS-84 with a spatial resolution of 1 km. Table 10.4 shows the definitions of these geographic windows.

Biomass quantity

A file is produced for each geographic window and sub-window containing the biomass quantity produced for the year, and another file is produced containing the mean value for the entire time series. Biomass is expressed in kilograms of dry matter per hectare [kg.ha^{-1}]. Null productivity is reported in desert areas and water. The annual biomass quantity is calculated as the sum of daily productivity during the growing season [kg.ha^{-1}.day^{-1}]. The growing season can be defined by the user. By default, it starts with the first decade of March and ends with the last decade of February of the following year.

The data set for the current year's growing season might be incomplete. If some decades are missing the biomass quantity calculation period is completed for the missing period using the observed average productivity. The biomass quantity map (Figure 10.3) for the current year (e.g. 2010) is an estimation of the total production dependent on the available decades.

Biomass anomaly

An output file is produced for each window and sub-window providing the biomass production anomaly (Figure 10.4), which is the difference between the biomass productivity of the year and the mean value calculated for the whole time series. The anomaly is expressed in percent.

TABLE 10.4
Coordinates of geographic windows and sizes of windows in pixels of BioGenerator 2 (v2.1) output data

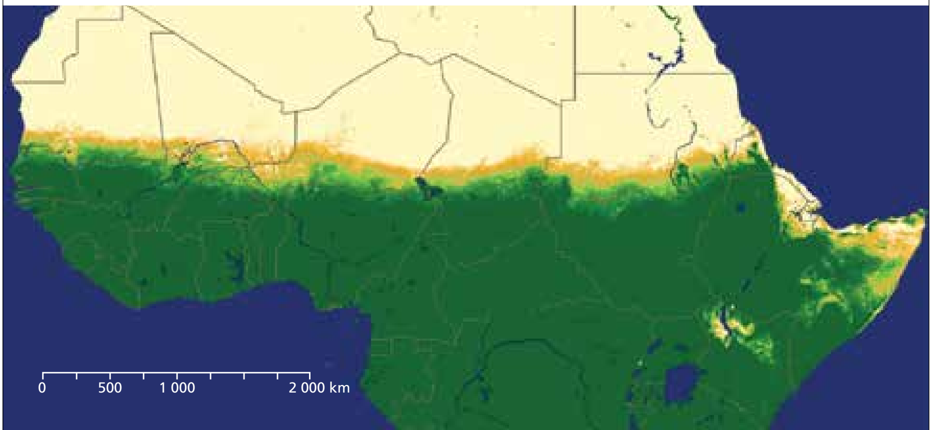
Window	Sub window	Upper left	Lower right	Size (pixels´rows)
Sub-Saharan	Sub-Saharan	-18.000E 27.375N	52.000E -5.02678611N	7841 × 3630
West Africa	Ouest_Afrique	-18.000E 27.375N	16.000E 9.000N	3810 × 2060
	Mali_Burkina	-12.500E 25.000N	5.5000E 9.000N	2018 × 1794
	Niger	0.000E 24.000N	16.000E 11.000N	1794 × 1458
	Senegal_Mauritanie_ Gambie_Guinée	-18.000E 27.375N	-4.500E 10.000N	1514 × 1948
Central Africa	Centre_Afrique	13.000E 24.000N	39.000E 2.000N	2914 × 2466
	Soudan	21.000E 24.000N	39.000E 3.000N	2018 × 2354
	Tchad_ RepCentreAfrique	13.000E 24.000N	28.000E 2.000N	1682 × 2466
East Africa	Est_Afrique	28.000E 18.000N	52.000E -5.000N	2689 × 2578
	Erythree_Ethiopie	32.000E 18.000N	48.000E 3.000N	1794 × 1682
	Ouganda_Kenya	29.000E 5.000N	42.000E -5.000N	1458 × 1122
	Rwanda_Burundi	28.000E -1.000N	31.000E -5.000N	338 × 450
	Somalie	40.000E 12.000N	52.000E -2.000N	1345 × 1570

For the current year, the anomaly is calculated using the available decades from the start of the growing period (start decade chosen by the user). To obtain significant anomaly values, the calculation only starts when a minimum of 15 percent of the mean productivity has already been produced. Otherwise, the pixel is given a flag value of 251 which means the growing period is not advanced enough to give significant and reliable anomaly values.

Overlay process

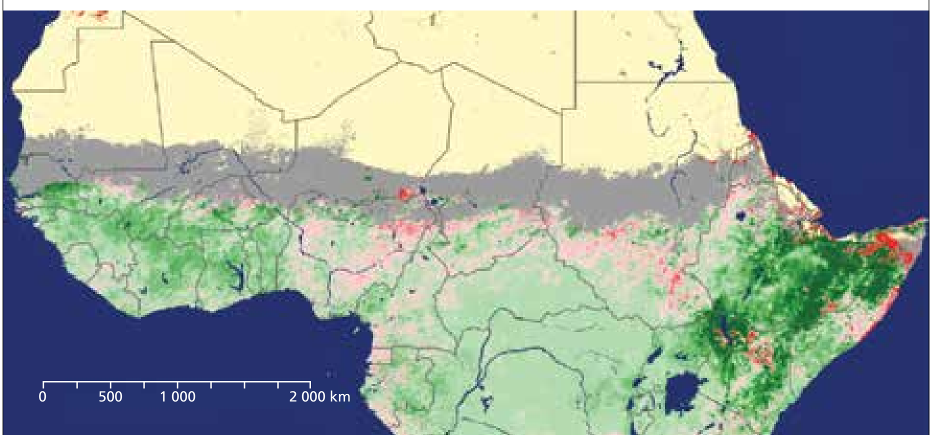
As stated earlier, biomass production monitoring is essential but not sufficient to obtain a proper feed inventory. Accessibility to forage, distance from water points and livestock

FIGURE 10.3
Biomass map [kg.ha^{-1}] in 2010 calculated in July 2010 (last decade)



Pas de biomasse
1 - 50
51 - 150
151 - 300
301 - 500
501 - 750
751 - 1 000
1 001 - 1 500
1 501 - 2 000
2 001 - 2 500
2 501 - 3 000
3 001 - 5 000
> 5 000

FIGURE 10.4
Biomass anomaly map (percent) of 2010 calculated at the end of July (last decade 2010)



0 - 20
21 - 40
41 - 60
61 - 80
81 - 100
101 - 120
121 - 140
141 - 160
161 - 180
181 - 200
Pas de biomasse
Saison pas commencée

behaviour are additional factors which must be considered. As shown in Figure 10.5, it is possible to achieve higher levels of accuracy by adding layers and improving the quality of each of these.

Surface water monitoring

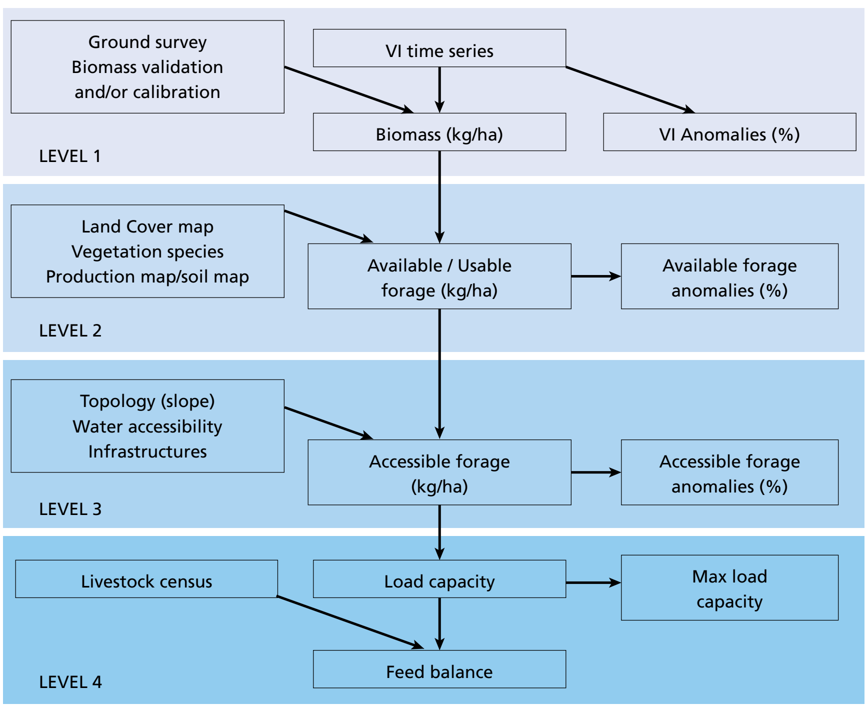
The *Hydrogenerator*, developed between 2009 and 2010 by ACF, considers surface water bodies and their evolution throughout the year. The tool realizes a decadal sum of detected cells and represents a cumulative surface water detection map for the period between 2000 and today. For one given year, the tool also products a surface water accessibility map which helps to characterize the zones considering the water residence time and their influence on a 30 km buffer ring around the detected cells.

This tool is available, but needs some additional ground truth work to be validated. Other tools and systems are also in development and could complement ACF systems (see **References** for existing studies).

Wells and boreholes database

Mapping out boreholes and wells can greatly complement the surface water monitoring process. Given that some areas rely heavily on surface water for livestock needs, some others are more dependent on underground water availability. An updated database available can assist in distinguishing areas that can be used for livestock feed.

FIGURE 10.5
Feed balance diagram



Concentration area mapping

Pastoral movements and concentration areas may largely vary considering the available resources. However, "usual" movements can be determined and compared with the effective movements of the considered year in order to obtain a better understanding of the possible adaptive strategies of breeders and also to be able to anticipate the difficulties people could face some time later. Analysing these patterns is important in the framework of feed inventory updating.

Topography

In hilly areas, some forage areas are not accessible and should not be taken into the feed inventory calculation. Overlaying a Digital Elevation Model can eliminate forage that is inaccessible to livestock from the feed inventory calculation.

Livestock census

A reliable livestock census plays an important role in the calculation of livestock feed balance as shown in Figure 10.5.

10.4 UPDATING THE INVENTORY

Every year, at the end of the rainy season, the feed inventory is updated, combining biomass and surface water maps as well as other data layers. Ongoing monitoring of cattle movements, concentration areas and livestock numbers is useful for identifying potentially vulnerable areas. All these elements comprise the basis for a basic feed inventory, but additional data and information would be useful to produce a fully reliable feed inventory, as shown in Figure 10.5. Higher levels of accuracy will be attained by utilizing additional data, provided they are available.

ACF International intends to further develop the system and distribute it to other countries in West Africa as well as East Africa. Improvements could lead, in time, to the development of an African pastoral vulnerability model.

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11. Development and application of Earth observation-based rangeland monitoring techniques in Namibia

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11.1 INTRODUCTION

A significant proportion of the Southern African population is dependent on livestock as a source of revenue and food, and most Southern African livestock rely exclusively on rangeland for fodder. Therefore, the monitoring of rangeland is an essential factor in assessing food security. In addition, because of the high spatial and temporal variability of vegetation growth in most parts of the region, it is essential to monitor rangeland vegetation at regular intervals during the growing season over large areas in order to provide real-time estimates of vegetation conditions. Remotely-sensed data is therefore particularly relevant.

Within the context of setting up a national feed assessment for rangeland vegetation, several approaches can be implemented which can complement each other. Ideally, this would form a series of steps with increasing degrees of precision in terms of available fodder quantity and quality estimates. Within the scope of this case study, this process can be undertaken in two separate steps:

- The initial step is the provision of satellite-derived data products of vegetation conditions over an entire country on a regular basis. This is presented in Step 1 below. The advantage of this approach is that it requires little or no calibration data and can provide regular estimates throughout a growing season. This approach has been applied in several Southern African countries and is now being applied operationally for the whole of Africa.
- A second step involves a more quantitative approach to estimate net primary production from the integration of field measurements with satellite imagery. These estimates can be linked to fodder availability. This approach is presented in Step 2 below. Although the example is for the Etosha National Park in Namibia, the method could be applied over a whole country.
- In a third step, not detailed here, national estimates could be derived by developing estimates for individual land use/cover types, such as agro-ecological/farming systems. These estimates could then be applied to a national land use/cover map. Land use/cover maps would normally be derived from remote-sensing data, or provided by government agencies.

11.2 STEP 1: REAL-TIME RANGELAND MONITORING WITH NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION - ADVANCED VERY HIGH RESOLUTION RADIOMETER (NOAA-AVHRR)

11.2.1 Introduction

Namibia is a dry semi-arid country located in southwestern Africa with a total area of 825 000 km^2. The population is just over two million but is increasing rapidly. Most of the country's climate is arid to semi-arid with a mean annual rainfall varying between almost 0 mm on the coastal desert up to 600 mm in the northeast. The rainfall is highly variable, both spatially and temporally. Only 1 percent of the country's land is fit for agriculture, although population pressure is forcing increases in agriculture into less suitable areas. The rest of the land is mostly occupied by rangeland and desert. The country's largest source of income after mining is cattle.

In the past two decades, the country has been hit by a number of droughts and the combination of low rainfall years and an increase in the animal population have led to overgrazing and ultimately land degradation in the most affected areas. However, it is difficult to say whether the situation has become irreversible or whether it will improve as soon as the rains return to normal. This situation has led government and donor agencies to seek better ways to monitor the current rangeland vegetation conditions in order to make better management decisions.

Previous studies (Hutchinson, 1991; Lambin *et al.*, 1993), have shown the advantage of satellite remote sensing, particularly NOAA-AVHRR, for the monitoring of vegetation conditions compared with methods based on rainfall data interpolation. In the case of Namibia, the available network of rain gauges is not sufficient to allow a reliable interpolation of spatial variation in annual rainfall over the whole country. The most widely used satellite-derived indicator of vegetation activity is the NDVI (Normalized Difference Vegetation Index).

There is a need to compare the current NDVI with historical data in order to assess whether vegetation conditions are better or poorer than usual and in the latter case to know if conditions are sufficiently extreme to adversely affect livestock and crops. Major international initiatives (USAID-FEWS[8], FAO) were set up to develop operational early warning systems which compare current NDVI images with the previous 10-day period or with the mean image for the 10-day period being considered (e.g. first 10 days of June for all years of data) (Hutchinson, 1991; Lambin *et al.,* 1993). The latter method assumes the annual variation of the NDVI for a location and a given 10-day period to follow a Gaussian distribution. This assumption is unreasonable because the lower limit of the NDVI is truncated by the response for bare soil. An improved method developed and tested by Sannier *et al.* (1998) in Namibia and Zambia, estimates the statistical distribution from the NDVI time-series by applying techniques commonly used in hydrology for the prediction of extreme events and defines a Vegetation Productivity Indicator (VPI). This section describes how this methodology was developed and adapted for the Namibia Early Warning System (EWS) at the Department of Meteorological Services and the Ministry of Agriculture of Namibia through the Northern Namibia Environmental Project.

[8] Famine Early Warning System

11.2.2 Implementation of real-time vegetation monitoring in Namibia

Real-time vegetation monitoring with satellite imagery is only possible if reliable local reception of satellite data is available. Over the last decade, the LARST (Local Application of Remote Sensing Technology) consortium led by the Natural Resources Institute (NRI) has developed low-cost satellite receivers capable of acquiring NOAA-HRPT (High Resolution Picture Transmission) data. The system comprises an antenna and a receiver connected to a PC with the appropriate capture card and software. One such system was installed at the Etosha Ecological Institute in Okaukuejo where NOAA-AVHRR data are acquired and used for production of NDVI images on a daily basis.

The ARTEMIS[9] NDVI archive that was used previously covered the 1981–91 period. There was a need to extend this period to improve the implementation of the VPI method. The NASA-GSFC (National Aeronautics and Space Administration - Goddard Space Flight Centre) Pathfinder AVHRR Land (PAL) data set was available up to September 1994. Additional data were also available on the ADDS (Africa Data Dissemination Services) internet site of the USGS which were processed the same way as the ARTEMIS data for the period starting August 1995 up to present (the data are being continuously updated). The combined data set covers a 15-year period.

The ARTEMIS and PAL archives were compared by Sannier *et al.* (1998) in the overlap period and showed that although there was a strong relationship between ARTEMIS and PAL NDVI values, they were significantly different. However, the PAL archive NDVI values for the 1991-94 period were matched to the ARTEMIS values using a regression relationship. Comparison of the ADDS data with ARTEMIS values over stable targets such as deserts showed that the values were directly compatible with ARTEMIS. An 18-year time series of 10-day maximum value composite NDVI images for Namibia and its surroundings was extracted from the various data sources identified in Table 11.1.

The ISODATA algorithm (ERDAS, 1995) was used to perform several unsupervised maximum likelihood classifications on the thirty-six 18-year mean 10-day images, varying clustering parameters and the number of classes. Cloudy pixels were eliminated in the calculation of the 18-year averages. Finally, a 14-class classification was selected to stratify the study area for the VPI method. The NDVI statistical distribution for each 10-day period and each stratum was determined using the method described by Sannier (1998). This was to determine the NDVI values corresponding to quintile probability thresholds used to define five vegetation status classes (very low, low, average, high and very high) in each stratum as shown in Figure 11.1. Figure 11.2 shows these thresholds plotted against time for two locations.

11.2.3 Development of outputs

The methodology was commissioned in the Ministry of Agriculture and the Ministry of Environment and Tourism and a workshop was held in Windhoek to discuss the format and dissemination pathways for outputs including maps, graphs and tabulated statistics. A map for reporting at ministerial level during the rainy season was identified. This consisted of the maximum VPI value obtained from three 10-day periods, was simple to implement and was thought to further remove cloudy pixels. An example of a monthly VPI map is shown in Figure 11.1.

[9] Advanced Research & Technology for Embedded Intelligence and Systems.

TABLE 11.1
Data sources for the 18-year Namibia data set

Time Period	Data Source
1st 10-day period August 1981 to 3rd 10-day period June 1991	FAO-ARTEMIS
1st 10-day period July 1991 to third 10-day period July 1994	NASA/GSFC PAL
1st 10-day period July 1995 to third 10-day period June 1997	USGS/FEWS/ADDS

The VPI maps show the spatial distribution of rangeland vegetation conditions for the whole of Namibia at a particular moment in time. It was also considered important to monitor vegetation condition at a single location over time by plotting the current NDVI on the vegetation status profiles such as the one shown in Figure 11.2. This supplements the information from the maps and assists the production of seasonal forecasts. Macros were developed to enable timely production of these plots for six main locations in the country (Gaborone, Kasane, Francistown, Maun, Guanzi and Tsabong). In the Kalahari (Figure 11.2a) the vegetation response was both exceptionally early and exceptionally high whereas in Mashare (Figure 11.2b) the growing season was two months later than usual and was still low at the time of the last image plotted. DMS and Ministry of Agriculture staff were shown these methods and were trained to produce similar graphs.

FIGURE 11.1
VPI map of Namibia for October 1999

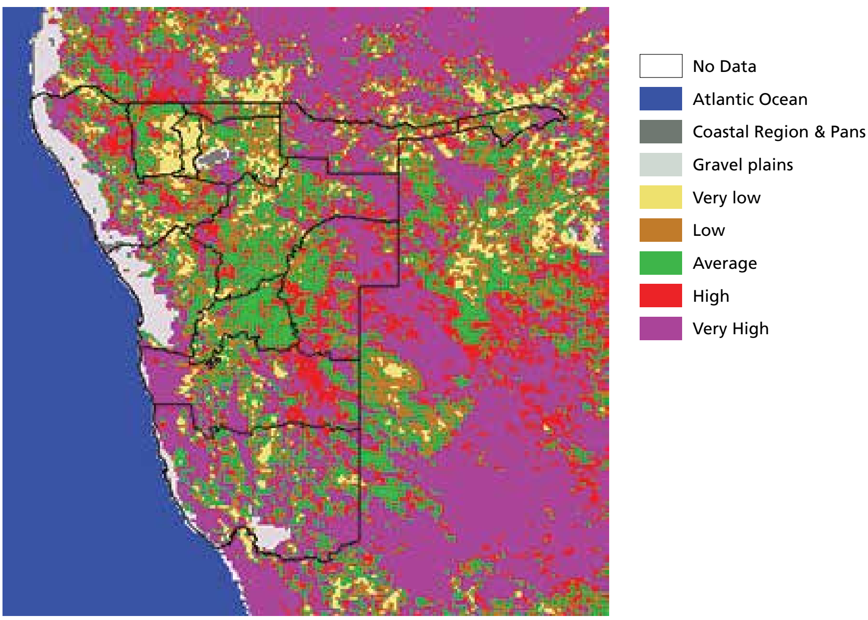
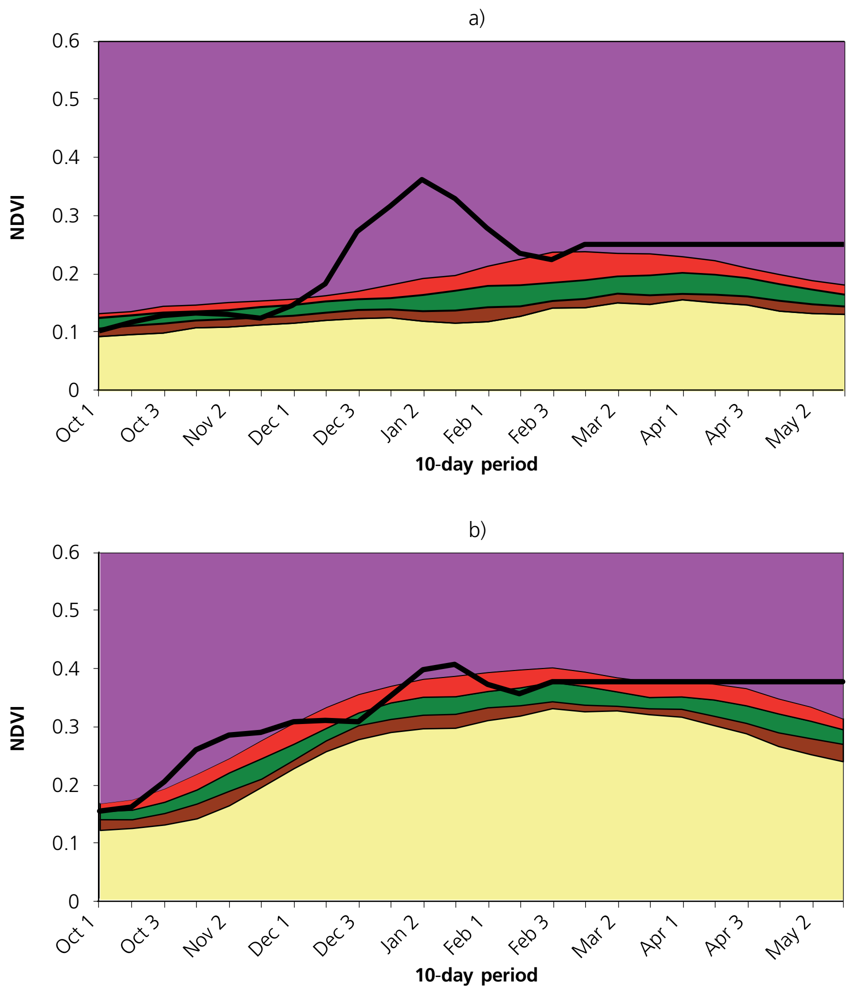


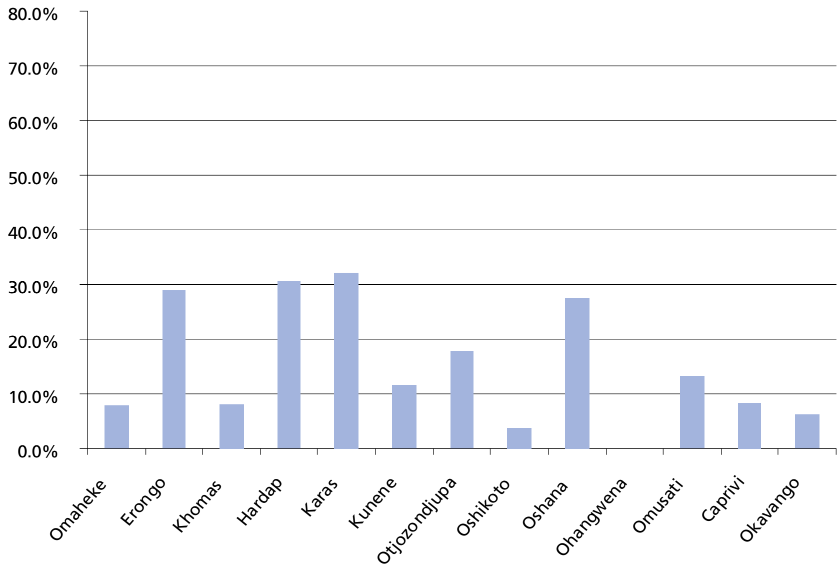
FIGURE 11.2
Evolution of vegetation conditions
(a) in Kalahari and (b) in Mashare, Namibia, during the 1998-99 season



Note: Colours in graphs represent VPI categories listed in Figure 11.1. Solid black line indicates current year vegetation condition.

There was also a need for a simple output to indicate conditions at the level of agricultural districts. The number of pixels below average conditions for each district was imported into a pre-formatted spreadsheet to produce a graph (Figure 11.3) of the percentage of each district suffering from potential drought conditions. This information contributes to the rapid identification of districts with problems.

FIGURE 11.3
Proportion of agricultural districts of Namibia below average in March 1999



11.2.4 Dissemination and field checking of outputs

Workshops and training seminars were held with Ministry of Agriculture and Ministry of Environment and Tourism staff. Presentations and interpretations of the VPI maps were given to the members of the Namibia EWS to raise awareness of the new information described above and to provide training in its use. This is an ongoing process that will be expanded to include users at a district level, in order to increase the use and impact of the products. The VPI maps and associated products have also been distributed to a wide range of general users in Namibia through 10-day and monthly agro-meteorology bulletins produced by the Ministry of Agriculture. The VPI maps are used to monitor potential drought conditions and to provide a visual summary of the current status of Namibia's rangelands.

National drought assessment tours are conducted by multidisciplinary teams at least twice a year to assess drought conditions on the ground. The VPI maps can be used to target visits to worst-hit areas and to assess the spatial extent of conditions that are identified in the field.

11.2.5 Conclusions

The implementation of the VPI methodology in Namibia seems to have worked extremely well and VPI maps are now being produced operationally and can be distributed to the relevant authorities. Initial field checking by NNEP staff also showed that VPI products were effectively picking up variations in vegetation development compared with the norm. The use of the VPI maps for drought monitoring has made a significant contribution to the identification of drought severity, the spatial extent of the area affected, and the drought relief measures to be introduced. VPI maps are now being used by range managers in Namibia as a monitoring tool.

11.3 STEP 2: COMBINATION OF FIELD DATA AND SATELLITE OBSERVATION FOR NEAR REAL-TIME MONITORING OF RANGELAND VEGETATION IN ETOSHA NATIONAL PARK

One of the key biophysical variables that is measured in assessments of rangeland vegetation conditions is biomass production or net primary production. Biomass observations can be collected in the field, but field methods are only suitable to cover a small area and are too costly and time consuming for real-time monitoring over large areas. On the other hand, satellite imagery can cover large areas on a daily basis using low spatial resolution satellite imagery. However, satellite imagery on its own can only provide qualitative estimates of biomass. Quantitative estimates derived from satellite imagery can only be achieved if images are calibrated with appropriate field observations.

This section presents a methodology relying on the combination of medium to low spatial resolution satellite imagery and detailed representative field observations of biomass. The objective is the provision of near real-time maps of biomass estimates.

The methodology was developed in the Etosha National Park in the northern part of Namibia. Etosha covers an area of approximately 23 000 km^2. The climate is semi-arid with a rainfall gradient varying from about 450 mm in the east to 300 mm in the west (Le Roux *et al.*, 1988). The main feature of the Park is the Etosha pan, a saline desert covering an area of approximately 5,000 km^2. Very little or no vegetation grows on the pan, which is sometimes covered with a thin water layer during the rainy season.

The work was carried out in four separate stages: rapid measurements of plant biomass, selection of biomass sites, site sampling strategy and processing of satellite observations. These stages are summarized below, but a more detailed discussion of the methodology is presented by Sannier *et al.* (2002).

11.3.1 Rapid measurement of plant biomass

Rapidity is required primarily for economic reasons (more observations can be collected with the same resources). A second reason is that vegetation growth is limited by rainfall, it develops very rapidly following rainfall events, and it is also consumed rapidly by livestock. Because the intention was to make the biomass observations coincide with satellite imagery, it was essential to derive field biomass estimates as close to the image acquisition date as possible. To estimate the total green biomass per unit area, it was necessary to calculate contributions from herbaceous and woody components at the scale of the pixels. This was done using a statistical estimator based on sample observations.

Herbaceous Biomass

The use of a rising plate or disc pasture meter (DPM) for estimating grass biomass in Australian pastures was first described by Mitchell (1982). It has the advantage of being objective, rapid and easy to operate and was adopted for herbaceous biomass assessment in this work. However, judgement is required when making measurements on stony ground to avoid false readings.

Previous work in Etosha by Kannenberg (1995) produced a calibration curve in using the same calibration procedure as Trollope and Potgieter (1986). The curve includes points from a wide range of locations and the single curve seems to be generally applicable for all Etosha grasses. The linear model for the regression produced a high coefficient of determination (r^2) but the scatter of points for biomass below 2000 kg/ha seems to deviate systematically below the regression line with a risk of overestimating biomass below this threshold. An alternative logarithmic model shown in Figure 11.4, and proposed for this work, is an improvement and has a higher r^2.

Woody plant biomass

Green biomass estimation of woody plants is usually estimated by using a regression relationship between dry matter weight obtained from direct harvest and a plant morphological variable such as height, stem diameter or crown diameter (Pieper, 1988). The dominant woody species in Etosha, accounting for about 85 percent of the shrubs and trees in the savanna, is mopane (*Colophospermum mopane*) which occurs in both forms. Data relating the branch diameter of mopane to leaf biomass was available from previous work at the Etosha Ecological Institute (Du Plessis, 1995). This was used to create a rapid field technique to estimate the biomass of mopane trees and shrubs. Table 11.2 shows the average leaf biomass of mopane for stems and branches in different size categories. The leaf biomass of a randomly selected sample of 80 mopane trees and shrubs was estimated in the field by counting the number of primary stems in each of the size categories and using the average leaf weights from the table. The height of the plant and its crown diameter in two perpendicular directions was also recorded. The estimated dry leaf weight was best correlated to the volume of the plant calculated as a cylinder with diameter equal to the average crown size and height equal to the estimated tree height as shown in Figure 11.5.

FIGURE 11.4
Estimation of grass biomass with the Disc Pasture Meter

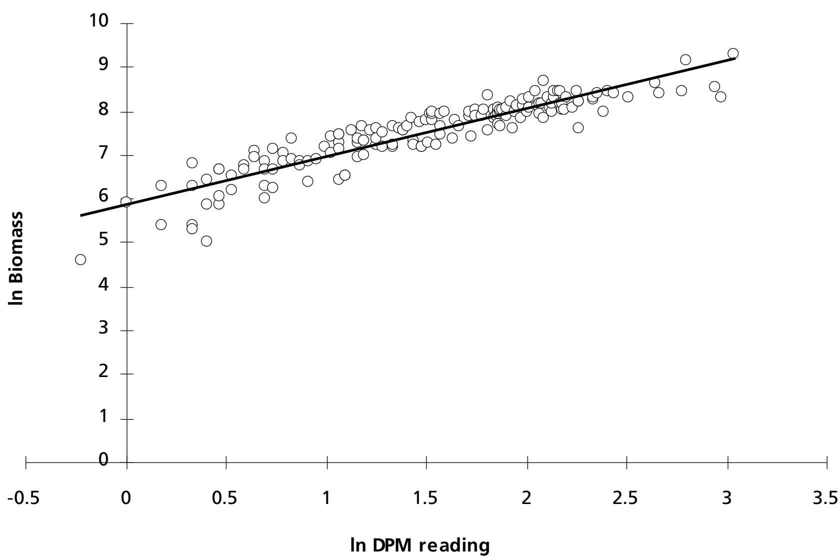
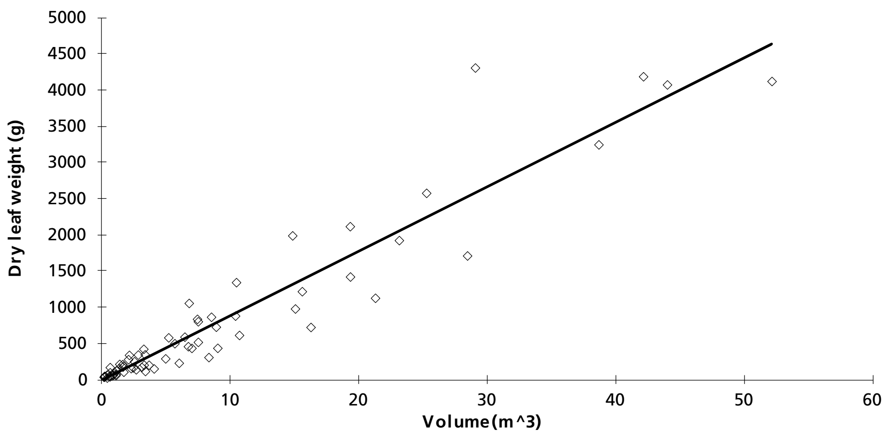


TABLE 11.2
Average leaf weight of mopane stems in full leaf, in different size ranges

Stem Diameter class (cm)	Average leaf dry weight (g)	Standard Error (g)
0 to 0.5	1.6	0.1
0.5 to 1	6.9	0.4
1 to 2	28.3	1.8
2 to 3	84.8	8.2
3 to 4	171.2	11.3
4 to 5	239.7	26.4
5 to 6	387.2	81.3
6 to 7		
7 to 8	785.2	83.6
8 to 10	1240.7	209.6
10 to 12	1595.0	223.9
12 to 14	1714.8	190.3
14 to 16	2683.0	216.6
21 to 28	2883.2	774.0

The dominant shrub in Etosha steppe areas is leucosphaera (*Leucosphaera bainesii*), accounting for around 80 percent of steppe shrubs. Unlike mopane, no previous work on the assessment of plant biomass had been done on leucosphaera. Seventy-two plants were randomly selected in the field; height and perpendicular crown diameters were measured, then the plants were harvested. Total dry plant weight was determined following standard

FIGURE 11.5
Calibration of shrub and tree green biomass with crown volume



oven drying. The total dry plant weight was considered more appropriate to use because the plants almost completely disappear during the dry season, therefore any plant material above the ground was considered new material. The best relationship between dry plant biomass and plant dimensions was found using crown area and is shown in Figure 11.6. Unlike mopane, plant volume was not the best correlate to biomass because leucosphaera is a smaller plant which develops itself horizontally rather than vertically.

11.3.2 Selection of biomass sites

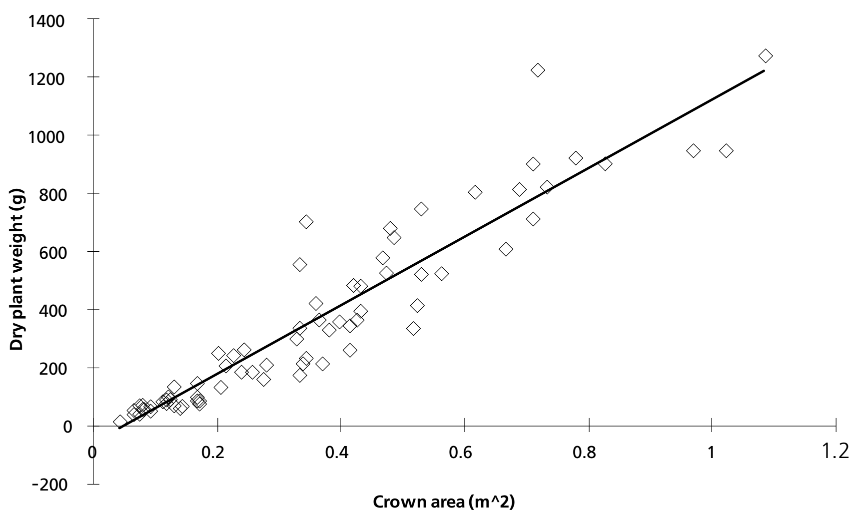
The criteria for selecting calibration sites were that they:

- be of sufficient size and internally homogeneous to reduce the effects of errors in co-location of the ground with satellite observations;
- be accessible; and
- reflect the range of biomass levels in the Park.

Sites were chosen to reflect the variation of the predominant grass, steppe and savanna types in the Park.

The formula derived by Justice and Townshend (1981) gives a guideline for the minimum size, *a*, of a sampling unit in relation to the geometric accuracy: $a = p(1+2l)$ where *p* is pixel dimensions in distance units and *l* the geometric accuracy in number of pixels. For example, a 1.1 km pixel size for NOAA-AVHRR and a geometric accuracy of 0.5 km pixel should result in a sampling unit of 2.2 km on each side. Generally, it is not feasible to have calibration sites large enough to meet this ideal and in past studies smaller sites have been used. We initially selected candidate homogeneous locations, several square km in size by photo-interpretation of geometrically corrected false colour composites from Landsat TM imagery. By selecting a 1 km^2 site in the middle of a larger homogeneous area, we expected to minimize the effects of geometric correction errors. This is because

FIGURE 11.6
Calibration of dwarf shrubs with plant crown area



variation of biomass in the immediate surrounding area was unlikely to be great and also because surrounding pixels would not be mixtures of other vegetation types. Field checking with geo-coded enlargements of the TM imagery verified the homogeneity of the selected sites. A total of 11 sites were selected as shown in Figure 11.7.

11.3.3 Site sampling strategy

Biomass sampling was carried out along a 1 km transect through the centre of the 1 km^2 sample site. Because of our previous selection procedure, it was assumed that the site is isotropic and homogeneous so that average biomass along the transect represents the average for the whole of the 1 km square area. The sampling scheme for herbaceous vegetation is shown in Figure 11.8. DPM measurements were made at ten equally spaced locations along the transect. Navigation was assisted by a Landsat TM enhanced geo-coded image hardcopy and a handheld GPS. Five clustered DPM readings were taken on each side of the transect. This resulted in a total of 100 DPM measurements per site which is the value suggested by Trollope and Potgieter (1986).

The woody plant biomass per unit area is the product of the biomass per plant and the number of plants per unit area. The number of plants per unit area is estimated by dividing proportion of plant cover (canopy area/unit ground area) by the canopy area per plant. The crown to gap method (Westfall and Panagos, 1984; Walker *et al.,* 1988) is a very fast and

FIGURE 11.7
Selection of survey sites

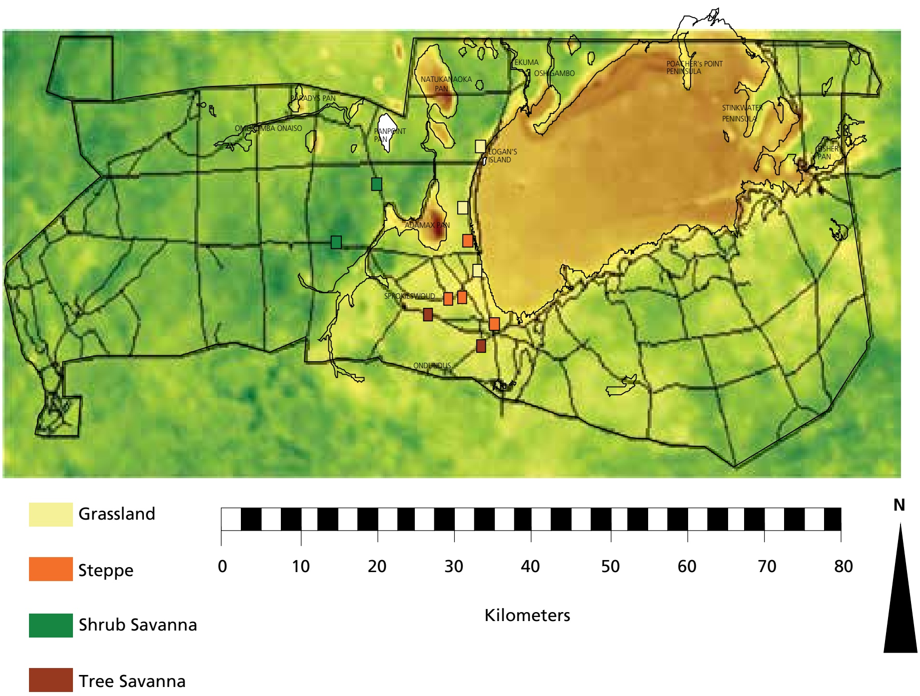
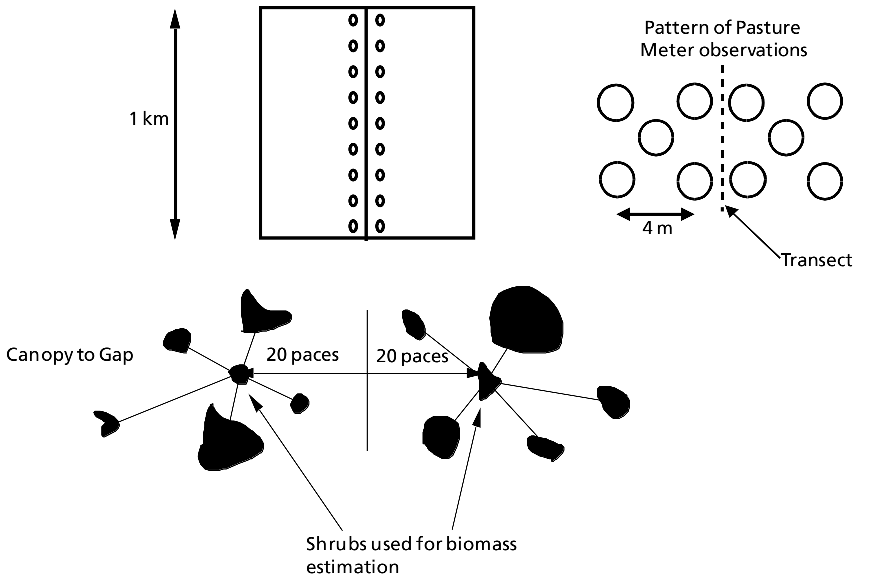


FIGURE 11.8
Sampling strategy for biomass measurements



unbiased method for estimating the percentage canopy cover of woody vegetation (trees, shrubs, dwarf shrubs, etc.) over relatively large areas from ground observations or surrogates such as photographs and was selected for this study. Two adjacent plants approximately the same distance from the observer were selected. The ratio ϕ, the distance between their crowns (*G*) to the diameter of the crown of one of them (*K*) in Equation 1

$$\phi = \frac{G}{K} \qquad (1)$$

can be estimated by eye or by a transparency gauge (Westfall and Panagos 1984) or measured on photographs. The average ratio $\bar{\phi}$, for at least 25 pairs of plants is used in Equation 2, described by Walker *et al.* (1988) to estimate the percentage covered by the crowns, *C*:

$$C = \frac{100\pi}{2\sqrt{3}}\left[\frac{1}{\left(\bar{\phi}+1\right)^2}\right] \qquad (2)$$

The sampling of woody vegetation was done on the same 10 locations along the transect as shown in Figure 11.8. A plant was randomly selected on each side of the transect by walking 20 paces perpendicular to the transect using the vehicle as a reference. Then the closest plant was selected to take plant measurements. The reference plant was also used to perform the canopy to gap procedure as shown in Figure 11.8 by choosing five other plants closest to it and evaluating visually the canopy to gap ratio between the reference plant and each of the five other plants measurement.

The whole procedure was repeated on the other side of the transect. In total, for each site, 100 DPM measurements, 100 canopy-to-gap ratio estimations and 20 plant dimensions were taken.

11.3.4 Determination of site total green biomass

The estimation of herbaceous biomass per site is simple because DPM measurements are directly related to biomass per unit area. DPM readings were recorded in a spreadsheet. Each cluster of five DPM readings (Figure 11.5) was averaged. This was to create observations comparable with the original calibration procedure. The calibration equation was applied to the averaged value resulting in 20 grass biomass value per site. The overall biomass of the site was calculated by taking the mean of the 20 biomass values. The same method was used in woody vegetation sites without taking into account the woody cover because grass also often grew under the trees and shrubs and a reading of zero was recorded when the DPM fell on a shrub.

The estimation of woody biomass includes several parameters and the process of averaging was carefully considered because of non-linearity. Each location along and on each side of the transect was treated individually. This was to take into account all of the variations within the site and the non-linearity of the canopy to gap ratio method. A biomass value was calculated for each of the 20 sampled plants associated with five measurements of density (canopy to gap ratio). These five estimates of density were averaged to establish the density at each plant location. The density combined with the plant area gives the number of plants per unit area. The number of plants per unit area multiplied by the plant weight gives the biomass corresponding to the plant and density considered. Twenty plants and five measurements of density per plant resulted in 100 observations of biomass per site. The estimate of biomass for the whole site was the arithmetic mean of these 100 biomass observations plus the grass biomass.

Biomass per plant, P, in kilogrammes is determined by the relationship between plant dimensions and biomass defined earlier. The density cover, C, is determined according to equation (2). The number of plants per hectare, N, is:

$$N = \frac{10000}{A} \cdot C \qquad (3)$$

Finally, the total woody biomass per hectare and plant, W_i, is equal to:

$$W = P \cdot N \qquad (4)$$

In the case of leucosphaera, the calculation of biomass is simplified because the crown area is used in both the calculation of P and N which are cancelled out. Therefore, for leucosphaera, woody biomass is only related to C and the slope of the calibration between plant biomass and area.

For mopane, where the relationship with biomass is based on volume, woody biomass is a function of the slope of the calibration, height and C. It means that once the relationship between biomass and plant dimensions has been established, it is not required to measure plant area in order to derive estimates of woody biomass. The total woody biomass per site is equal to the average of the 20 estimates derived per plant. The combined grass and woody biomass is obtained by adding the two estimates.

In total, 25 observations of biomass were made for the 11 sites selected over two seasons as shown in Table 11.3.

11.3.5 Processing of satellite imagery

NOAA-AVHRR imagery was used for this work and was acquired in real time from a LARST receiving station (Williams and Rosenberg, 1993). This allowed us to produce NDVI images in near real time, to select only the best images and to make sure that the images would coincide with the fieldwork. A total of seven images was selected. Data processing consisted of radiometric and geometric correction of the imagery and NDVI calculation.

Radiometric corrections were based on the work published by Kaufman and Holben (1993) and Los (1993) for NOAA9 data and Rao and Chen (1996) for NOAA14, which took sensor degradations into account and was later updated monthly on the NOAA web site.

Geometric correction was based on the selection of control points from the geo-referenced Landsat TM mosaic covering the entire Park. This made it possible to achieve a geometric accuracy of about 0.5 pixel, which is much better than could have been achieved using satellite orbital parameters.

No atmospheric or bidirectional effects correction was performed because it was thought that careful selection of imagery, free of clouds and nearest as possible to nadir, would be more efficient in keeping atmospheric effects to a minimum rather than applying an approximate atmospheric correction. Existing methods for removing atmospheric effects often assume constant effects over the entire scene and require ground meteorological data that are not realistic to obtain for near real time application.

Digital number (DN) values were extracted from the imagery for each waveband and for each site. The data were input into a spreadsheet where radiometric corrections and NDVI calculations were carried out. Corresponding biomass values were input in the spreadsheet as shown in Table 11.3 and regression models were developed as shown in Figure 11.9.

The relationship including all observations (Figure 11.9a) was weaker than the relationship including only grassland sites (Figure 11.9b). This seemed to suggest that different regression relationships would have to be developed for each vegetation types. However, insufficient data were available to test this hypothesis on the other cover type, and more data would need to be collected. Nevertheless the pooled relationship (Figure 11.9b) is still highly significant and it was used to produce the biomass maps.

11.3.6 Production and applications of biomass maps

The pooled relationship developed in the previous section (Figure 11.9a) can be used to transform NDVI images acquired at the NOAA HRPT receiving station into biomass maps. There are a number of ways in which these biomass maps can be used. From the point of view of food security, this could include the monitoring of animal movements in relationship to fodder availability during a growing season, or the monitoring of the animal carrying capacity from year to year and throughout a study area.

However, a more direct application of biomass maps is the correlation between fuel loads and fire risks. Fires occur naturally in the Park and are normally triggered by lightning

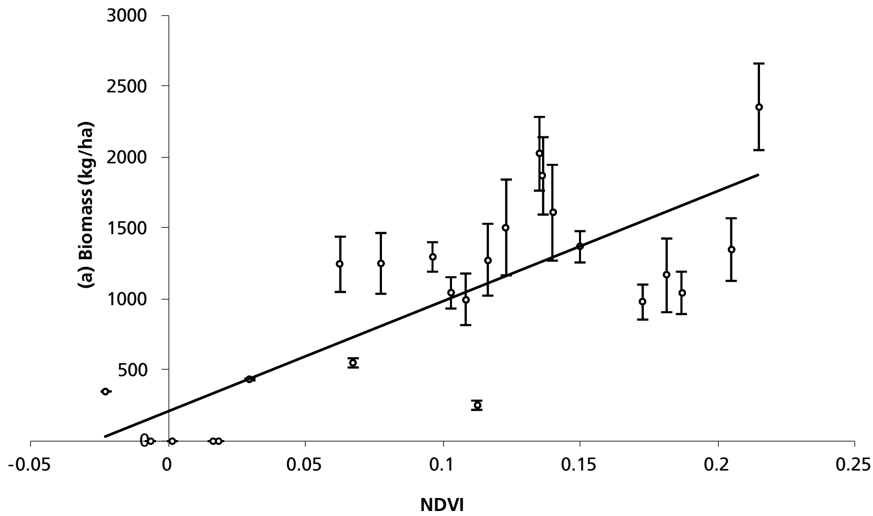
TABLE 11.3
NOAA-AVHRR biomass calibration results

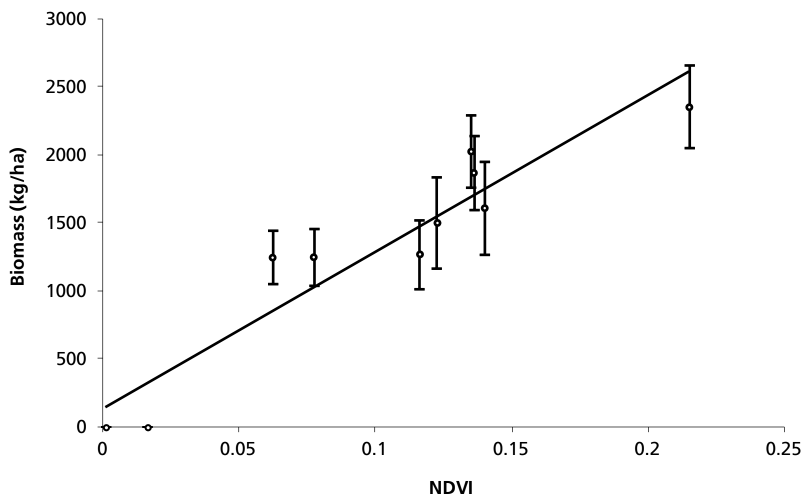
Site	Vegetation Type	Survey date	Image acquisition	NDVI	Biomass (kg/ha)
S4	Grassland	15/02/95	16/01/95	-0.007	0
S6	Grassland	15/02/95	16/01/95	0.001	0
S7	Grassland	15/02/95	16/01/95	0.016	0
S7	Grassland	01/03/95	02/03/95	0.077	1 254
S4	Grassland	01/03/95	02/03/95	0.029	437
S6	Grassland	01/03/95	02/03/95	0.062	1 251
S4	Grassland	10/03/95	10/03/95	-0.023	350
S6	Grassland	21/03/95	21/03/95	0.122	1 506
S7	Grassland	21/03/95	21/03/95	0.135	2 031
S4	Grassland	30/03/95	27/03/95	0.067	553
S6	Grassland	31/03/95	27/03/95	0.140	1 615
S7	Grassland	31/03/95	27/03/95	0.136	1 874
S4	Grassland	25/03/96	19/03/96	0.112	254
S6	Grassland	21/03/96	19/03/96	0.116	1 275
S7	Grassland	25/03/96	19/03/96	0.215	2 357
M1	Savanna	20/03/96	18/03/96	0.187	1 046
M2	Savanna	27/03/96	06/04/99	0.181	1 175
M3	Savanna	28/03/96	06/04/96	0.150	1 375
M4	Savanna	03/04/96	06/04/96	0.205	1 352
S1	Steppe	15/02/95	16/01/95	0.018	0
S3	Steppe	15/02/95	16/01/95	0.016	0
S1	Steppe	26/03/96	19/03/96	0.172	985
S2	Steppe	19/03/96	19/03/96	0.103	1 048
S3	Steppe	01/04/96	19/03/96	0.096	1 300
S5	Steppe	02/04/96	19/03/96	0.108	997

(Heady, 1975). Under favourable conditions, wildfires can spread over large areas and can cause major damage to wildlife and vegetation. However, controlled or prescribed burning is often used to prevent the occurrence of wildfires by reducing fuel loads. Furthermore, controlled fires may benefit livestock and wildlife through positive effects on vegetation regeneration and habitat diversity (Heady, 1975; Holechek *et al.,* 1995). Controlled fires have been used in Etosha National Park for the above reasons and the Park was divided into a number of fire blocks as shown in Figure 11.10.

Trollope and Potgieter (1986) have shown that in the Kruger National Park, biomass fuel loads needed to reach at least 1500 kg/ha to propagate. Therefore, it is possible to use biomass maps reclassified according to a series of thresholds indicating the levels of fire risk. This is illustrated in Figure 11.10, where biomass maps were produced at the end of the

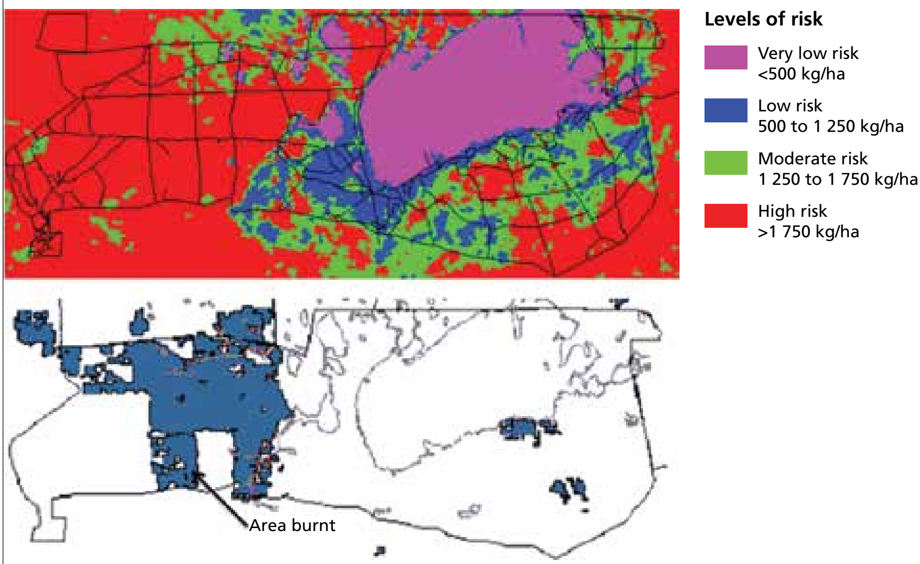
FIGURE 11.9
Relationship between NDVI and biomass for (a) all sites, *n* = 25, *y* = 7735× + 208, r^2 = 0.61 (p <0.01) and (b) all grassland sites, *n* = 10 r^2 = 0.89





Note: Error bars represent the standard deviation of the field biomass estimate.

FIGURE 11.10
Example of a biomass map used to estimate fire risk level, and the extent of the fire that occurred two years after



rainy season for 1995, 1996 and 1997 using the pooled NDVI/biomass regression relationship shown in Figure 11.9a. Looking especially at 1995 and 1996, it is apparent how, for controlled burning, such maps could be used to target fire blocks corresponding to the high to very high risk classes. The year 1997 was exceptional, with rainfall in excess of 40–60 percent of the median between 1981 and 1996, which explains the extremely high levels of biomass reached throughout the park. As a result, all the conditions for an extensive fire were met and a wildfire started at the end of the dry season, which burnt nearly 21 percent of the park's area outside the pans, crossing several fire breaks. The conditions of 1997 were very unusual, but it is possible that, had some controlled burning taken place in fire blocks where biomass was already relatively high in previous seasons, the wildfire that took place in 1997 would not have spread so extensively.

11.3.7 Conclusion and further development

This study has demonstrated methods for near real time monitoring of biomass quantity with NOAA-AVHRR. The value and reliability of the DPM has been demonstrated and was shown to be suitable for measuring biomass of grasslands across large areas. However, its use should really be limited to the grass types for which it has been calibrated. It is possible, in certain circumstances, that several calibration curves might be required depending on the grass types present. The DPM is unsuitable for reliably measuring biomass below 1000 kg/ha and other techniques, such as visual estimation, should be used.

Concerning woody plant biomass, the set of techniques that were developed appeared to be reasonably reliable. The calibration of green plant biomass based on dimensions worked particularly well. The canopy to gap method was also very rapid to implement and seemed to be a fairly reliable way to assess canopy cover. Once the calibration of plant biomass with dimensions has been determined, the measurement of woody biomass becomes extremely rapid especially for plant species for which the calibration is based on plant area. In this case, the only parameter required is canopy cover. For plant species in which the calibration is based on volume, the parameters required are the canopy cover and plant height. This makes the assessment of biomass monitoring sites much faster and it is possible to increase the sample size from 20 to 40 plants within a site allowing a better characterization of site variations.

It would also be desirable to extend the work to other plant species, although the existing calibrations that were developed are valid for about 85 percent of the park.

The need to develop a suitable sampling scheme was also identified. The assistance of high resolution imagery for site selection proved to be very useful and allowed the identification of homogeneous sites for selected cover types at the scale of NOAA. It also proved crucial to develop a suitable sampling scheme for the measurement of biomass within the site. The random selection of plants along the transect proved to be particularly important and the measurement of canopy cover needs to be based on the selected plants. This allows measurements of variations within the site and thus assessments of the precision of the estimates.

It was also demonstrated that single AVHRR images, received locally, could be calibrated against biomass allowing near real time monitoring of biomass quantity. Moreover, the methodology could also be applicable to other types of imagery such as SPOT VEGETATION[10] or TERRA/AQUA MODIS[11]. Nevertheless, the number of points available for the calibration is still limited and more observations would be needed to confirm that the calibration remains stable through space and time. It already appears that the same calibration could be used for grassland and steppe. This is particularly encouraging because grassland and steppe are present in the same areas and are difficult to differentiate at the scale of NOAA-AVHRR. However, it seems that savanna sites need a different calibration especially when the proportion of woody biomass reaches a certain level. More observations need to be collected to be able to confirm this theory and to determine this threshold.

Biomass maps could potentially be used for several purposes linked to rangeland and wildlife management such as monitoring of animal movement and assessment of carrying capacity. It was shown that biomass maps could be used for the planning of prescribed burning. If local reception of NOAA-AVHRR data is possible, biomass maps can be produced in near real time and a direct application will be possible to target areas suitable for controlled burning to prevent large-scale wildfires. However, more work is required on refining the relationship between biomass and the NDVI for different vegetation communities, and to investigate whether the effective burning threshold varies according to the

[10] The VEGETATION programme is the fruit of space collaboration between various European partners: Belgium, France, Italy, Sweden and the European Commission. In 1998, it was grafted onto the SPOT programme, founded by Belgium, France and Sweden in 1978. It consists of two observation instruments in orbit, VEGETATION 1 and VEGETATION 2, as well as ground infrastructures.

[11] MODIS (or Moderate Resolution Imaging Spectroradiometer) is a key instrument aboard the Terra (EOS AM) and Aqua (EOS PM) satellites.

vegetation type. This latter point stresses the importance of having land cover mapping products as a basis for stratifying the study area.

Finally, although the method was developed over an area of 23 000 km², it could potentially be used over a much larger area, such as nationally, provided a suitable sampling scheme is implemented across the study area.

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