7. LITERATURE REVIEW ON PRINCIPLES AND PRACTICES OF METHODS USED IN THIS STUDY

7.1. DEVELOPMENT OF ECOLOGICAL PRACTICES

Phytosociology studies the characteristics of plant communities and their classification (Becking 1957, Mueller-Dombois and Ellenberg 1974). Vegetation ecology and phytosociology as being part of ecology developed as a science in the context of biogeography, which, in the 19th century, started formalising concepts and criteria to describe patterns and distributions of organisms. A pioneer of formal biogeography was Alexander Von Humboldt, who described and measured zones of vegetation coinciding with climatic gradients. He characterised vegetation according to the physiognomy of the dominant vegetation (McIntosh 1991).

The delineation and description of a plant community has led to the development of various concepts and hence also schools of thought (with a large difference in opinion and non-acceptance between European and American and British scientists) in plant ecology, which all in the end differently contribute to vegetation description and -mapping.

i. The Holistic-Organismic Mono-Climax Theory of Clements

Clements, who did much of his initial work on the grassy plains of northern America, defined plant communities as clearly recognisable and repeatedly occurring units, which function as a part of all their components, similar to an organism. Plant communities exist in several climax states, which can also be divided into climax formations and -communities. After disturbance, such communities would always, through a process of succession in the absence of further disturbance, revert back to their original climax states (Kent and Coker 1992, McCook 1994). As this approach is practical to investigate, this approach, although recently criticised, is still widely used, e.g. as part of the "Range Succession Model" (Werger 1974, Westoby *et al.* 1989).

Clements further suggested a basic method for vegetation mapping, which consisted of a survey of the abundance of all species in a pre-defined quadratic area of vegetation (Joyce 1993).

ii. The Individualistic Species and Continuum-Concept of Gleason

Gleason stated that it is virtually impossible to describe a static plant community, as individual plant species are distributed over a continuum of environmental gradients. Successional patterns observed are thus rather the sum of individual species response to a perturbation than the response of an entire community. The co-existence of several plant species at any point in space is regarded as more coincidental, depending on the ecological adaptations of such species, and a group of species could not as such be found repeatedly in a region (Kent and Coker 1992, McCook 1994). Understandably, it is difficult to describe vegetation units especially of larger areas following this approach. Nevertheless, Gleason's concept is highly useful when studying plant species strategies and responses or plant population dynamics, see Grime 2001, Harper 1977 (quoted by Kent and Ballard 1988).

iii. The Zurich-Montpellier (Z-M) School of Phytosociology

Braun-Blanquet, as some of the most famous authors of this group, regards all plants growing in the same habitat as forming a phytocoenose. The different characteristics of phytocoenoses can be used to systematically classify the vegetation of a larger area. Any change in habitat will in due time be reflected by the characteristics of the phytocoenose. Another term for phytocoenose was "association", which is basically as "abstract" plant community, being characterised and defined according to the taxonomic species concept (Becking 1957, Mueller-Dombois and Ellenberg 1974).

This plant community as a basis of a phytosociological classification was first defined in 1910 by Schröter and Flahault (quoted by Werger 1974) as: an association, which has a definite floristic composition, a uniform physiognomy and is bound to uniform habitat conditions. Associations are defined according to their total floristic composition.

Associations may be subdivided into sub-associations and variants, which are characterised by their respective differential species. Associations may also be combined into alliances and the latter into orders, based on characters and differential species. Orders again can be combined into vegetation classes, based on vegetation characteristics (Becking 1957, Werger 1974).

The Z-M methodology has become popular in southern Africa, these days being regarded as the standard method used in vegetation descriptions (Volk and Leippert 1971 and Werger 1973 in Werger 1974). This methodology has been well described by various workers (Werger 1974, Mueller-Dombois and Ellenberg 1974, Le Houerou 1974). In short, it consists of different phases, viz.: (a) reconnaissance study in which the worker familiarises himself with the flora and the area to be studied, (b) Inventory consisting of detailed data collection by means of relevés, looking at both environmental and floristic characters, (c) data analysis, usually by classification techniques to group the various phytocoenoses into synthetic higher units and (d) usually as an end result the mapping of the defined synthetic units. These units are named according to the guidelines of the International Code of Phytosociological Nomenclature (3rd edition by Weber *et al.* 2000).

Present-day viewpoints of plant communities accept the community-unit theory, and vegetation of a region being a mosaic of such community units (Kent and Coker 1992). Further, it has become common practice to combine concepts of the different schools of thought, especially in the study and description of vegetation patterns linked to underlying environmental gradients. Systematic classifications of communities are verified by ecological criteria simplified by ordination techniques (Mueller-Dombois and Ellenberg 1974, Gauch 1986, Kent and Ballard 1988, Bredenkamp *et al.* 1983).

7. 2. CHOICE OF METHODS OF DATA ANALYSIS IN VEGETATION DESCRIPTION

A wide range of techniques of data analysis have been devised for both classification and ordination, which is often bewildering and confusing to ecologists who are not specialist of these methods themselves. Throughout the literature there seems to be little consensus over which methods should be used in general vegetation descriptions, further compounded by a vast number of publications on methods themselves, rather their practical use. Rather than stating why a specific technique was used, many authors apparently use the "latest", assuming it to be the best method available (Kent and Ballard

1988). Multivariate data analysis has been described in detail by several authors (Mueller-Dombois and Ellenberg 1974, Whittaker 1978 and 1982, Gauch 1986, Kent and Coker 1992).

For the purpose of vegetation description and -mapping, the following has been applied in many publications (see below) and can be recommended:

Relevés should be grouped with a classification procedure, e.g. TWINSPAN (Two-Way Indicator Species Analysis), which is supported by the TWINSPAN PC program. One advantage is that a relatively large data set, which will inevitably be collected for describing vegetation units of a larger area, are easily handled and simplified by such a classification procedure. A TWINSPAN classification is often refined using Braun-Blanquet procedures (Gauch 1986, Kent and Ballard 1988, Kent and Coker 1992, Bredenkamp and Bezuidenhout 1995, Hill 1996, Hoare and Bredenkamp 1999).

The most widely used ordination techniques are Principal Components Analysis (PCA), Detrended Correspondence Analysis (DCA) and Canonical Correspondence Analysis (CCA) (Kent and Ballard 1988). The choice of method depends on the data set available and the outcome hoped for.

PCA is a multivariate statistical technique, determining the axes by a linear combination of weighted species abundances. Much criticism has been given to this ordination technique because it is based on a linear model. It is best applied where data from a relatively narrow range of environmental and compositional data exist. Despite it's shortcomings, this makes it an easy method to apply to "summarised data", e.g. a data-set already classified into communities, adding environmental data, to make some ecological sense of the data set (Ludwig and Reynolds 1988, Kent and Ballard 1988).

DCA is useful to detect possible relationships or gradients in and between plant communities, while also detecting the more important habitat gradients influencing the vegetation. Usually, DCA is performed as a second, independent step after communities have been delimited, but the most important habitat factors influencing these communities need to be defined. DCA, like the classification, ordinates samples according to their floristic characteristics, while environmental gradients are inferred from species composition data, therefore resulting in a indirect gradient analysis patterns (Palmer 1993, Bezuidenhout *et al.* 1994, Hill 1996). Environmental variables used here are not necessarily specifically measured at each relevé.

CCA is a direct gradient analysis, which includes environmental factors as independent variables and species and sample data as dependent variables. CCA is thus useful if no prior classification of communities has been done, but detailed environmental variables have also been recorded for each relevé. Although CCA is regarded the most accurate of all ordination methods (Palmer 1993), its success depends on detailed environmental variables.

7.3. VEGETATION MAPPING WITH THE AID OF REMOTE SENSING

Vegetation classifications themselves are based on measurements made directly in the field. Vegetation maps, on the other hand, while relying on some guidance from field data, are mostly constructed manually or processed digitally from remotely sensed data (Plumb 1991). Thematic maps are in essence highly generalised abstractions of reality, especially in terms of their spatial resolution, boundary delineation and classification detail. Maps derived from remotely sensed data are based on units that can be spectrally separated. A drawback is that cartographers interpreting digital data become so involved in identifying spectrally separable units, that the nature of the vegetation these units represent is neglected (Plumb 1991, Tanser and Palmer 2000). This is further complicated by what cartographers, even after 20 years of development of image processing techniques, refer to as the "difficult third dimension" of vegetation: Existing remote sensing techniques are very effective in detecting vegetation structural types or percentage cover or stress symptoms, but is less able to discriminate different species assemblages like plant communities or variations thereof (Lewis 1998, Bork *et al.* 1999). The use of various vegetation indices, of which the NDVI is probably the best known, are used on a regular basis to assess plant production or drought stress, but cannot be used to delimit vegetation on a much finer scale than biome-level. However, it is exactly this understanding of specific types of vegetation composition which is important to environmental management and monitoring, e.g. on a farmland scale (Lewis 1998, Bork *et al.* 1999, Strohbach 2001). The other reality is that in countries such as Namibia the area to be mapped is so vast and baseline data so limited, that only a small proportion of the area on the ground can actually be visited for field evaluation with common time- and financial constraints (Stoms 1996, Strohbach 2001). It is thus a great advantage if, for the larger part of a potential vegetation map, the cartographer can rely on remotely sensed data, bearing in mind its limitations (Tanser and Palmer 2000, Langley *et al.* 2001).

Vegetation maps of spectral images are created by classification of spectral signatures contained within each pixel (Albertz 2001). Ideally, such image classification should recover the true class of every point in the image. In practice, a classification can only recover dominant classes (spectral signatures) of each pixel. A strong correspondence is definitely apparent between most plant associations classified by traditional field method and the different categories of spectral characteristics, but there are often vegetation types which overlap spectrally (ERDAS 1997, Albertz 2001). Even more confusing is the occurrence of vegetation types, especially with a very patchy structure such as open savannas, are represented by a very broad range of spectral characteristics, which a processing program may inevitably misclassify. Looking at the image itself there may be mixed pixels which may overlap two well-defined classes, or the spectral discrimination between classes is so minute that misclassifications may be common. Such cases are especially true where vegetation is sparse, with a high degree of open soil or rock confusing the spectral image of the vegetation (Plumb 1991, Goodchild 1994, Lewis 1998, Tanser and Palmer 2000). This brings about some major uncertainty in image processing which cannot be resolved without the knowledge of the actual circumstances on the ground. It is very important that vegetation mapping is not done with remote sensing alone, a classification of field measurements of the vegetation is indispensable (Frederiksen and Lawesson 1992, Akthar *et al.* 1995, Bork *et al.* 1999).

The accuracy of an image classification can be compared to a vegetation classification with statistical matrices, of which the Kappa statistic is the most widely used. It calculates the percentage of misclassified pixels. Statistical methods should be used with caution though - accuracy assessments are regarded most effective for small-scale mapping with a high spatial resolution and relatively few classes. The requirements for statistically sound measures of class accuracy are a minimum of 50 ground-samples to be conducted for every spectral class (Congalton 1991 in Stoms 1996 and Lewis 1998). It is appreciable that for larger area maps, such as in this study, such an amount of sampling would be very difficult to achieve for reasons mentioned above already. Added to that, on a larger scale, the cartographer chooses the level of resolution of the map which should meet the mapping objectives - finer-grain features are often treated as inherent heterogeneity. In such case boundary detection should be done either by a pre-determined number of additional samples over vegetation boundaries, or should be derived subjectively from photo-interpretation of satellite-images and/or aerial photographs. Other thematic maps, such as soil maps, may also be used to aid in boundary detection (Stoms 1996).

7.3.1 Some basic technical background on satellite image processing

Images obtained from satellites are, in their initial format, distorted, especially at the edges. This is a simply a result of the roundness of the earth's surface. Further, image quality may be poor due to haze, angle of the sun or other factors, which may be improved by various techniques. This pre-processing is rather complex and, although important, beyond the scope of this study. Following will be based on the assumption that a properly rectified and geo-referenced image is at hand.

The digital image consists of a multivariate field, with each pixel being a representative value of the spectral response measured for that particular point on earth at that particular time. In subsequent scans at a different time of day or year, such value for the same point on earth will inevitably vary (making it difficult to for e.g. combine successive or multi-temporal images). Pixel size varies for different satellite systems. For LANDSAT -7-TM, from which our images were derived, the pixel size represents roughly 30 x 30 m on the ground, meaning that relevé size of field surveys may not be smaller than this size, but preferably bigger to be used for image processing. In comparison, AVHRR images - commonly referred to as NOAA, used for NDVI calculations, have a pixel size of 1000 x 1000 m.

i. Types of image classification

There are primarily two approaches to image classification:

i.i Unsupervised multispectral classification attempts to delineate major land cover classes without prior knowledge of their identity. This can be useful in planning field sampling procedures, deciding beforehand how many samples should be representative of the classes and where these samples should be taken. Depending on the amount of classes distinguished, however, for reason mentioned above this may lead to the omission of some veld types.

Note: the use of (unclassified) false-colour composite images may be useful to effectively choose representative, homogenous areas to sample, rather than relying on the traditional reconnaissance survey alone.

i.ii Supervised multispectral classification uses statistical properties of "training sites" to identify land cover classes with similar spectral properties. These "training sites" are most sensibly chosen based on field samples, whose location can be superimposed onto a digital image, and include a pre-set minimum of pixels around this sampling point which are as closely related to the field sample as possible. Training sites are selected on screen, using imaging software such as ERDAS.

ii. Multi-temporal or single date scanned image, and which date is best?

Following the literature, there is as much argument for the use of multi-temporal images as against. Multi-temporal merely refers to the combination of images of the same scene taken at different times of the year, combined, and then classified. The successful use of any digital image for classification depends on adequate spectral contrast between vegetation types, which some authors tried to obtain by combining wet- and dry-season images. The idea behind this practice is to take advantage of phenological differences between vegetation types being more pronounced during different seasons (Lewis 1998). This approach proved very successful to discriminate between crops, but not as good for natural vegetation. Several workers have found that a single date-image, taken at the "dry-off" season, produced the best classification results. During the dry-off season (after the peak of the rainy season), some parts of the vegetation may be fully grown, other already starting to die back, thus representing the most diverse phenological stages between vegetation types (compare with Lewis 1998, Langley *et al.* 2001, Clark *et al.* 2001).

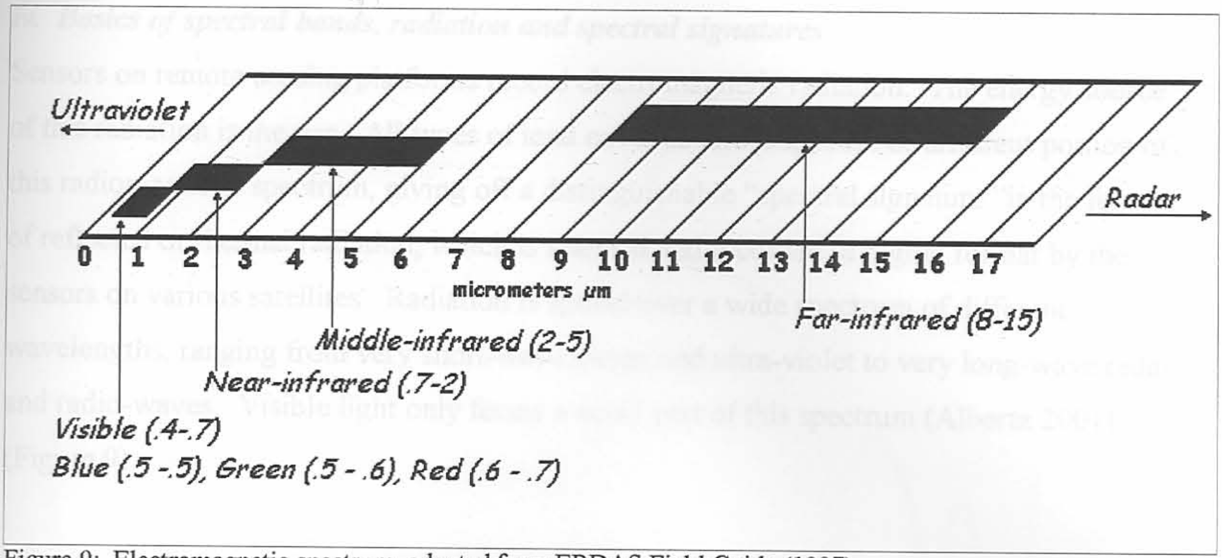

Figure 9: Electromagnetic spectrum, adapted from ERDAS Field Guide (1997).

iii. Minimum requirements of field sampling and data analysis for the most realistic spectral classification

Several early workers have collected floristic data only, but that alone will not suffice to try to understand very heterogeneous vegetation patterns. Based on above discussions, it is thus recommended that for the best correlation of classifications of a digital image with objective numeric vegetation classifications, following guidelines should be followed:

- to quantify vegetation, plant cover estimates rather than density or presence/absence should be recorded
- inclusion of physical cover, e.g. % bare soil or summation of total vegetation cover is often useful, this is especially important in more arid habitats where total vegetation cover is sparse
- incorporation of abiotic factors (habitat) for vegetation classification is likely to result in a stronger relationship between spectral and vegetation classification
- use of an objective classification of field data prior to satellite image classification is advisable; should certain standardized classification methods be preferred in a region, e.g. TWINSPAN in southern Africa, use such methods on a preferential (albeit not exclusive) basis
- when choosing training sites for the spectral classification, select as many sample sites typical of vegetation-units (identified by the classification of the field-data) as possible. Avoid outliers, as these will most likely also result in "outlier" spectral signatures, which should be excluded from the classification of satellite data.

iv. Basics of spectral bands, radiation and spectral signatures

Sensors on remote sensing platforms record electromagnetic radiation. The energy source of this radiation is the sun. All types of land cover absorb a specific or different portion of this radiomagnetic spectrum, giving off a distinguishable "spectral signature" in the form of reflected or thermal radiation, which is scanned and recorded in digital format by the sensors on various satellites. Radiation is spread over a wide spectrum of different wavelengths, ranging from very short-wave x-rays and ultra-violet to very long-wave radar and radio-waves. Visible light only forms a small part of this spectrum (Albertz 2001) (Figure 9).

Specific wavelengths are absorbed by gases in the atmosphere, some so strong, that scanned values do not give sensible images. Multispectral scanners such as LANDSAT -7-ETM (ETM = Enhanced Thematic Mapper), have different sensors scanning different wavelengths, which are carefully selected to avoid wavelengths which are mostly absorbed (Albertz 2001) (Figure 10).

LANDSAT ETM band 3 (0.63 - 0.69 µm) is an important band for vegetation discrimination, known as the red chlorophyll absorption band. It is largely controlled by chlorophylls a and b, as well as leaf pigments such as carotenoids, xanthophylls and anthocyanins. Band 4 (0.76 - 0.90 µm) is sensitive to canopy cover of vegetation biomass - it is controlled by cell structures. Leaves from the top of the canopy may reflect 50-60% of the near-infrared radiation, while lower leaves may re-transmit such radiation back through the upper canopy. Band 5 (1.55 - 1.73 µm) is sensitive to the water-content of vegetation, hence reflect vegetation stress or disease, which affects leaf turgor. Wilted leaves scatter less light, therefore increasing the reflectance of red (band 3) and a decrease in mid-infrared due to a decrease of chlorophyll and water content. Thus, band 3,4, and 5 are usually selected for image processing in vegetation studies (Albertz 2001, Langley *et al.* 2001).

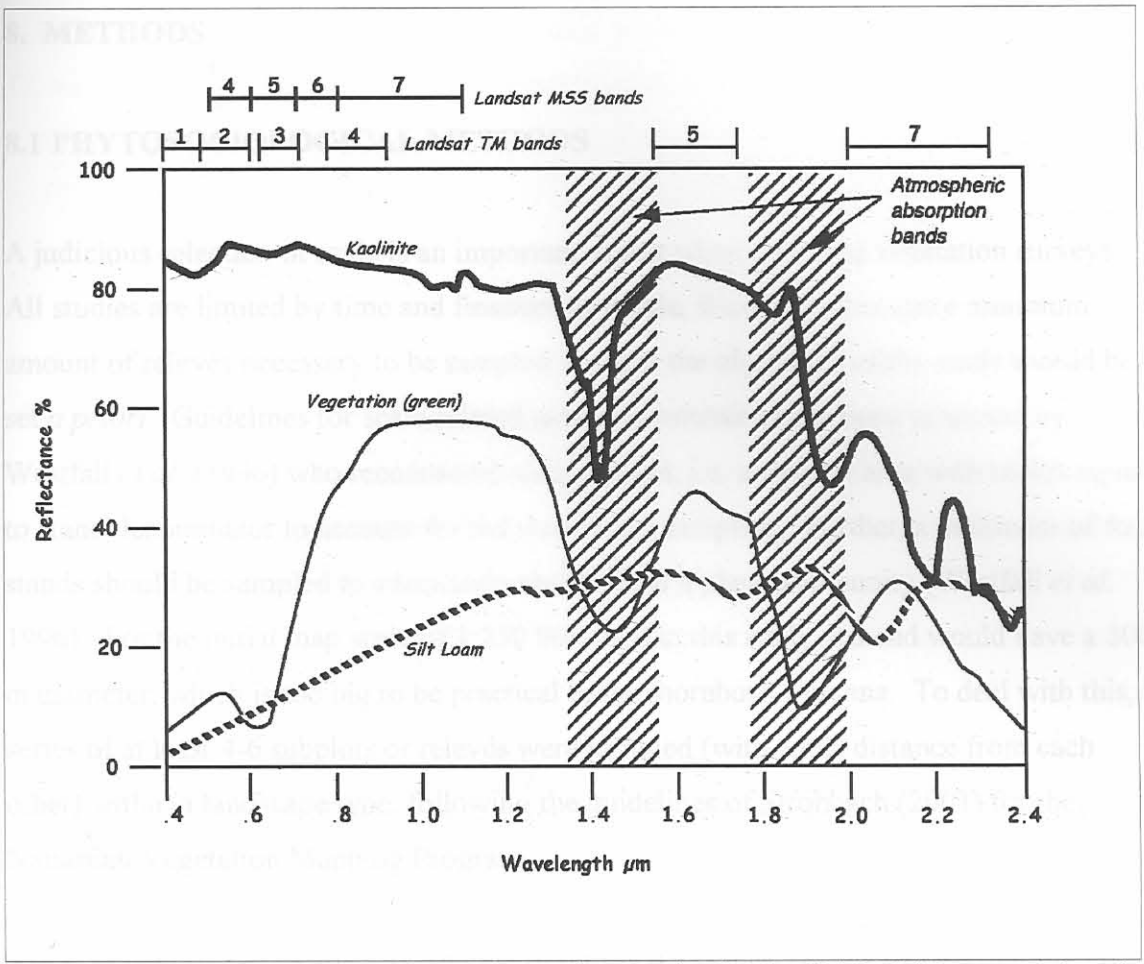

Figure 10: Some typical reflectance spectra compared to scanning-bands of LANDSAT sensors (adapted from ERDAS field guide)