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DECLARATION

**A DECISION SUPPORT SYSTEM FOR THE MANAGEMENT
OF BIODIVERSITY RESOURCES IN KENYA:
A CASE STUDY FROM KENYA WILDLIFE SERVICE** //

BY

Charles Lwenya / Amuyunzu

**A thesis submitted in partial fulfilment for the degree of Doctor of
Philosophy, Kenyatta University**

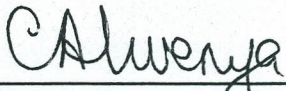
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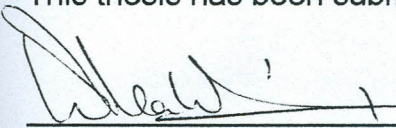
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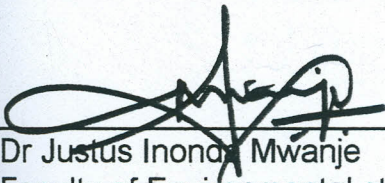
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Dedication

This thesis is dedicated to my parent, Mr David Lwenya Avihama and Mrs Serah I. Lwenya for teaching me how to set goals, work hard, remain focussed and persevere until I reach my set target.

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Abstract

Throughout the world, environmental problems resulting from human activities are causing great concern to environmental scientists and the general public. Although many of the human activities that contribute to these problems are localized, the repercussions are felt not only at the local level but also at the regional, national, supra-regional, continental and global levels. Concern about many of these problems was first expressed in the late 1960s and culminated in the first United Nations Conference on the Human Environment, in Stockholm in 1972, that led to the establishment of the United Nations Environment Programme (UNEP). However, it took another 21 years to formalize the international legitimacy of these issues, which found its expression in the United Nations Conference on Environment and Development (UNCED), held in Rio de Janeiro in 1992, and its Agenda 21—an agreement that was signed by many heads of state. Loss of biodiversity is one such problem. Over the last two decades, there has been general agreement that global biological resources are declining at an accelerated rate, mainly through species extinction. Concern for the loss of biodiversity in Kenya has resulted in a number of government policy initiatives that address the problem. The Kenya Wildlife Service (KWS) has been given the mandate to conserve the existing biodiversity resources in the country.

Decisions related to biodiversity conservation are made at three levels: national, regional and local levels, each of which requires different levels of abstraction of information. Although the different decisions made at each level generally require specific information, similar data acquisition procedures are needed at all levels (ground truth, airborne and satellite data). Because collection of data on biodiversity resources can be very costly, a large organization like KWS needs to restrict acquisition to those data items that are essential for information to support biodiversity conservation decisions and to ensure consistency in the use of data and subsequently derived information. Research to determine how this can be accomplished was the main focus of this study and Tsavo ecosystem was used as a case study. This study was designed to define, develop and test a prototype of such a decision-support system for management of biodiversity resources on a sustainable basis.

This study applied existing system analysis and information system development methodologies, tools, and techniques to develop a prototype decision support system for management of biodiversity resources in Kenya. This system has been tested using two case studies from the Tsavo Ecosystem.

Results from the case studies show that modern information technology concepts and theories can be modified to provide a powerful tool for effective and efficient management of biodiversity resources on a sustainable basis. The prototype should now be tested and implemented in the whole Kenya Wildlife Service organization.

List of Abbreviations

ANOVA	Analysis of Variance
CASE	Computer-assisted Software Engineering
CBD	Convention on Biodiversity
DEM	Digital Elevation Model
DBMS	Database Management Systems
DFD	Data flow diagrams
ER	Entity Relation
EER	Extended Entity Relationship
FDS	Formal Data Structure
FAO	Food and Agriculture Organization
GIS	Geographic Information System
GPS	Global Positioning System
IBM	International Business Machine
IUCN	International Union for Conservation of Nature
KWS	Kenya Wildlife Service
MBW	Metabolic Weights
NGO	Non Governmental Organization
SDM	System Development Methodology
SDW	Systems Workbench
SQL	Structured Query Language
SRF	Systematic reconnaissance flight
TLU	Tropical Livestock Unit
TM	Thematic Mapper
UNEP	United Nations Environment Programme
UNCED	United Nations Conference on Environment and Development
UTM	Universal Trans Mercator

Chapter 1 Introduction

1.1 Background to the Problem

Throughout the world, environmental problems resulting from human activities are causing great concern to environmental scientists and the general public. Examples of these problems are many, but those that are notable and have received the greatest attention in recent years include: global warming, resulting in part from increased carbon dioxide levels in the atmosphere; loss of biodiversity; heavy-metal pollution of rivers, oceans and ground water aquifers; acid precipitation; land degradation such as desertification; and the depletion of the ozone layer. Although many of the human activities that contribute to these problems are localized, the repercussions are felt not only at the local level but also at the regional, national, supra-regional, continental and global levels.

Concern about many of these problems was first expressed in the late 1960s and culminated in the first United Nations Conference on the Human Environment, in Stockholm in 1972, that led to the establishment of the United Nations Environment Programme (UNEP). However, it took another 21 years to formalize the international legitimacy of these issues, which found its expression in the United Nations Conference on Environment and Development (UNCED), held in Rio de Janeiro in 1992, and its Agenda 21—an agreement that was signed by many heads of state. The general consensus in 1972 and now is that these problems, many of which transcend national boundaries, represent formidable challenges that can be effectively addressed only through better co-operation among governments to ensure that activities under their control do not damage their environment and that of other states or areas beyond their national jurisdictions (see Hinteregger, 1992). This requires the establishment of a policy and operational framework under which governments can address specific problems of common interest.

Over the last two decades, a variety of global conventions, protocols and inter-

governmental treaties have been formulated to address specific environmental problems. The underlying concept in all these instruments is generally the same, that is, think globally and act locally. Governments which become signatories are expected to work towards achieving specific objectives and goals set within the frameworks of these treaties, protocols and conventions, by among other ways developing policies and legislation which will enable them fulfil their obligations, especially at the national level. At the regional level, these policies have to be translated into practical programmes for implementation at the local level.

The different levels in the decision making hierarchy represent different decision making contexts. Each of these requires different levels of abstraction of information. At the lowest level, this often includes data from direct surveys. At higher levels, information entities are defined as derived survey information. In the design of a survey system, it will be necessary- for efficiency, to ensure data consistency and to avoid redundancy--to attempt to carry out one survey from which all the other information at the different context levels can be derived. The challenge for governments is putting into effect the 'conventions, protocols and treaties' to which they are signatories, and acquiring data at the lowest cost from which information to support management decision making at all levels can be derived. This challenge constitutes the main focus of this study as set out in the statement of the research problem .

1.2 Statement of the Research Problem

Over the last two decades, there has been general agreement that global biological resources are declining at an accelerated rate, mainly through species extinction (Pellew, 1995; Huston, 1994; McKendry and Machlis, 1991; Wilson, 1988). The attention given to this loss of biological resources has led to the addition of a new word in the English language, "biodiversity" (a contraction of 'biological diversity', Wilson, 1988). It is as a result of the global concern about the continued loss of these resources that the Convention on

Biodiversity (CBD) resources was approved at the UNCED conference in Rio de Janeiro in 1992.

Concern for the loss of species in Kenya has resulted in a number of government policy initiatives that address the problem. The Kenya Wildlife Service (KWS) has been given the mandate to conserve the existing biodiversity resources in the country. Before the establishment of KWS in 1989, the main emphasis of conservation as carried out by the Game Department was on wildlife species. In this context, wildlife species were referred to only as free-ranging birds and large mammals. Under the KWS, the emphasis changed to the conservation of overall biodiversity resources in the country. The organization has recently undergone the process of restructuring to better meet this challenge of conserving nature. In the new structure, decisions related to biodiversity conservation are made at three levels of a nested spatial hierarchy: national, regional and local (protected area) levels. The national level establishes long-term policy on biodiversity conservation. Due to practical and financial constraints, it is not possible to protect all available resources. A typical question for management at this level is *'what biodiversity resources need to be conserved?'* This requires a systematic approach to analyzing and prioritizing the available biodiversity resources on the basis of well defined criteria. This is to ensure that all biodiversity resources in the country are assessed in a consistent manner.

A decision hierarchy provides a suitable tool for such an approach. Such a hierarchy should be based on ecological principles: first, the management has to decide on which level (genetic, species or ecosystem) the biodiversity resources should be measured, and then in sequence determine: what biodiversity resources are present and where they occur, secondly, whether they are endemic, and thirdly whether they are under threat of extinction and whether the population is viable and its conservation is sustainable. These decisions would require data on distribution and densities of the targeted resources and land use. This would be generalized qualitative information with a coarse spatial resolution. This information would normally be acquired from ground and airborne surveys and from satellite data.

Having established the biodiversity resources which should be conserved, the regional-level management is challenged to translate these decisions into action programmes. The information support required at this level should involve some inventory, but more importantly, it involves monitoring and prediction to assess performance and environmental impact, and for planning and design. Regional management requires quantitative information with a higher spatial resolution than at the national level. Although this is a key management level in the conservation of biodiversity, it has no independent source of data for the information it needs because most of them come from local units that report to it. Most of this information is acquired from ground and airborne surveys and satellite data analysed at a more detailed scale than at the national level.

Conservation programmes are usually executed at the local level. The management at this level has to decide on what biodiversity conservation activities are acceptable to the local communities. The management here requires current information so as to address current resource issues, and it is critical that there should be an accessible information system. These requirements place a significant demand on the system to provide the required information, to an agreed level of accuracy and reliability, within a set time frame (McCloy, 1995). Most of this information is acquired from large-scale photographs and ground survey data.

Given the above discussion, it is clear that information is a critical factor in the success of biodiversity conservation. It is also clear that information required to support decisions in biodiversity conservation is contextual in the sense that specific information is needed for certain decisions at different levels. Although the different decisions made at each level generally require specific information, similar data acquisition procedures are needed at all levels (ground truth, airborne and satellite data). Because data collection can be very costly, a large organization like KWS needs to restrict acquisition to those data items that are essential for information to support biodiversity conservation decisions and to ensure consistency in the use of data and subsequently derived information. Research to determine

how this can be accomplished was the main strategy of this study. The Tsavo ecosystem was found suitable for use as a case study.

Information for biodiversity conservation is extracted from spatial data on biodiversity resources. Biodiversity conservation involves managing processes related to the resource, predicting the impact of different management interventions on the resources and evaluating the effects on the resources of those management interventions. There must therefore be a structure for the definition of the data that are required, for monitoring and regular updating of data on the resource, and for transforming these data (which may come from different sources) into management information. This implies that for biodiversity conservation, KWS needs a decision-support system. In this study, the definition of a decision-support system by McCloy (1995) is used i.e. a computer-based system that transforms and presents survey information in a form and manner to assist managers make specific resource management decisions. A Geographic Information System (GIS) is one such system that provides a certain structure for the description of spatial data and the tools for storing, retrieving, transforming and displaying geographic data (Burrough, 1986; Johnson, 1990; Haines-Young *et al.*, 1993). Identifying the need for a decision-support system in biodiversity conservation is the first step. The next step should be to define a framework under which this technology (GIS) could be designed and implemented, the institutional conditions that need to be created, the investments that need to be made and the time required to enhance the chances of its successful integration into the decision making process.

1.3 Research Questions

As a step towards addressing the above biodiversity conservation issues, answers to several questions had to be sought through research. These questions include:

- (1) What are the different levels of management decision making in biodiversity

conservation ?,

- (2) What information is needed to support decisions at these different levels and how is it used?,
- (3) What data are required to provide this information?,
- (4) How can these data be efficiently acquired, stored and managed?,
- (5) Does Tsavo National Park provide adequate protection for all the biodiversity resources in the region?,
- (6) What is the status and trends in the wide herbivore resources of the Tsavo ecosystem?,
- (7) How can one predict the potential for human/wildlife conflict in the Tsavo ecosystem?.

1.4 Study Objectives

The broad objective of this study was:

To develop a mechanism for the provision of information necessary for effective and efficient management of biodiversity resources in Kenya.

The specific objectives were to :

- (1) Design an information-abstraction structure for multi-level management decision support in biodiversity conservation in Kenya,
- (2) Test the decision-support system designed in (1) above, in the Tsavo Ecosystem (Taita Taveta district) to: (a) model biodiversity resources and the current trends in the resources at a regional and national scales, and (b) model threats to biodiversity resources at a local scale.

1.5 Study Hypotheses

This study had an overall and specific hypothesis.

1.5.1 Overall Hypothesis

This study involved the development of methodology and techniques for applying modern (digital) information technology theories and concepts to the sustainable management of biodiversity resources in Kenya. It entailed a detailed examination of processes and procedures. Consequently, the overall hypothesis could not be tested in the traditional way that draws on parametric models. Instead, cases studies have been used to determine whether techniques and methodologies developed do provide information that is needed to support decisions in the sustainable management of biodiversity resources.

Thus, the overall hypothesis of this study was:

That digital information technology provides a powerful decision support tool for efficient and effective management of biodiversity resources on a sustainable basis.

1.5.2 Specific Hypothesis

Within the framework of case studies, the specific hypotheses were:

a) Given the general linear regression model

$$Y_i = \beta_0 + \beta_1 X_{1i} + \beta_2 X_{2i} + \dots + \beta_p X_{pi} + \varepsilon_i$$

Where

β_0 = regression constant

$\beta_{1, s}$; $V_{1, s} = 1, \dots, p$ are partial regression coefficients

ε_i = random errors; $\varepsilon_i \sim N(0, \sigma^2)$

Y_i = the i^{th} observation of the dependant variable

x_{pi} = the i^{th} observation of the independent variable p .

For $\forall \beta_{i,s} = 0$, where $i = 2, \dots, p$, the general linear regression model becomes a simple linear regression model

Hence, the specific hypothesis for this model was:

$$H_0 \beta_{i,s} = 0$$

H_1 : Alternative

The above hypothesis was tested at the sub-class level (data on individual animal species was used); class level (data on animal species were grouped on the basis of their feeding habits, i.e. grazers, mixed feeders and browsers); and the super-class level (data were grouped on the basis of food types). Each level of analysis was done at three spatial units: area inside Tsavo protected area, area outside Tsavo protected area, and the entire Tsavo ecosystem. The adopted model set Y , animal population estimate as the response variable, and time (years), as the explanatory variable.

b) To study animal population trends, a quadratic model was adopted. This model was of the form:

$$Y_i = \beta_0 + \beta_1 x_i + \beta_2 x_i^2 + \epsilon_i$$

Where

β_0 = regression constant

$\beta_{i,s}$: $V_{i,s} = 1, 2$, are partial regression coefficients

ϵ_i = random errors; $\epsilon_i \sim N(0, \sigma^2)$

Y_i = the i^{th} observation of the dependant variable

x_{pi} = the i^{th} observation of the single independent variable.

Hence the specific hypothesis for this model was:

$$H_0: \beta_{i,s} = 0$$

$$H_1: \beta_{i,s} < \text{or} > 0$$

Using the same spatial units as was the case under specific hypothesis (a) above, Y was set as the animal population estimate (response variable) and X, time (years) being the explanatory variable.

- c) To fit the logit regression on animal distribution data in Tsavo Ecosystem, the biodiversity resources model was stated:

$$\text{OBS} = 1/1 + \exp(a + b \cdot \text{scdst} + c \cdot \text{scdst}^2 + d \cdot \text{veg} + e \cdot \text{veg}^2)$$

Where

OBS = the possibility of observing an elephant based on distance to water and vegetation cover

scdst = distance to watering point

veg = distance to vegetation cover

This is a second order polynomial response function with specific hypothesis:

$$H_0: \text{OBS} = 1/(1 - \exp^*a)$$

H₁: Alternative

1.6.2. Practical Significance

1.6 Research Rationale

This study is significant at both the scientific and practical level.

1.6.1 Scientific Significance

Biodiversity resources can be viewed at three hierarchical levels, ie, genetic, species and ecosystem. The structure, functioning and behaviour of any given animal or plant species is determined by a unique set of inherited genetic material. Species in turn are the building blocks of ecosystems, and ecosystems provide the life support systems for humans. It is in

this sense that the conservation of species diversity assumes indispensable importance.

Parliament established a Biodiversity Commission in 1996.

Biodiversity resources provide social, cultural, ethical and economic values to society. These resources, especially when maintained as natural systems, assist in controlling runoff, are reservoirs of many valuable plants and animals, can yield timber on a sustainable basis, build soils and control erosion, and attract tourists hence, generate revenue for the country. Given these multiple values, it is imperative that these resources are conserved. Although biodiversity resources are renewable, they are also fragile. The way they are managed can enhance or reduce their diversity. Effective management systems can ensure that these resources not only survive, but also increase while they are being used, thus providing the foundation for sustainable development. To effectively manage biodiversity resources, managers need to have adequate information about their structure and functioning. This information is usually extracted from data collected on these resources. Due to the vast nature of these resources, large volumes of data are usually collected. For effective utilization of these data, there is need to have a mechanism for their collection, handling, storage, analysis and presentation. This study set out to develop such a mechanism to support the effective management of biodiversity resources in Kenya.

This study set out to develop a prototype decision support system for

1.6.2 Practical Significance

The resulting prototype set to be used to improve the

Since the beginning of this century, wildlife in Kenya has been managed through a network of national parks and game reserves. Until 1976, national parks were managed by a Board of Trustees under the National Park Service, while game reserves were managed by the game department. The *1976 Wildlife Conservation and Management Act* brought the management of national parks under the Department of Wildlife Management and Conservation in the Central Government. In the period between the 1970s and late 1980s, there was a rapid decline in the numbers of certain wildlife species, notably elephants and rhinos, mainly through poaching (Mbugua and Stevens, 1977; Ottichilo *et al.*, 1981; Van Wijngaarden, 1985; Cobb, 1976; Kenya Wildlife Service, 1990; Mwenje International

Associates Ltd, 1980). In reaction to this decline, the government in 1989, through an Act of parliament, established a parastatal organization, the Kenya Wildlife Service with the mandate to deal with the problem of poaching, in addition to managing wildlife. By 1994, poaching in most protected areas had been brought under control and the Kenya Wildlife Service could concentrate on the other aspects of its mandate.

In 1994, the government instructed KWS to propose changes to the wildlife policy by taking into consideration the changing environmental and socio-economic values with regards to biodiversity and to prioritize issues related to biodiversity resources, and to address their sustainable use. The new policy defined a new mission for KWS (KWS, 1996). The new mission for KWS was to conserve biodiversity, promote partnership in biodiversity conservation and promote nature tourism based on the country's total biodiversity. KWS is therefore mandated to coordinate the management of all biodiversity resources in Kenya. Given this setting, this study contributes towards this mandate through the development of a mechanism for the provision of information to support decisions in the management of biodiversity resources in Kenya at the different hierarchical levels.

This study set out to develop was a prototype decision support system for the management of biodiversity resources in Kenya. The resulting prototype had to be evaluated for its effectiveness and efficiency in a real life situation. Tsavo ecosystem provides a unique site for such an evaluation because:

- (1) it spreads over five agro- climatic zones and therefore has a wide range of biodiversity resources.
- (2) it has one of the highest concentration of wild animal species (Mbugua and Stevens, 1977; Ottichilo *et al.*, 1981; Van Wijngaarden, 1985; Cobb, 1976; Kenya Wildlife Service, 1990; and Mwenge International Associates Ltd, 1980).
- (3) all known major threats to biodiversity conservation in Kenya are present in this area ; habitat alteration, rapid human population growth in the surrounding areas, over-harvesting and poaching (Van Wijngaarden, 1985; Cobb, 1976; and Kenya Wildlife Service, 1990).

Chapter 2 Literature Review

2.1 Concepts of Biodiversity Resources Conservation

There are various concepts that are applied in biodiversity resources conservation. This chapter deals with literature on emerging concepts in information technology that can be applied as a management tool in the conservation of biodiversity resources in Kenya. Key concepts that were applied in this study are discussed in subsequent sub-sections of this chapter.

2.1.1 The Value and Threats to Biological Resources

Drawing on the World Charter for Nature, adopted by the General Assembly of the United Nations on October 1982 and World Conservation Strategy (IUCN, 1982), the IUCN's working group on ethics and conservation produced an ethical foundation for conservation (McNeely, et al. 1990). It concluded that the ethical basis for conserving biodiversity should be consistent with ecologic principles while promoting their sustainable use. The priority given by countries to the conservation of biodiversity resources should be based on the contribution of these resources to the economy at national, regional and local levels. Countries should strive to maintain maximum variety in their biodiversity resources to ensure the well being of present and future generations. However, in many countries, Kenya included, there are many threats to the maintenance of maximum variety in biodiversity resources. The most notable ones are:

- a. **Habitat alteration**, usually from highly diverse natural systems to far less diverse (often monocultural) agroecosystems. This is clearly the most important threat, often related to land-use changes on a regional scale that involve great reduction in the area of natural vegetation (McNeely, et al., 1990; FAO/UNEP, 1982; FAO, 1981). Such a reduction in area - often involving fragmentation of species habitats -

inevitably mean reductions in populations of species, with a resulting loss in genetic diversity and an increase in the vulnerability of species and populations to diseases, hunting and random population changes (Soule' and Wilcox, 1980).

- b. **Rapid population growth**, as a result of better health care. The human population which was estimated at 1 billion at the beginning of the 19th century, reached 2 billion in the 1920s, and totals over 6 billion today (McNeely, et al., 1990). This rapid growth has been accompanied by a corresponding increase in demand for fuelwood for cooking and food. Land under highly diverse natural systems has to be cleared and converted to production of food and fuelwood leading to habitat alteration as stated above.
- c. **Over-harvesting and poaching**, i.e. the taking of individuals at a higher rate than can be sustained by the natural reproductive capability of the population being harvested. This is especially common with large herbivore species, fish and tropical rain forests.
- d. **Introduction of new species**, which in certain cases may virtually replace native species of plants or animals. An example is the weed *Salvinia molesta* which invaded the natural water system of Lake Naivasha, in the African Rift Valley, and has greatly reduced the fish resources within the lake.

Effective management of biodiversity resources requires a clear understanding of the manifestations of these threats on species and habitats. For this, there is a need for data from which information can be extracted to support management decisions. In this context, the following terms are important:

Species: Extinction of species has always been there since their origin. In the past, extinctions occurred by natural processes, but now most extinctions are due

to human activities, especially the destruction of tropical forests (habitat loss), introduction of predators, and over-harvesting. Given that only about 10 % of the total species in tropical forests have been described (McNeely, et al., 1990), it is possible that many species could become extinct even before they are described. Species diversity is also being reduced through the loss of races and varieties of domesticated species as a result of their breeding by humans. Major crops like maize and rice are examples of species where the gene pool amounts to only a fraction of the genetic diversity they harboured many years ago. This makes them much more vulnerable to disease, climate change and other environmental adversities. It is therefore vital that human induced species extinctions are reduced significantly.

Habitats: Tropical rain forests cover only 7 % of the earth's surface but contain at least 50 % of all the plant and animal species on the earth (McNeely, et al., 1990). This species richness was illustrated by Whitmore et al. (1985), who counted 233 species of vascular plants in just 100 square meters of lowland tropical forest in Costa Rica. These forests are increasingly threatened by human destructive activities. FAO/UNEP (1982) estimated that 11.1 million ha of tropical forests are eliminated each year and that all closed forests would be cleared in 177 years (FAO, 1981). This deforestation leads to a reduction in plant species diversity and a loss of habitat for many animal species which in turn become threatened with extinction. Other habitats where biodiversity resources are threatened by human activity are wetlands, marine ecosystems and Mediterranean forests.

It is essential to conserve biodiversity resources because they make an important contribution to human welfare. Conservation should be done at the ecosystem level in order to preserve community processes and organization (habitats), and at the species level in order to address specific taxa that might be threatened. Conservation at these two levels

will ensure the preservation of species genetic variability. Managers of biodiversity resources need sufficient information, on which to base their decisions. To identify the different types of threats to biodiversity resources, information in different contexts has to be extracted from the same database and there has to be a mechanism to facilitate this process. Currently, such a mechanism does not exist in KWS. Hence this study.

2.1.2 Approaches to Conserving Biodiversity

Traditionally, the main focus of biodiversity conservation has been on use of protected areas and *ex-situ* mechanisms. Recently, it become apparent that at times, a large portion of wildlife resources, especially large herbivores, are to be found outside protected area boundaries. These have to be included in any management plans for biodiversity resources. A description of the basic concepts underlying these two approaches to conservation follow.

2.1.2.1 Protected Areas

Protected areas are regions designated by legislation for the protection and conservation of environmental resources. They are protected from illegal intrusions. There are 10 different categories of protected areas (IUCN, 1978). The basic principle of protected areas involves setting aside representative areas of unique and unspoiled parts of the country as public parks for the benefit and quiet enjoyment of the people, and for the detailed study of nature. Their establishment and management are based on ecologic principles, and emphasis is placed on ensuring that a country's natural resources are conserved for the benefit of mankind, both now and in future.

A protected area must possess special or unique natural qualities, e.g., great species diversity, the concentration of particular species or the presence of endangered species. Other criteria include:

- a. The area set aside should be sufficient for the maintenance of a 'minimum viable population' for the survival of the different species present.
- b. Protected areas should ensure positive interaction among the species within their confines, between the species and their environment, and between the species and the human population (and their activities) outside the park confines.

Although the first documented protected area was established in 252 BC, when Emperor Asoka of India passed an edict for the protection of animals, fish and forests (IUCN, 1986), Yellowstone National Park was the world's first protected area to be established on the basis of modern concepts and criteria. It was established as a 'public park or pleasuring ground for the benefit and enjoyment of the people' with the necessary legislation to safeguard it. By 1885, only three countries (the United States of America, Australia and Canada) had designated parks for the protection of wildlife (Eidsvik, 1986). Wildlife conservation in Africa had its start in 1897 when Hluhluwe, Umfolozi and St Lucia reserves, South Africa, were established (Harris and Sullivan, 1980). The earliest legislation that established game reserves and introduced controls on hunting in Kenya was enacted in 1898 (Kenya Wildlife Service, 1990). A game department to manage wildlife was established in 1907 and its main objective was to regulate hunting. In 1945, legislation was enacted that allowed the establishment of a board of trustees to manage land set aside for National Parks, and the first national park (Nairobi National Park) was established in 1946. The main emphasis here was on wildlife conservation. Currently, there are over 52 wildlife protected areas in Kenya (Kenya Wildlife Service, 1990).

At the time of establishing the first modern protected area, ecology as a subject was still embedded in biology, and the ecologic principles so central to nature conservation were just beginning to emerge. The ecosystem concept was not introduced until 1935 (Tansley, 1935). Since then, the ecosystem has been recognized as a fundamental organizational unit in ecology, especially in nature conservation. This is the unit that is used in testing the

prototype Decision Support System developed in this study. Many of the current problems that plague protected areas all over the world, and specifically in Kenya, can be traced to the fact that many were established without clear reference to ecologic principles. At the time of establishing the first modern protected area, ecology as a subject was still embedded in biology, and the ecologic principles so central to nature conservation were just beginning to emerge. Initially, the concept of conservation was to establish protected areas to conserve nature for its own sake. Sites were established, demarcated and made 'off limits' for any other type of land use. They were managed without much reference to the surrounding areas. This has resulted in sharp boundaries between protected areas and the adjoining populated areas, transforming the former into islands. Over the years, the concept of protected areas has evolved and now emphasizes their benefits to mankind, however, the underlying principle is still that of preserving wildlife.

Many protected areas were established at a time of low population pressure in areas traditionally used by pastoralists. Consequently, the pastoralists were excluded from the resources within and confined to the resources in the buffer zones. In this study, the term 'buffer zone' refers to an area adjacent to a protected area, where wild animals spend part of their time usually in search of forage and water.

Size, that is, sufficient size to be ecologically viable, is one of the most important criteria in establishing protected areas. This principle was not applied when establishing many of the present protected areas in Kenya. Emphasis was on conserving wild animals, and their distribution at the time of establishing the protected areas determined the placement of boundaries. Consequently, the home ranges of many large migratory species such as wildebeest, zebra, buffalo, elephant and gazelle have not been protected in their entirety, and for part of the year these animals are to be found outside protected area boundaries, thus leading to human/wildlife-related conflicts.

Wildlife distribution as a criterion in establishing protected areas has serious limitations. Some protected areas exclude climax plant communities, while others exclude successional stages effected by burning and grazing regimes, yet these are necessary in a proper conservation strategy. The exclusion of domestic grazing animals has resulted in changes in the vegetation composition in many protected areas, sometimes reducing diversity as pre-climax or climax dominants have become established (Tivy, 1994).

Initially, conflicting demands for the land resources were rare and went largely unnoticed. However as the human population grew and demands for land resources multiplied through changing land use practices, land use conflicts have increased. The recent rapid increase in small-scale agriculture at the expense of pastoralism in the buffer zone have made protected areas more isolated. This portends a primary threat to the wildlife within, given that the affected areas are increasingly becoming islands in the midst of change, and resource managers are being confronted with fundamental questions that must be addressed: (1) What is the minimum area required to protect the existing animal population in the long term without causing serious overgrazing and degradation of plant and soil resources? (2) Are the different animal species populations represented in adequate numbers to be ecologically viable in the long term? (3) What internal and external factors threaten the long-term survival of the protected areas? (4) Are there any animals in the area that need protection?

Besides being species- habitat- or ecosystem-oriented (Tivy, 1994), conservation management can also be landscape-oriented. Many of the early conservation efforts were based on individual plant or animal species, and they continue to be so. This strategy has tended to concentrate on known endangered or threatened species of plants or animals, with minimal focus on the population communities, processes, functions and dynamics of ecosystems. Inadequate monitoring means that the effects of this approach are only just becoming evident through soil erosion or habitat change. Hence the importance of a landscape approach.

The long-term survival of protected areas will depend on efficient management. This is conditional on resource managers having an in-depth understanding of the structure, functioning and dynamics of these areas. Although the requisite tools and techniques are now more readily available, data on any given protected area are rarely sufficient or up-to-date. Therefore, a logical starting point in the efficient management of protected areas is a comprehensive inventory of resources at local, sub-regional, national and regional levels. This forms the basis for resource monitoring. Such data should be compatible and comparable. This study aims at filling this gap by defining tools and a mechanism that will assist resource managers determine what type of data are required for effective management of biodiversity resources in Kenya.

2.1.2.2 **Ex Situ Conservation**

Biodiversity resources can also be conserved *Ex-situ* i.e. away from their natural habitat. *Ex situ* conservation mechanisms of biodiversity resources include botanical gardens, game farms, zoological gardens and gene banks. *Ex-situ* conservation of biodiversity resources provide for the long-term storage, analysis, testing, and propagation of threatened and rare species of plants and animals and their propagules. They are particularly important for wild species whose populations are highly reduced in numbers, serving as a backup to *in situ* conservation, as a source of material for reintroduction, and as a major repository of genetic material for future breeding, especially, of domestic species (McNeely, et al. 1990). The contribution of *ex situ* mechanism to conservation of biodiversity resources is limited by the fact that only a limited number of species can be kept in zoological and botanical gardens, and gene banks. Besides, little directional habitat-responsive evolution can take place *ex situ*, so the captive population are not responding to changing environmental conditions (McNeely, et al. 1990). The *ex situ* population is also likely to have a narrow gene base as a wide range of genotypes is unlikely to have been collected. Conway (1988) concludes that because of the limitations of space and the numbers required to maintain viable populations, it is impractical for zoos to sustain in the long term more than about 900 species of vertebrates and probably far fewer in conventional breeding programmes.

2.1.3 New Integrated Approach to Biodiversity Conservation

Many governments, Non Governmental Organizations (NGOs) and international agencies are now adopting an integrated approach to biodiversity conservation (Kenya Wildlife Service, 1990). This involves land management systems that contribute to conserving biodiversity while contributing sustainably to human needs. Population growth and economic development are threatening protected areas in many countries. Increasing populations require more food, consequently more land must be put under crop production. In many developing countries, this land is normally obtained by clearing natural vegetation. Besides, economic development can only be sustained by a steady supply of raw materials most of which are obtained from wild lands, especially forests. The list of demands placed on wild lands is expanding. Thus, governments today recognize that strictly protected areas can not be managed to meet society's growing list of goods and services, involving such diverse activities as genetic resource management, watershed protection, recreation and education (McNeely, et al. 1990; Mbugua and Stevens, 1977; Ottichilo et al., 1981; Van Wijngaarden, 1985; Cobb, 1976; Kenya Wildlife Service, 1990; Mwenge International Associates Ltd, 1980).

Additional approaches to the management of wild lands are required to supplement the protected areas, where some sustainable harvesting of biodiversity resources, incorporation of other land use types and local human population can be among the objectives of protected area management. In the integrated approach to biodiversity conservation, local support for protected areas should be increased through such measures as education, revenue sharing, participation in decision making, complementary development schemes adjacent to protected areas, and where compatible with protected area objectives, access to resources. In this approach, economic incentives are being used to make the local people appreciate and identify themselves with the protection of biodiversity resources (Kenya Wildlife Service, 1990).

The integrated approach would be effective, if resource managers recognize the three basic scales of biodiversity, i.e. *alpha*, *beta* and *gamma*. *Alpha diversity* is the number of

species within a single habitat or community while *beta diversity* reflects the change in species composition along an environmental gradient or a series of habitats (Whittaker, 1972). Karr (1976) interprets alpha and beta diversity as roughly equivalent to within and between habitat diversities. Finally, the total diversity of a large geographic region (e.g. a landscape or larger) has been called *gamma diversity* (Whittaker, 1972). These three basic scales of diversity may be affected differently by human activity in any given area.

To implement the integrated approach to the management of biodiversity resources, KWS has adopted a hierarchical structure of biodiversity conservation. In this structure, management decisions are taken at three levels i.e. national, regional and local level. These different levels in the decision making hierarchy represent different decision making contexts. Each of these requires different levels of abstraction of information. Unfortunately, KWS is yet to actualize these levels with regard to information organization. Basically at the lowest level, this often includes data from direct surveys. At higher levels, information entities are defined as derived survey information. In the design of a survey system, it will be necessary—for efficiency, to ensure data consistency and to avoid redundancy—to attempt to carry out one survey from which all the other information at the different context levels can be derived. Hence this study defines such a system that will provide KWS with information to support biodiversity management decisions at the different management levels.

2.1.4 Threats to Biodiversity Resources in Kenya

Several problems are currently threatening biodiversity conservation in Kenya. Among them are:

- (a) Over the last 50 years, Kenya's human population has quadrupled, from an estimated figure of less than six million in 1945, when the first protected area was established (Nairobi National Park), to approximately 25 million in 1999 (Central

Bureau of Statistics, 2001). Consequently, there has been a corresponding increase in demand for food crops and land on which to grow them, leading to large areas that formerly supported natural vegetation being cleared for agricultural production as depicted in Fig. 2.1. This change in land use has an impact on biodiversity resources. The increased population, coupled with cultural practices and better animal husbandry, have resulted in an increase in livestock numbers as documented by Mbugua and Stevens, (1977); and Ottichilo *et al.*, (1981), and thus increased competition with wildlife for grazing resources. In his scenario of the 'pastoral road to extinction', Prins (1992) noted that 'at first, livestock partly supplants wildlife. Then, when the ratio between humans and livestock increases, and wildlife is out competed by livestock, people ultimately switch to agriculture or horticulture, and there is less and less space for wildlife. Ultimately, agriculture has to give space for urbanization and no space or food will be left for wildlife'. Recent findings show an increasing ratio between humans and livestock (Fosbrooke, 1989; Brown, 1971) and strongly suggest that the real problem is an increase of the human population, which outgrows the livestock population (Prins, 1992). The consequences for biodiversity of these developments include a decline in wildlife populations because of a reduction in resources available to them, isolation of wildlife populations because of fragmentation of their habitat, and increased direct wildlife-human interactions. The challenge for KWS is how to protect biodiversity outside protected areas in the context of increasing human population and changing land use and land tenure systems.

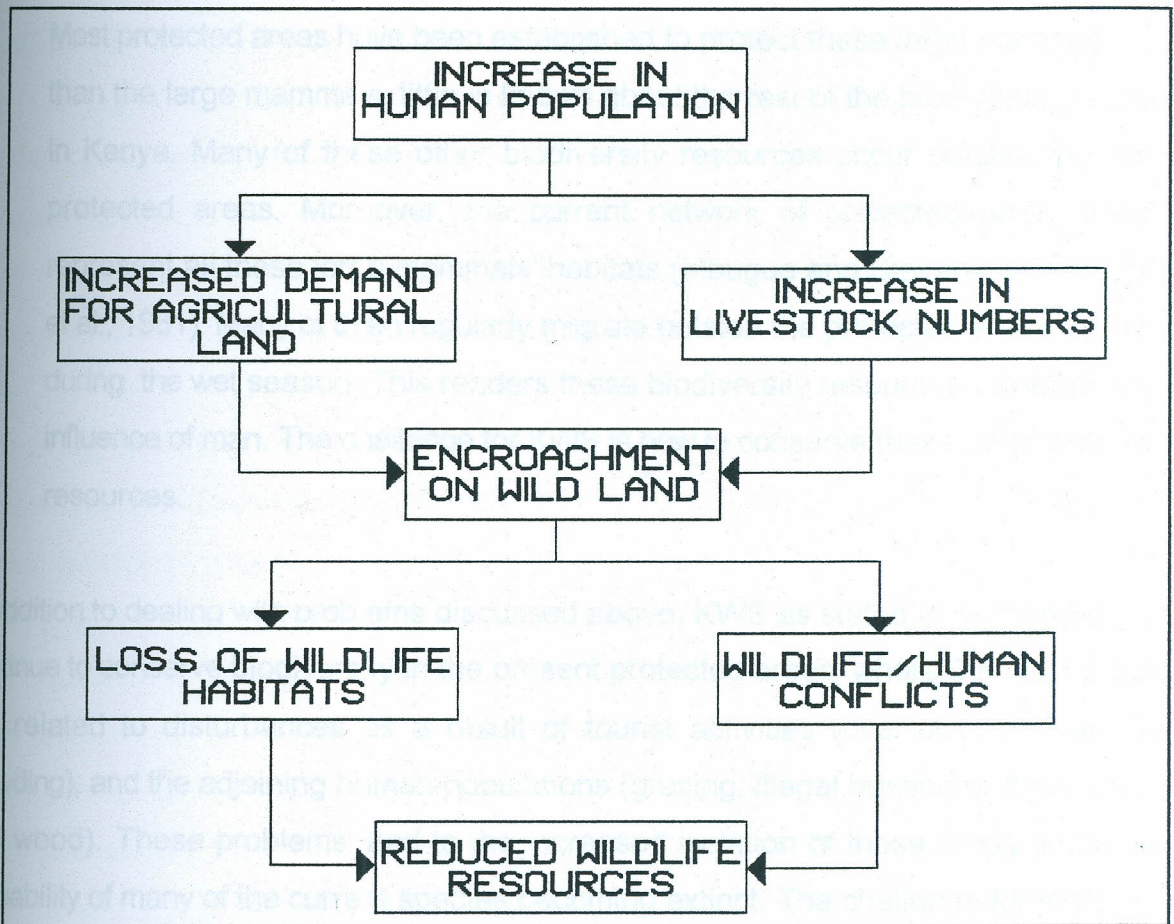


Fig. 2.1 The Impact of Human Population Increase on Wildlife Resources

- (b) Wildlife tourism is based mainly on the large mammals (elephant, rhino, buffalo, wildebeest, hippopotamus, zebra, lion, cheetah and leopard). This has led to over-utilization by tourists of the parks they inhabit. Impacts of this over-utilization include destruction of wildlife habitat and the disruption of the natural activities of wild animals. The challenge for KWS is to reduce the negative impact of the current trends nature tourism.
- (c) Since the inception of KWS in 1989, there has been increased interest in biodiversity conservation. This has led to the recognition that past wildlife conservation policies

laid too much emphasis on five species (elephant, rhino, buffalo, lion and leopard). Most protected areas have been established to protect these large mammals. Other than the large mammals, little is known about the rest of the biodiversity resources in Kenya. Many of these other biodiversity resources occur outside the present protected areas. Moreover, the current network of protected areas does not represent all these large mammals' habitats (Mbugua and Stevens, 1977; Ottichilo et al., 1981). Many of them regularly migrate outside the protected areas, especially during the wet season. This renders these biodiversity resources vulnerable to the influence of man. The challenge for KWS is how to conserve these other biodiversity resources.

In addition to dealing with problems discussed above, KWS as stated in its mandate, must continue to conserve biodiversity in the present protected areas, where the main problems are related to disturbances as a result of tourist activities (over-utilization and over-crowding), and the adjoining human populations (grazing, illegal hunting and harvesting of fuel wood). These problems lead to the increased isolation of these areas and a higher probability of many of the current species becoming extinct. The challenge for KWS is how to maintain viable species populations while optimizing tourist activities. To do this, KWS will require to fill this information gap on various aspects of the biodiversity resources. Although quite a lot of data from which this information can be extracted already exists in KWS and other organizations, it is not structured in such a format as to support decisions at the different hierarchical levels in an integrated approach to management of biodiversity resources in Kenya. This study defines and tests a prototype of such a structure.

2.1.5 Information Requirements for Biodiversity Conservation at different Hierarchical Levels

One of the biggest challenges to KWS is to translate its mission into activities that contribute to biodiversity conservation. Many of the problems facing KWS are linked to the environment

in which these resources occur and are poorly or insufficiently structured. In such a situation, decisions can be made only in a given context (see Guariso and Werthner, 1989). Ideally, these problems need to be structured so as to provide new insights about the nature of the problem, produce alternative solutions and evaluate them. The hierarchical nature of KWS also makes it necessary to structure these problems, because solutions can be developed only if there is clarity about which activities are to be executed and at what level in the hierarchy. This is to avoid duplication of efforts and wastage of resources.

Presently, the main objective of KWS is to conserve biodiversity resources. The main problem is to define what this means and how to do it. This is an unstructured problem to which a solution is possible only after systematically decomposing it into structured sub-problems. An aggregate of the solutions to the sub-problems should be able to provide a viable solution to the main problem. Yet, it is difficult to understand any phenomenon with as many complex components and scale of spatial and temporal variability as biodiversity, unless it can be divided into components within which repeatable patterns and consistent behaviour occurs (Huston, 1994). Each component is influenced by different processes and the problem is to identify these processes at the three hierarchical levels considered below.

2.1.5.1 National Level

Priorities for conservation of biodiversity have to be set at the national level because those that are based on local criteria could be misleading since a resource which is rare in one area may be abundant in another. Consequently, it is necessary to develop criteria for use in decision making in relation to biodiversity management. First, management needs information on what biodiversity resources occur in the country. Because it is not practical and financially feasible to protect all national biodiversity resources, the national management has to decide and determine the components (*hereafter referred to as species or ecosystems*) which should be given a priority for conservation. In this connection, management would need information

on what species are rare or which ecosystems are unique, what is the uniqueness of these species or ecosystems in the international context (endemism) and this determines if Kenya is an important area for the conservation of these species or ecosystems, and what human activities or natural processes threaten the survival of these species or ecosystems and to what extent.

Having selected priority species or ecosystems for conservation, the management must rank them in their spatial context. For this, management needs information on those species or ecosystems that are suitable for biodiversity conservation. Such selection should be evaluated on the basis of whether the species population or ecosystems is large enough to remain viable in the long term, conservation of the species or ecosystem is sustainable, and it is possible to regulate human impacts on the threatened species or ecosystem.

On the basis of the foregoing, it is clear that most of the information required at this level relates to the distribution and abundance of biodiversity resources, and land use. A large amount of this information is collected by organizations other than the KWS, such as the East African Herbarium, Forest Department, Department of Resource Surveys and Remote Sensing and the Kenya and Marine and Fisheries Research Institute, among others. In its mission, KWS has entered into collaborative agreement with these organizations.

2.1.5.2 Regional Level

The priority programmes established at the national level should be translated into action plans at the regional level. In formulating action plans, regional biodiversity resource managers require detailed information on where the species or ecosystems to be conserved occur, what processes threaten their survival, whether these processes are natural or result from human activity, and how to counteract the impact

of these processes.

Most of the information required at the regional level is on the distribution and abundance of biodiversity resources and land use. This information comes from within KWS (and is collected at the local level) and involves setting up a detailed inventory of the resources. This information is used to model processes within the resources so as to gain an insight into the potential and actual threats, assess the level of threat, and produce and evaluate alternative solutions to these threats. This information is more quantitative, has a higher spatial resolution than that needed at the national level and should be highly accurate.

2.1.5.3 Local Level

The action plans produced at the regional level are implemented at the local level with agreement or support of local communities. Management at the local level should be sensitive to day-to-day issues on biodiversity resources in order to respond quickly using primary on-site or internal information. The information required at this level is on the distribution and abundance of biodiversity resources, and land use and under different land tenure systems. This information is of high resolution and is usually used quickly in empirical models. If the goal of measuring species biodiversity is to understand what processes are influencing diversity, it is critical to restrict samples to groups of organisms that are likely to be influenced by the same processes (Huston, 1994). This is possible only at the local level. The local level also monitors the implementation of different programmes and passes the information to the regional level, which uses it to evaluate and verify its models. This information is then generalized and passed on to the national level for use in re-evaluating biodiversity conservation priorities and policies.

The description outlined above illustrates that, by structuring problems and specifying at what level they should be addressed, information of different scales is required to support decisions at the different levels in the management hierarchy of KWS. Thus, KWS should strive, for efficiency's sake, to abstract most of the information from the same survey data set.

2.1.6 Data Collection

Data collection (especially spatial data) is in the long term the most expensive activity in organizations dealing with biodiversity conservation. Lack of coordination in data definition and collection in a large organization can lead to the duplication of efforts and storage of large amounts of redundant data. The use of modern tools, such as GIS, which incorporate a database management system can help eliminate costly duplication and optimize the use of information available in an organization. However, in an organization like KWS, which requires information to support decisions at various levels in its management hierarchy, there is also a need for a method to acquire and support abstraction of this information from the database at various scales. Currently, such an information system does not exist nor does a method for information abstraction. This study aimed to develop and test such a system that could be used in the management of biodiversity resources in Kenya.

2.2 Tools for Managing of Biodiversity Resources

Biodiversity resources today are faced with a diversity of problems both internally and externally, many of which require different management strategies. The problems are a result of a combination of factors related to specific conservation issues, available resources and their use, and local, regional and national development needs and desires. Thus an effective biodiversity resources management strategy must deal with local issues while taking into consideration regional and national management strategies. Such a strategy should incorporate provision of information to support decision making particularly with

regard to availability of adequate, timely and good-quality data. This should be complemented by equally good and appropriate analytical tools and techniques. Models and Geographic Information Systems (GISs) are two of the most important tools, while modelling is an important technique in biodiversity conservation.

2.2.1 Models and Modelling

Models are simplified abstractions of the real world. Because of the complexity of the biodiversity resources environment, resource managers can work with only simplified abstractions of the real world in a given context. Jorgensen, (1988) describes in detail the different types of models currently in use. This study was restricted to those models used as management tools, i.e. management models with the main emphasis on data models. In solving specific environmental problems, data models help in identifying the relevant objects and in describing both their spatial and functional relationships. Such models can be used to describe events at a given point in time (static models) or over a period of time (dynamic models), or to predict and forecast future events. Dynamic models are most appropriate in the management of biodiversity resources. This is because biodiversity resources are dynamic, as they constantly change their structure and functioning as a result of both human activities and environmental factors.

Data models are products of the modelling process and include maps, tables and information. Such models are often used to get answers to three questions normally asked in biodiversity resource management: what is the state of the green cover (*vegetation*); what will be the effect of a certain decision; and how can that effect be evaluated? (Van Wijngaarden, 1991). The answers to these questions are crucial for effective conservation of biodiversity.

The effectiveness of models in the management of biodiversity resources depends on the availability of reliable information. Information is normally extracted from data and to ensure

that this information is credible, the data must be reliable and free of errors. This is only possible if these data are collected in a consistent manner using reliable methods and techniques. Observance of this condition is crucial in situations where data on biodiversity resources are being collected for the purpose of monitoring trends. Rules must be developed to regulate and ensure credibility and consistency in data collection, handling, integration, storage and information extraction. Currently, such rules are not well defined and not able to provide adequate information to support multi-level decision making in the management of biodiversity resources in Kenya. The aim of this study defines such rules and tests them by means of case studies.

2.2.2 Geographic Information Systems

Real-world objects which are appropriately described by models can be translated into digital formats that can be handled by a computer. Such objects can be georeferenced. Consequently, data describing them can be stored, retrieved and manipulated in a geographic information systems (GIS) to facilitate management decisions.

Over the last decade, rapid advances in computer hardware and software have led to the evolution of geographic information systems into a tool that permits the quantitative assessment of land resources (of which biodiversity is one) over a broad range of spatial and temporal scales (Johnson, 1990; Burrough, 1986; Haines-Young et al., 1993; and Bridgewater, 1993). GISs have been variously defined by different disciplines and usually depend on the context in which they are applied. This study used the definition of GISs by Molenaar (1991b) as a "special class of information system that handle geoinformation". The GISs provide a set of tools for capturing, storing, retrieving, transforming and displaying spatial data from the real world for a particular set of purposes (Burrough, 1986). An efficient GIS must be well structured (Fig. 2.2). According to Wintraecken (1987), the four basic components of a GIS are: an information processor (computer hardware), a grammar module containing rules for system behaviour and reaction to messages from the internal

environment, an interface that enables interaction with the external environment, and an information base (computer software modules and databases).

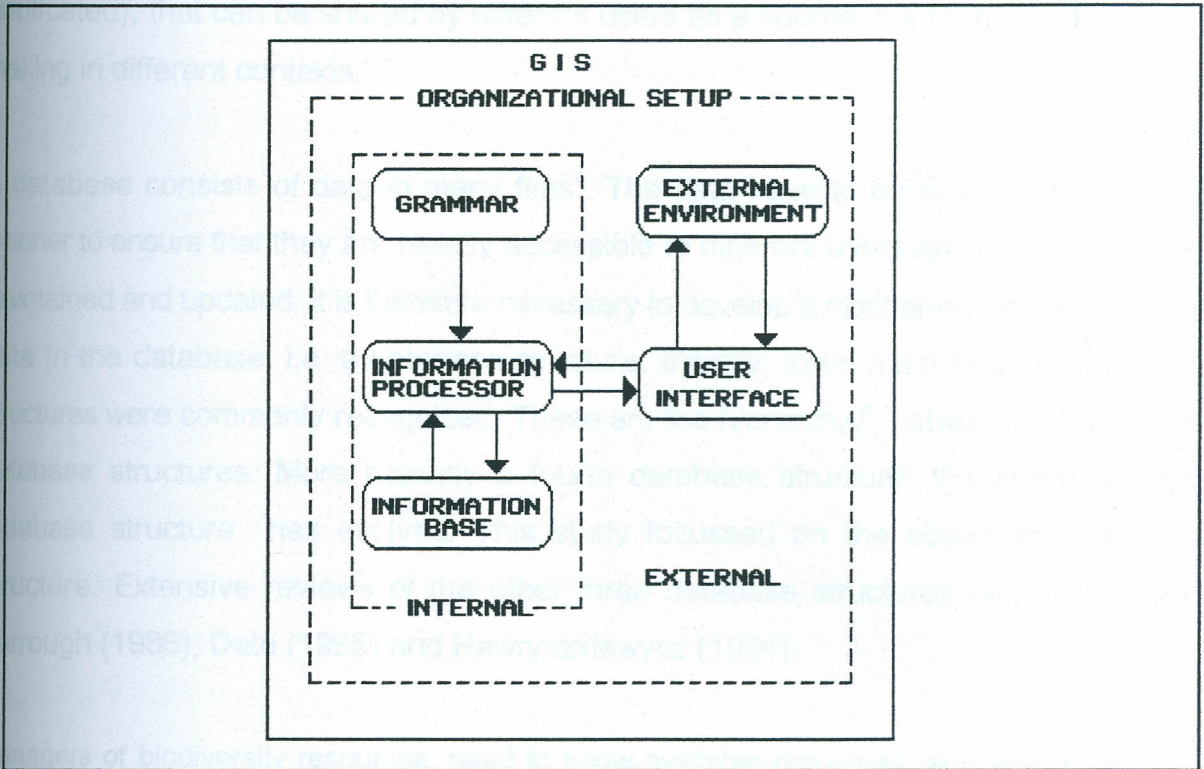


Fig. 2.2 Components of a Geographic Information System (modified from Wintraecken, 1985)

The information base stores data on terrain objects and software modules for data analysis and processing. Terrain objects are features, natural and man-made, that are present on the Earth's surface and can be represented in a GIS as conceptual entities defined within the context of some mapping discipline (Molenaar and Janssen, 1994). For example, when mapping land-cover, object classes represent land-cover types. Terrain objects may have discrete boundaries that can easily be placed on a map, for example, agricultural fields, or non discrete boundaries (fuzzy boundaries), for example, in natural vegetation where the different vegetation types conform to an environmental gradient. In this case, the object classes represent the products of the environmental gradient. In the information base, data

2.3 Conceptual Framework

on terrain objects are organized in a database. A database is essentially a repository for the collection and arrangement of interrelated and non-redundant data, (ie, data that are not duplicated), that can be shared by different users as a source of information for decision making in different contexts.

A database consists of data in many files¹. The data have to be organized in such a manner to ensure that they are readily accessible to different users and can be regularly maintained and updated. It is therefore necessary to develop a mechanism to organize the data in the database, i.e. a database structure. Initially, three main kinds of database structures were commonly recognized. These are the hierarchic², network and relational database structures. More recently a fourth database structure, the object-oriented database structure has evolved. This study focussed on the object oriented data structure. Extensive reviews of the other three database structures can be found in Burrough (1986), Date (1995) and Hawryszkiewicz (1991).

Managers of biodiversity resources, need to know available resources and where they are located at any one time. GISs are an appropriate tool for providing them with such information. The provision of information to support decisions in the management of biodiversity resources is a three stage process: determination of the data required to provide information, data collection and abstraction and storage. A conceptual frame work for this process is discussed in the next section. Concepts involved at each stage are discussed in the next chapter.

¹ A file is a collection of related information in a computer that can be accessed by a unique name.

² A *hierarchic database structure* is a method of arranging computer files or other information so that the units of data storage are connected by a hierarchically defined pathway (Burrough, 1986), while a *network database structure* is a method of arranging data in a database so that explicit connections and relations are defined by links and pointers of a many-to-many type, and a *relational database structure* is a method of structuring data in the form of sets of records so that relations between different entities and attributes can be used for data access and transformation.

2.3 Conceptual Framework

Figure 2.3 illustrates the conceptual framework for this study. Biodiversity resources in Kenya are managed at three hierarchical levels (local, regional, and national). Information is essential to support decisions for their effective and efficient management. This information has to be extracted from data on the resources. Information to support decisions at the three levels of management can be extracted from the same database if it is well structured. Once decisions have been made at the different levels, they are implemented and there has to be a mechanism to evaluate the impact of management interventions on the resources. The results from the evaluation could be positive or negative. If negative, then there would be a need to develop alternative decisions. More information will be required. This would have to be extracted from data held in the database. These data might not be adequate hence there will be a need to collect more data. The system developed here has to evolve through a series of refinements and feed back mechanisms until it is able to support the sustainable management of biodiversity resources in Kenya.

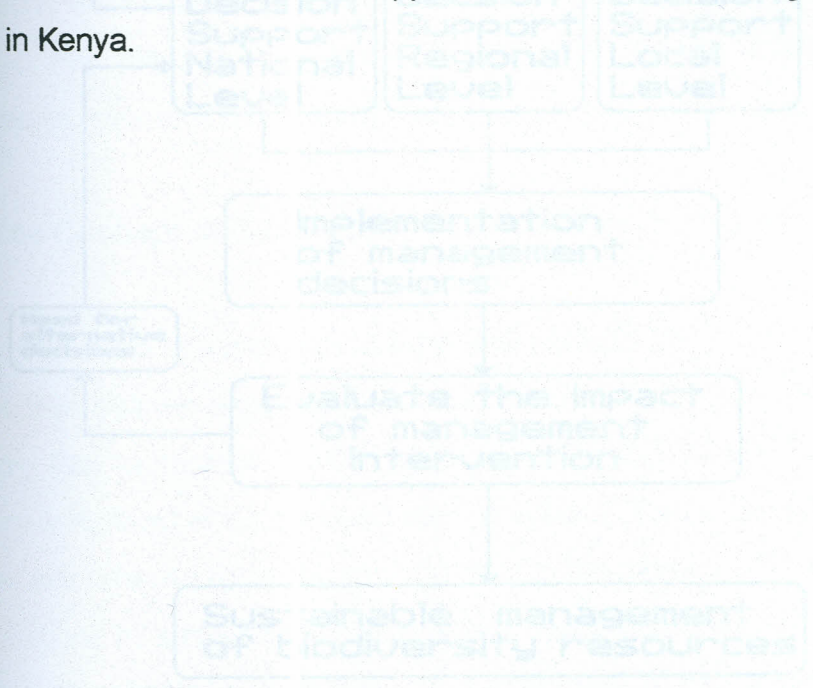


Figure 2.3 Conceptual Framework for the Sustainable Management of Biodiversity Resources

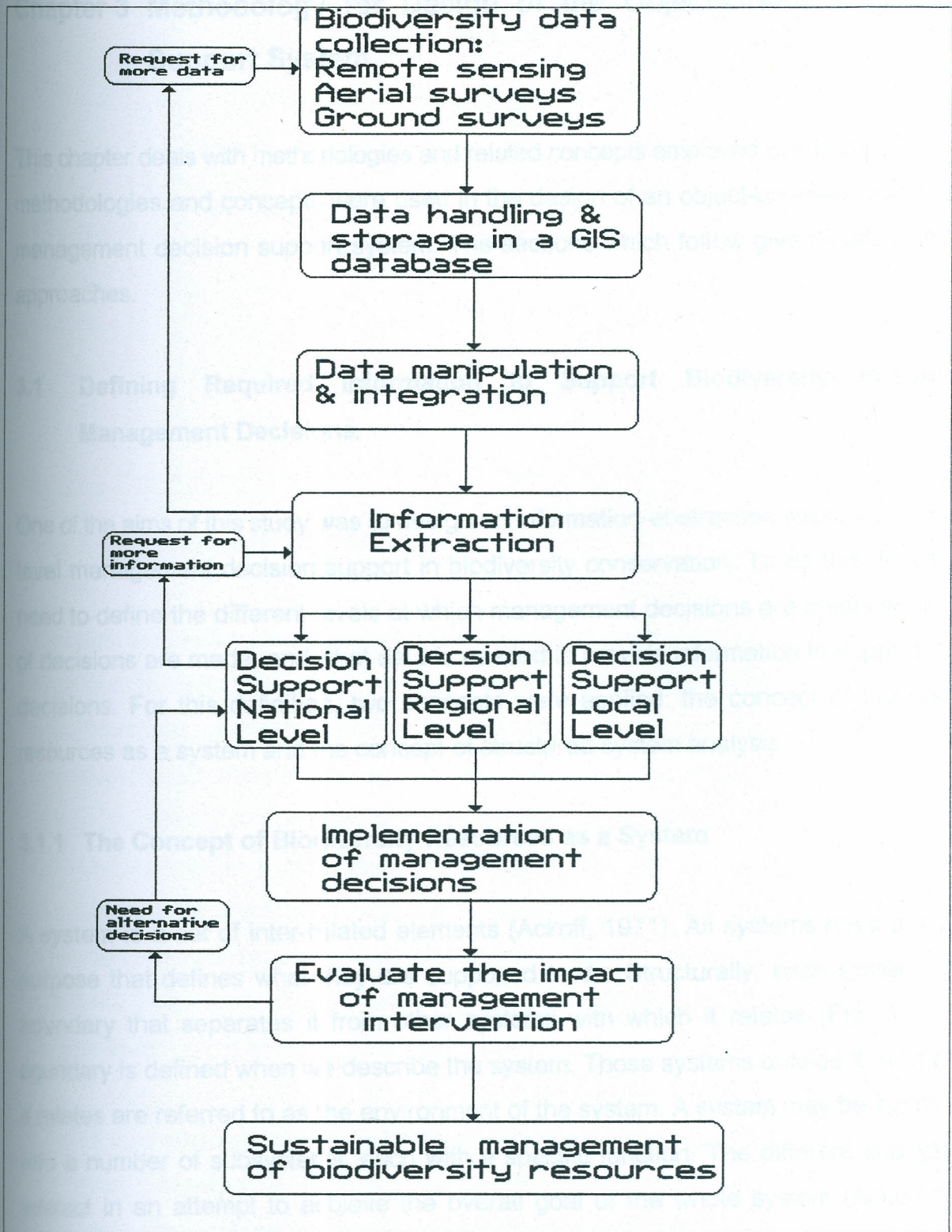


Fig. 2.3 Conceptual Framework for the Sustainable Management of Biodiversity Resources

Chapter 3 Methodology for Design of the Object-Oriented Decision Support System

This chapter deals with methodologies and related concepts employed in this study. These methodologies and concepts were used in the design of an object-oriented biodiversity management decision support system. The sections which follow give details of these approaches.

3.1 Defining Required Information to Support Biodiversity Resources Management Decisions

One of the aims of this study was to design an information-abstraction structure for multi-level management decision support in biodiversity conservation. To do this, there was need to define the different levels at which management decisions are made, what type of decisions are made, and what data is needed to provide information to support these decisions. For this definition, two concepts were applied: the concept of biodiversity resources as a system and the concept of structured system analysis.

3.1.1 The Concept of Biodiversity Resources as a System

A system is a set of inter-related elements (Ackoff, 1971). All systems have a goal or purpose that defines what they are supposed to do. Structurally, each system has a boundary that separates it from other systems with which it relates (Fig. 3.1). This boundary is defined when we describe the system. Those systems outside it, with which it relates are referred to as the environment of the system. A system may be subdivided into a number of subsystems, each with a specific function. The different subsystems interact in an attempt to achieve the overall goal of the whole system (Ackoff 1971; Hawryskiewicz, 1991).

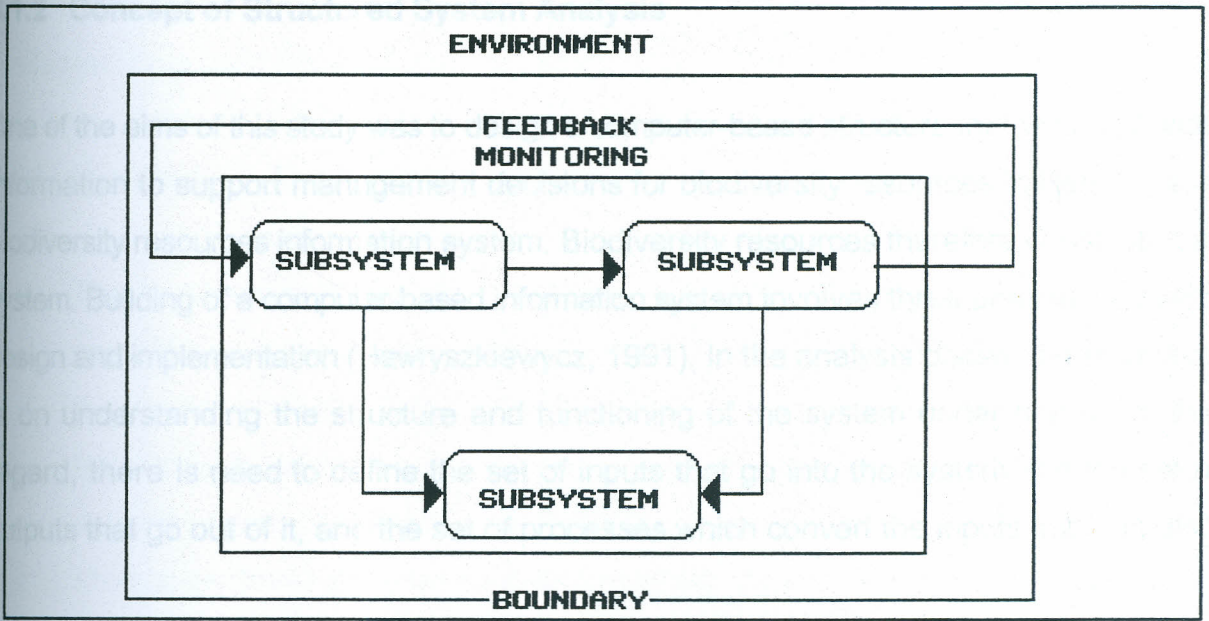


Fig. 3.1 A Conceptual View of a System

This forms the basis for the principles of feedback and monitoring that define the system's behaviour. Systems are either natural or artificial. Biodiversity resources fall under the natural systems category. Natural systems are usually complex, with hard-to-define boundaries; to describe and manage many of these systems, artificial boundaries usually have to be defined on the basis of given criteria. For management and conservation of biodiversity resources, a management hierarchy based on spatial objects is used to define the boundaries of the system. Using the concept of *levels of organization* (i.e. species, population, community, ecosystem, biome) as a criterion, biodiversity resources can be described. This approach provides information to support management decisions at the different levels in the management hierarchy.

Systems exchange information with their environment, both influencing the environment and being influenced by it. This influence can have positive and/or negative effects. Biodiversity resources as systems have an influence on the surrounding areas. Similarly, the surrounding areas have influence on the biodiversity resources.

3.1.2 Concept of Structured System Analysis

One of the aims of this study was to design a computer-based structure that would provide information to support management decisions for biodiversity resources in Kenya, i.e. a biodiversity resources information system. Biodiversity resources therefore constitute our system. Building of a computer-based information system involves three phases: analysis, design and implementation (Hawryszkiewicz, 1991). In the analysis phase, the emphasis is on understanding the structure and functioning of the system under review. In this regard, there is need to define the set of inputs that go into the system and the set of outputs that go out of it, and the set of processes which convert the inputs into outputs.

There are several generalized methodologies for analyzing a system. These include: the systems approach, the planning approaches, prototyping, structured methodologies, among others. These methodologies employ different techniques and tools. An extensive review of the different methodologies is found in Avison and Fitzgerald, (1988). This study uses the structured system analysis methodologies which are based on functional decomposition, ie, the breaking down of a complex problem into manageable units in a disciplined way (Avison and Fitzgerald, 1988). Some of the techniques and tools associated with structured system analysis that were used in this study include: functional decomposition, decision trees, data flow diagrams and Computer-Assisted Software Engineering (CASE) tools.

Decision tree consist of a series of nodes (see Avison and Fitzgerald, 1988). At each node, two or more actions can be taken, and decision rules have to be applied to determine which of the actions should be taken. When constructing a decision tree, the problem is stated in terms of conditions (possible alternative solutions) and actions (things to do). Decision tree usually follow a stepwise refinement process, breaking up the largest condition into basic conditions until a complete tree is formulated. Decision trees are central in the taxonomy and mapping (classification) of plant biodiversity resources.

Data Flow Diagrams (DFD) provide a technique for modelling system components, ie, processes, data used and produced by these processes, any external entities that interact with the system, and information flow. These components are usually represented by symbols in the DFD. The four basic symbols (Fig. 3.2) of a DFD are:

- (1) The terminators: these are sources of data from other subsystems inside and outside the organization. They also serve as external depositories or sinks for information produced in the subsystem.
- (2) Data flows: these show in which direction the data are moving. They may also show subsets of data contained in a terminator.
- (3) Processes: these show the functions in which data are being used or produced.
- (4) Data stores: these represent depositories for the data produced. They may store permanent data or transitory data to be used in the next process.

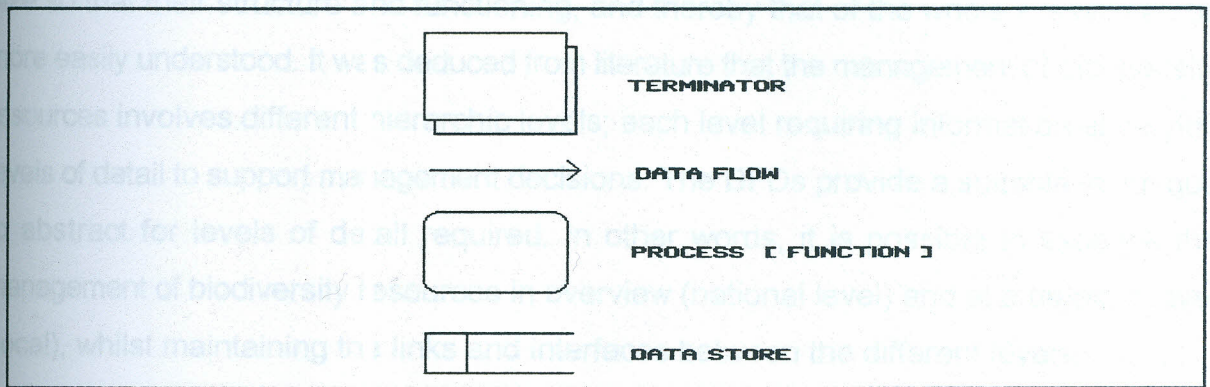


Fig. 3.2 Symbols Used in Data Flow Diagrams (DFD) ((Avison and Fitzgerald, 1988)

In this study, DFDs are used to analyze the management of biodiversity resource systems in Kenya by KWS.

The current trend is to support the system analysis process by means of automated tools, generally known as CASE tools. These serve two purposes: to provide documentation and to assist in the analysis. Most CASE tools pertain to documentation support, or the storage

of information and models created during the analysis process. The Systems Workbench (SDW (Cap Gemini, 1991)) was used in this study as a CASE tool in the analysis of the biodiversity resources management system.

3.1.3 Linking Structured System Analysis with the Biodiversity Resources Concept

As explained in section 3.1.1, biodiversity resources represent a system that is complex but also has a structure. Effective conservation including assessing the impact of management intervention requires a clear understanding of this structure and the functioning of these resources. That understanding is achieved through a systematic analysis of biodiversity resource systems and their management structure. Structured system analysis provides an appropriate methodology for carrying out such an analysis. Using DFDs, the system can be partitioned (or structured) into subsystems of desirable size so that their structure and functioning, and thereby that of the whole system can be more easily understood. It was deduced from literature that the management of biodiversity resources involves different hierarchic levels; each level requiring information at varying levels of detail to support management decisions. The DFDs provide a suitable technique to abstract for levels of detail required. In other words, it is possible to examine the management of biodiversity resources in overview (national level) and at a detailed level (local), whilst maintaining the links and interfaces between the different levels.

3.2 Sources of Biodiversity Data

The concept of biodiversity resources implicitly refers to space on the Earth's surface, and these areas can be mapped according to any given map projection. Their management therefore depends to a large extent on geographic data, that includes information on both plant and animal resources. Methods used to acquire these data are described in the next two sections of this chapter.

3.2.1 Source of Plant Biodiversity Data

Data on plant resources was collected at three spatial scales depending on their source (i.e. remote sensing, aerial photographs and ground surveys). These sources of data are described in more detail in the following sections.

(a) Remote Sensing

Remote sensing is the source of data at the highest level. Remotely sensed digital satellite data and spatial analysis techniques provide timely and relatively inexpensive information on plant biodiversity resources. Because of their high spectral resolution, these data provide a broad view of terrain objects, and in vegetation mapping it is possible to identify general vegetation types. In recent years, computer-aided classification of satellite digital data has proved useful for inventorying and monitoring vegetation cover over large and varied landscapes (Tucker et al., 1985; Cibula, 1987; Franklin and Hiernaux, 1991; Niemann, 1993; Huising, 1993; Janssen, 1994). In mapping vegetation, satellite data are digitally classified on the basis of the spectral characteristics of the image. The classes are then assigned labels that represent different vegetation types. However, data quality in terms of reliability and accuracy is sometimes unsuitable for certain management applications. It is sometimes difficult to identify classes on the basis of their spectral characteristics, resulting in misclassification and the lower overall accuracy of the information extracted, especially in areas of very pronounced relief variation (Franklin, 1989). Overall accuracies have varied from 50% to 90%, depending on topography, land cover type, classification hierarchies and image acquisition date (Shimoda et al., 1988; Niemann, 1993; Jansen et al., 1990). Anuta (1977) and Hutchinson (1982) concluded that spectral data alone are inadequate descriptors of many terrain phenomena and must be augmented from other information sources.

There are several ways to improve information extraction from satellite data for land cover mapping. One of the most promising approaches is the integration of remotely sensed and ancillary data using spatial analysis techniques. Ancillary data can be incorporated in image classification during: pre-classification scene stratification, post-classification sorting and classification modification through prior probabilities (Hutchinson, 1982). This involves human intervention and judgement, and the effects are reflected in the overall accuracy of the final land cover map, which determines its usefulness in a given context. Ancillary data can be used to improve land cover classification accuracy only if their relationship with an image class is known. Most of these data are readily available in the form of thematic maps such as soil, topography, geology and climate.

Various studies have applied the three approaches of incorporating ancillary data with varying results. Middelkoop and Janssen (1991), using ancillary data and knowledge as prior probabilities in a knowledge-based classification of satellite images, obtained an improvement in the overall accuracy of 4% to 20% with respect to results based on only spectral information. Niemann (1993) integrated thematic mapper (TM) data, a digital elevation model (DEM) and locational information data in land cover classification, and the results indicated that TM data with ancillary data are not adequate to generate the results desired in an old-growth forest inventory. For this study, Niemann used 11 features: seven TM bands and four extra bands of ancillary data. Benson and DeGloria (1985) used expert knowledge for the visual interpretation of TM data to discriminate different land cover types, and obtained a low overall accuracy of 56% compared with the minimum classification accuracy of 85% that was considered acceptable for the study. Kenk et al., (1988) assessed three approaches for improving classification accuracy, and concluded that the best results were obtained by using a combination of three spectral bands; beyond that, the choice of bands had no significance. The use of ancillary data (elevation, slope, aspect, forest cover) as extra bands in digital image analysis only marginally improved the overall accuracy. The use of context techniques yielded a more acceptable map product with ecologically significant boundaries.

Several methods of image analysis and pattern recognition are available. The mathematical basis is well established and examples are provided by Mather (1987) and Swain and Davis (1978). A detailed overview and an update of recent developments in the methodology of pattern recognition analysis and knowledge-based classification is provided by Argailas and Harlow (1990). The methods use different algorithms to assign individual pixels to different classes. Among the more commonly used algorithms are the maximum likelihood, minimum distance and Mahalanobis distance classifiers. The maximum likelihood classifier was used in this study (see Strahler, 1980).

(b) Aerial Photographs

Information on general vegetation types extracted from digital remotely sensed data forms the basis for desegregating terrain objects for more detailed study at a lower level. Here, data are obtained through the interpretation of aerial photographs. Aerial photographs have a higher spatial resolution than satellite images, making it possible to identify more specific vegetation types, because of the direct relationship between spatial and thematic resolutions, i.e. the higher the spatial resolution, the better the thematic resolution. Aerial photo interpretation is a less intensive technique, in comparison to ground surveys discussed below, but involves greater uncertainty because of reliance on subjective rather than quantitative assessment. Subjective assessment makes the photo interpretation technique less repeatable and of limited use in monitoring (Pickup and Chewings, 1994).

(c) Ground Surveys

Data at the lowest level are obtained through ground surveys, and help to define specific vegetation types. Although more accurate, ground surveys are slow and expensive because many locations must be sampled to represent the diversity of many landscapes.

At each level of data abstraction, the Earth's surface is stratified into regions that fall under specific classes sharing the same descriptive structure. Problems common to each class can be identified and solutions sought. Each level of data abstraction is therefore useful in defining a context for further detailed studies at the lower level. To extract optimal information for decision support in biodiversity conservation, all levels of data acquisition must be viewed as complementary. With a GIS, it is possible to integrate data from different sources as demonstrated by Janssen, (1994); Molenaar, (1994); Trotter, (1991); Milchalak, (1993).

This study used data from the three different sources after integrating them in a GIS environment. Ground truth data used in land cover mapping (Chapter 7) was collected using procedures described in the following paragraph.

Ground reference data, for training statistics and accuracy assessment, were obtained through field observations in April and June to September 1994. These data were used to define land cover classes in the study area. A total of 150 sites were visited between June and September 1994, ensuring that all cover classes were well represented. However the number of sites in each class depended on geographic extent and accessibility. The position of each site was recorded in the Universal Trans Mercator (UTM) coordinate system using a Global Positioning System (GPS).

The Braun-Blanquet technique was used in sampling, which involved ocular estimates of the percentage cover of three vegetation strata: herbaceous plants, woody species below 2 m and woody species above 2 m in height (Braun-Blanquet, 1964). The sites were clustered using Twinspan (Hill, 1979), and the information was used to define land cover classes based on the ITC world land cover and land use classification system (Zonneveld, 1988), and land cover types using interpretation rules. The number of classes defined for land cover classification is context-dependent and they have to be distinguished spectrally from remotely sensed data.

3.2.2 Source of Animal Biodiversity Data

There are two main sources of animal biodiversity data: using systematic reconnaissance flights and through ground surveys. Each of these are explained below:

(a) Systematic Reconnaissance Flights

Systematic Reconnaissance Flight (SRF) is a sampling technique for quantifying the spatial distribution of large animal resources through a combination of visual observations and oblique photography from low-flying, high-wing light aircraft (Norton-Griffiths, 1978). The aircraft flies parallel transects (flight lines) across a study area. Visual observations of animal resources are recorded continuously along the length of each transect, but are divided into successive 'sub-units' on the basis of lapsed distance (e.g. 5 km). The key characteristic of SRF method is that it delivers a set of data points each of which is geo-referenced making them suitable for representation in a GIS.

SRF is typically carried out within the framework of a sampling grid. The UTM grid system is widely used for such sampling frame, for it is a world-wide standard grid system which is projected onto many maps (Clarke, 1986). Each subunit is assigned to an individual grid cell, and each grid cell contains a unique set of subunits. The grid cells within an SRF survey area have three important uses: they provide standard location information, they provide very convenient mapping units, and they can be used to standardize maps and thematic information, and for representation of data in a GIS. Animal resource data acquired through SRF were used in this study to implement the data structure that was developed.

(b) Ground Surveys

Ground surveys are used to acquire detailed information including those on population structure and dynamics, genetic composition, energy flow, etc. These surveys are also used to acquire data on animal resources that can not be seen from the air. Data on animal resources is collected at either sample points or from sample plots that can be georeferenced thus making them suitable for representation in a GIS.

3.3 Abstraction Concepts used in Biodiversity Resources

Collected biodiversity resources data should be represented in a database to provide information for management decision support. Since most of data on biodiversity resources can be geo-referenced, it is suited for a GIS database. A GIS is a spatial database that can represent real world objects from the management of biodiversity resources point of view. The design of such a database involves three stages: The first stage involves the conceptualization of reality in a data model, i.e. the conceptual data model. This is a process of conceptual data modelling. There are two approaches to conceptualizing the 'real world': the field-based, and the object-based approaches. The field-based approach conceptualizes 'reality' as space composed of a collection of spatial units in which thematic data are recorded for each unit, while the object-based concept views reality as space filled by terrain objects (Ehlers *et al*, 1989; Goodchild, 1992; Kufoniya, 1995). This study used the object-based concept and was restricted to three domains: what biodiversity resources were present (terrain objects), where they were located (location), and at given point in time (time). To simplify the abstraction process, the time domain will be pre-determined (wet or dry season) and the location and the different biodiversity resources will be observed. The second stage involves the transformation of the conceptual data model into a logical data model (i.e. database structure) for representation in a computer, while the third stage involves the design of a file structure for the storage of the structured data in a computer.

In the object-based approach to conceptualizing reality, terrain objects (e.g. biodiversity resources) are analyzed on the basis of their geometric (spatial) and thematic (non-spatial) aspects. The former comprises of topology, shape, size and position while the latter indicates the non-spatial attributes of the objects.

The traditional approach to conceptual data modelling has been to use a semantic data modelling techniques (e.g. Entity Relation (ER), Chen 1976) and later its extended form, the Extended Entity Relationship (EER) (Hughes, 1991), to formalize the non-spatial component of the objects. The geometric components are then formalized based on the preferred form of representation, whether vector (in which the individual object (entity) is the basic data unit for which spatial information is explicitly recorded) or tessellation (where the basic unit is a unit of space for which entity information is explicitly recorded in digital form). The geometric and thematic structures would then be linked by a common object identifier.

A suitable logical data model (database structure) is required to organize data for subsequent representation in a computer after formalizing the conceptual data model. Before the advent of GISs, the relational data model was the most widely accepted structure among the three traditional database structures (network, hierarchical and relational). This was because of its simplicity and the availability of a standard language (the Structured Query Language, SQL) for the manipulation of the database -in contrast to the other two. Consequently, many commercial relational Database Management Systems (DBMS) are available (e.g. dBASE, Oracle, etc). However these conventional DBMS are more suitable for the management of thematic data such as business application (Kufoniyi 1995). Thus in GIS applications, the thematic data are often represented by a relational structure, while the geometric data are represented in a file implementation of a topographic structure. By using the relational structure to organize spatial data in a database, we are often forced to decompose data concerning a single spatial object into different structures. For example, thematic data may be organized in a

relational structure and geometric data in another structure. Consequently two different DBMS may be required for the same object. This is not the most efficient way of handling spatial data and that is why in recent years, a lot of research has gone into defining a new approach for a unified representation of all components of an object in a spatial database (Hughes, 1991; Egenhofer, 1992; Date, 1995). This new approach, called 'object-oriented' data modelling, has been advocated for spatial applications whereby real world entities and their properties are modelled as objects in order to support the treatment of complex (geometric) entities (Kufoniyi, 1995). The product of such an approach is a data model that can be represented in a GIS. Such a data model, based on the Formal Data Structure (FDS) defined by Molenaar (1989a, 1989b and 1991a), is presented in this study. The advantage of the FDS is that it is formulated at an abstract level without reference to any particular database model. The FDS also represents an object-based approach to data modelling. This approach has distinct advantages for biodiversity management.

3.3.1 Formal Data Structure

The FDS is a combination of object and topologic models. Their basic philosophy is that: all terrain objects can be classified as point, line or area objects, each terrain object consists of geometric data, each terrain object consists of thematic data, and each terrain object has a unique identifier in a GIS (Fig. 3.3).

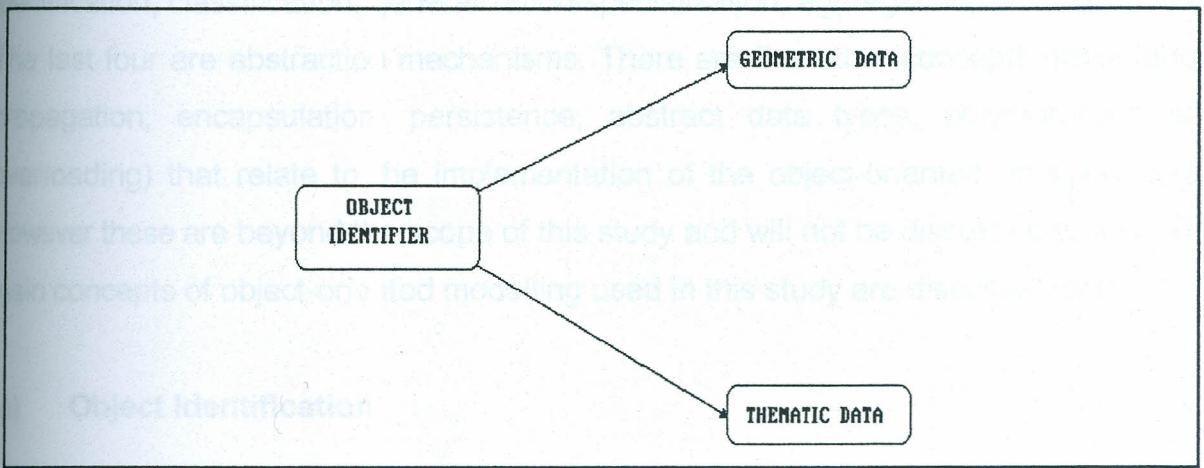


Fig. 3.3 Basic Structure for Representing Terrain Objects in a GIS

The FDS has been developed for single-valued vector maps in which classes form a thematic partition and objects form a geometric partition. To model the thematic components of objects, the terrain objects occurring in a vector map are grouped into several distinct classes according to their thematic characteristics. Each class has an accompanying list of attributes and a unique identification label. The FDS supports a class hierarchy in which classes that have common attributes are grouped into a superclass.

In the model, the geometric partition consists of data on three independent aspects: topology, shape and size, and position. This geometric data-set has been carefully structured in the FDS, leading to a semantically-rich, query-oriented and expendable data model in which information on topology, shape and size, and position can be retrieved (Molenaar, 1991a, Kufoniyi, 1995). This characteristic of the FDS is very valuable to biodiversity resource managers who need to know what type of resources are available and their spatial extent.

3.3.2 Object-oriented Data Modelling Concepts

There are five main object-oriented modelling concepts (i.e. modelling constructs): object

identification, classification, generalization/specialization, aggregation, and association. The last four are abstraction mechanisms. There are five other concepts (inheritance, propagation, encapsulation, persistence, abstract data types, polymorphism and overloading) that relate to the implementation of the object-oriented data structure). However these are beyond the scope of this study and will not be discussed further. The main concepts of object-oriented modelling used in this study are discussed below.

(a) Object Identification

In object-oriented modelling, all conceptual entities are modelled as objects (Hughes, 1991, Worboy, 1992, Kufoniyi, 1995), with each object having a unique identity. An object has a 'state' and 'behaviour'. The state of an object is defined or described by properties or attributes, but unlike in a relational structure, such properties are not restricted to non-decomposable data types and may in fact be objects themselves. The behaviour of an object is defined as a set of procedures that are encapsulated with the properties of the object. For example if we take the object plant community in biodiversity resources, then its properties include community name, structure, dormant plant species, rare plant species, other plant species, conservation status, etc. Its procedures include fragmentation (break into smaller units), conservation, destruction, harvesting, etc. These properties and procedures are built into the definition of the property. The identity of an object should be immutable despite changes in its properties.

(b) Classification, Classification Hierarchies and Generalization/Specialization

The process of classification is central to the object-oriented approach and involves the grouping of objects with similar properties and behaviour into object classes. Classification can be defined as the mapping of several objects (instances) to a common class (Egenhofer and Frank, 1989). It is often referred to as the 'instance of' relationship because the individuals are instances (occurrences) of the corresponding class (Fig 3.4)

illustrates this relationship. This class structure, encompassing both properties and behaviour, is the natural unit of abstraction in object-oriented systems and may be used to model both entity objects and relationship objects (Hughes, 1991).

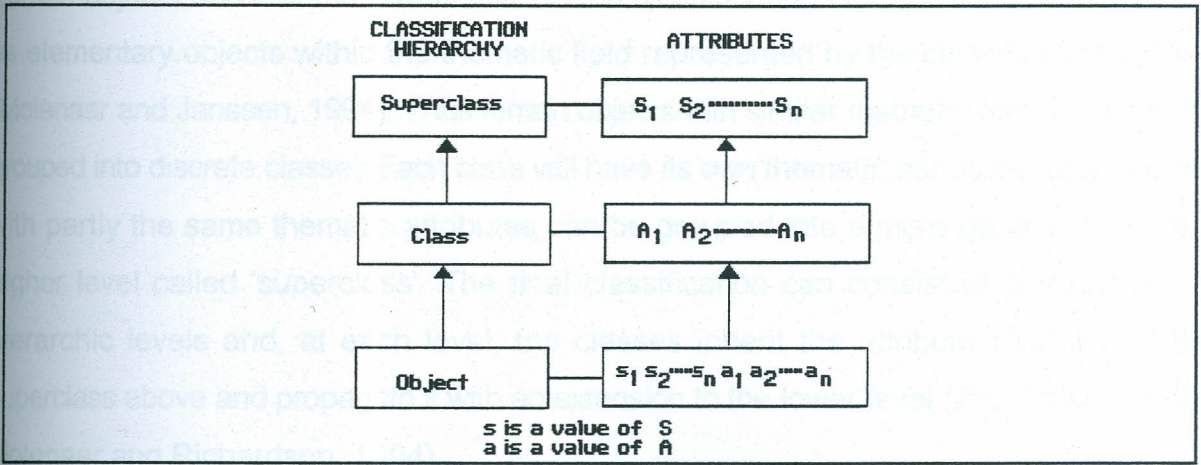


Fig. 3.4 The Hierarchic Relationships between Objects, Classes and Attributes (Source: Molenaar, 1994)

Biologists classify biodiversity resources into a widely accepted hierarchical system that reflects evolutionary relationships among the organisms. In ascending order, the main categories (taxa) in biodiversity resources are: Species, Genus, Family, Order, Class, Phylum and Kingdom. Classification also forms the basis for mapping vegetation i.e. plant biodiversity resources. Areas with similar species combinations are given the same vegetation type label. The central role played by the classification concept in defining biodiversity resources makes it a suitable abstraction mechanism in the conceptual modelling of these resources.

Above, it has been shown that decisions related to the management of biodiversity resources are made at three levels (national, regional and local). The different levels in the decision making hierarchy represent different decision making contexts. Each of these require different levels of abstraction of information. The use of classification hierarchies (discussed in this section) and aggregation hierarchies (discussed in section c, below) in

conceptualizing reality (i.e. terrain objects), makes it possible to obtain information from the same database, that will support management decisions at the different levels.

Terrain objects occur at the lowest level in the classification hierarchy and are regarded as elementary objects within the thematic field represented by the classification system (Molenaar and Janssen, 1994). Thus terrain objects with similar thematic attributes can be grouped into discrete classes. Each class will have its own thematic attributes, and classes with partly the same thematic attributes can be grouped into a more general class at a higher level called 'superclass'. The final classification can consist of any number of hierarchic levels and, at each level, the classes inherit the attribute structure of the superclass above and propagate it with an extension to the lower level (Richardson, 1993; Molenaar and Richardson, 1994).

In semantic modelling, the upward links of the classification hierarchy are labelled 'IS_A' links (Oxborrow and Kemp, 1989; Hughes, 1991; Molenaar and Richardson, 1994) and represent a form of thematic generalization. This is an abstraction mechanism that provides views of the same geographic space in different levels of detail. At a lower level, a class may be decomposed into other classes called 'subclasses'. These are object types which share all the thematic attributes of another class (superclass) but which also process more specific thematic attributes not shared with the superclass. They therefore represent a 'specialization' of the superclass. Specialization is the converse of generalization. In this abstraction mechanism, the class inherits the attributes of the superclass and the subclass inherits the attributes of the class plus those of the superclass. Fig. 3.5 illustrates the concepts of classification hierarchy and generalization/specialization using biodiversity resources as an example. On the basis of specific characteristics, biodiversity resources can be classified as being either vegetation or animal. Based on their origin, each vegetation can be classified further into either natural or planted vegetation. At a lower level, natural vegetation can be classified into forest, woodland, bushland or grassland using structure as a criterion. A step further down the hierarchy, forests can be classified

This results in the formation of an aggregation hierarchy that may have several levels. Each constituent object of the aggregation has its own properties and operations, and the operations of the aggregate are not usually compatible with the operations of the parts. Fig. 3.6 illustrates how aggregation can conceptualize biodiversity resources for representation in a GIS. The objects *biodiversity resources* B_1 , B_2 and B_n are all parts of the object *local biodiversity resource* B , and the objects *biodiversity resources* E_1 and E_{n+1} are all parts of the object *biodiversity resources* E . Biodiversity resources A ,

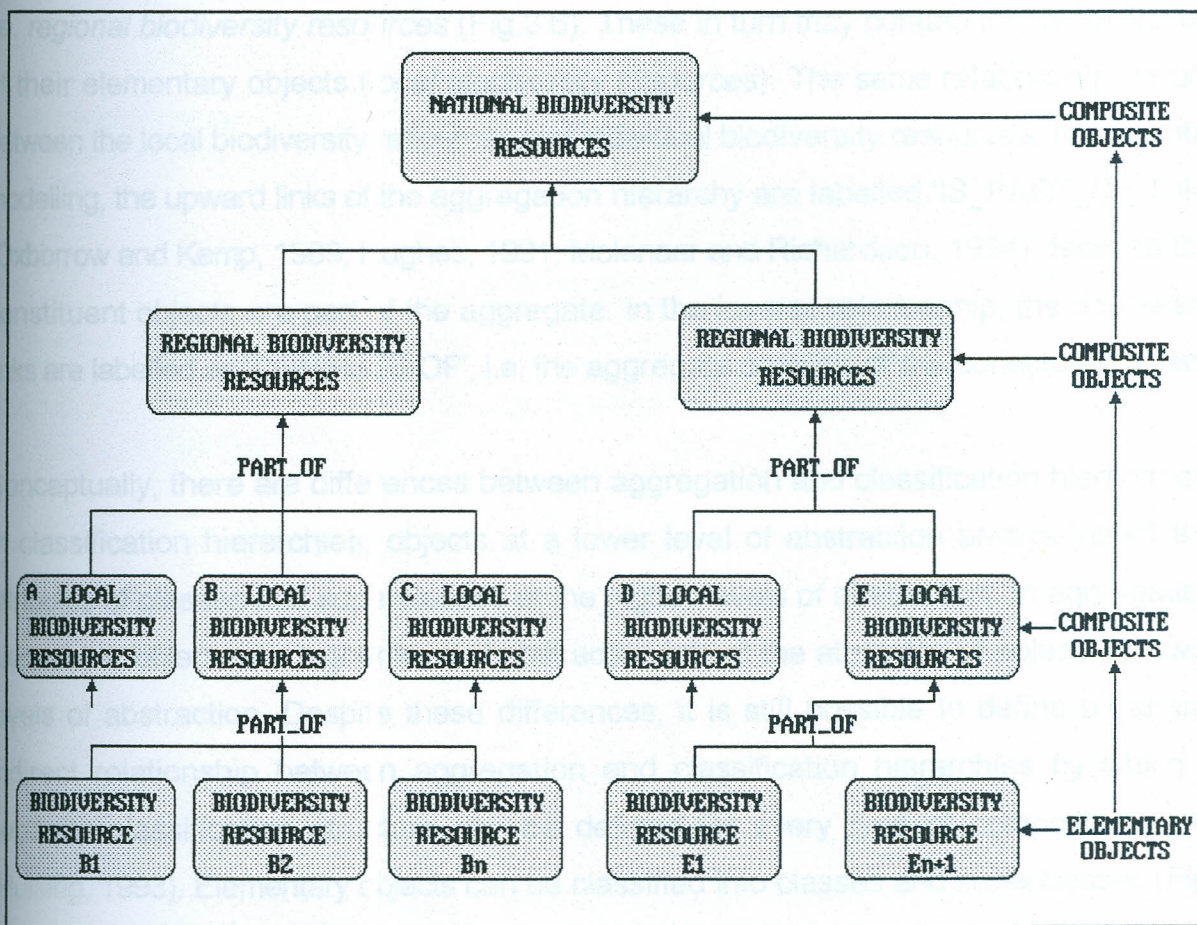


Fig. 3.6 Biodiversity Resources Composite Object Hierarchy showing the "PART_OF" Relationship between Elementary and Composite Objects

B , C , D and E are therefore composite objects that at a different level of abstraction form

the elementary objects of the *regional biodiversity resources* composite object. The same relationship is repeated between the regional biodiversity resources and the national biodiversity resources. The composite object normally inherits the attribute values of the elementary objects.

The national biodiversity resources contain not only attributes that define the name, distribution, status, etc., of each biodiversity resource, but may also contain pointers or reference to a part of the database containing the full definition of their elementary objects, i.e. *regional biodiversity resources* (Fig.3.6). These in turn may contain the full definition of their elementary objects (*local biodiversity resources*). The same relationship occurs between the local biodiversity resources and individual biodiversity resources. In semantic modelling, the upward links of the aggregation hierarchy are labelled 'IS_PART_OF' links (Oxborrow and Kemp, 1989; Hughes, 1991; Molenaar and Richardson, 1994) because the constituent objects are part of the aggregate. In the inverse relationship, the downward links are labelled as 'CONSISTS OF', i.e. the aggregate consists of the constituent object.

Relationship Between Aggregation and Classification Hierarchies (Huisig, 1993)

Conceptually, there are differences between aggregation and classification hierarchies. In classification hierarchies, objects at a lower level of abstraction always inherit the attributes of classes and superclasses at the higher levels of abstraction. In aggregation hierarchies, objects at a higher level of abstraction inherit the attributes of objects at lower levels of abstraction. Despite these differences, it is still possible to define a general indirect relationship between aggregation and classification hierarchies by which a separate classification structure can be defined for every type of composite object (Huisig, 1993). Elementary objects can be classified into classes and superclasses (Fig. 3.7). The same elementary objects can be aggregated to form composite objects that can in turn be aggregated to form other composite objects at a higher level. At each of these levels, the composite objects can also be classified into different classes and superclasses.

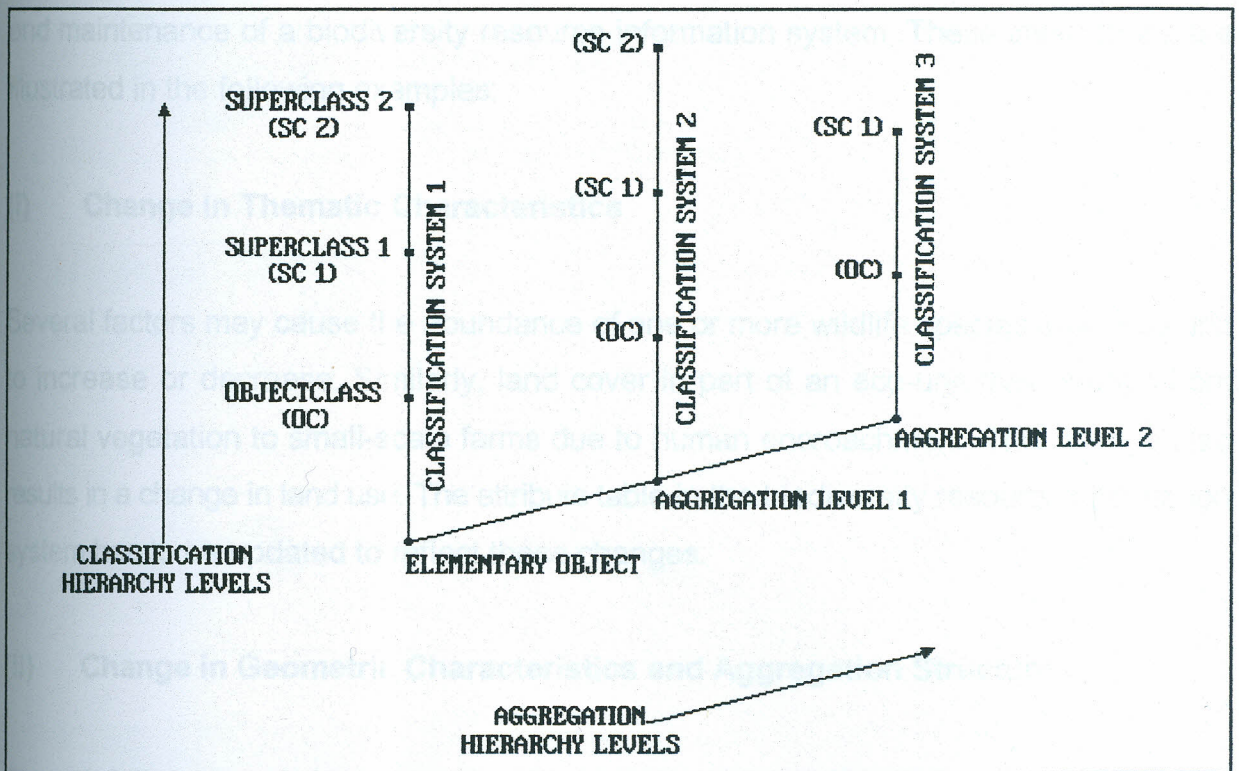


Fig. 3.7 Relationship between Aggregation and Classification Hierarchies (after Huising, 1993)

3.4 Dynamics of Biodiversity Resources and their Implications for the Biodiversity Information Model

Section 2.2.2 showed that GIS is a tool that can be used in storing spatial data on biodiversity resources in the form of terrain objects. Due to human population activities and natural ecologic processes, the internal structure and spatial extent of biodiversity resources is constantly changing. Consequently, terrain objects stored in a GIS have to be updated on a regular basis if they are to maintain a valid representation of the real-world features. This means that geometric and/or thematic data for elementary objects need to be updated while for composite objects, a redefinition of the aggregation structure

is required (Molenaar and Janssen, 1994). Distribution and abundance¹, are the most important dynamic aspects in biodiversity resources that have implications for updating and maintenance of a biodiversity resource information system. These implications are illustrated in the following examples:

(i) Change in Thematic Characteristics

Several factors may cause the abundance of one or more wildlife species in an eco-unit to increase or decrease. Similarly, land cover in part of an eco-unit may change from natural vegetation to small-scale farms due to human encroachment. This change also results in a change in land use. The attribute table in the biodiversity resource information system has to be updated to reflect these changes.

(ii) Change in Geometric Characteristics and Aggregation Structure

Figure 3.8 illustrates changes in geometric characteristics and aggregation structure that occur in biodiversity resources. Change in land cover due to change in land use (e.g. conversion of natural vegetation to agriculture) leads to change in the distribution of plant biodiversity resources in a given eco-unit (Fig. 3.8 -b). This results in a change in the geometric characteristics (size and shape) of the terrain object with no topologic implications.

¹ Distribution is used here to refer to the area occupied by a given plant or animal population or species and Abundance is used to refer to a measure of the population or species present in an area..

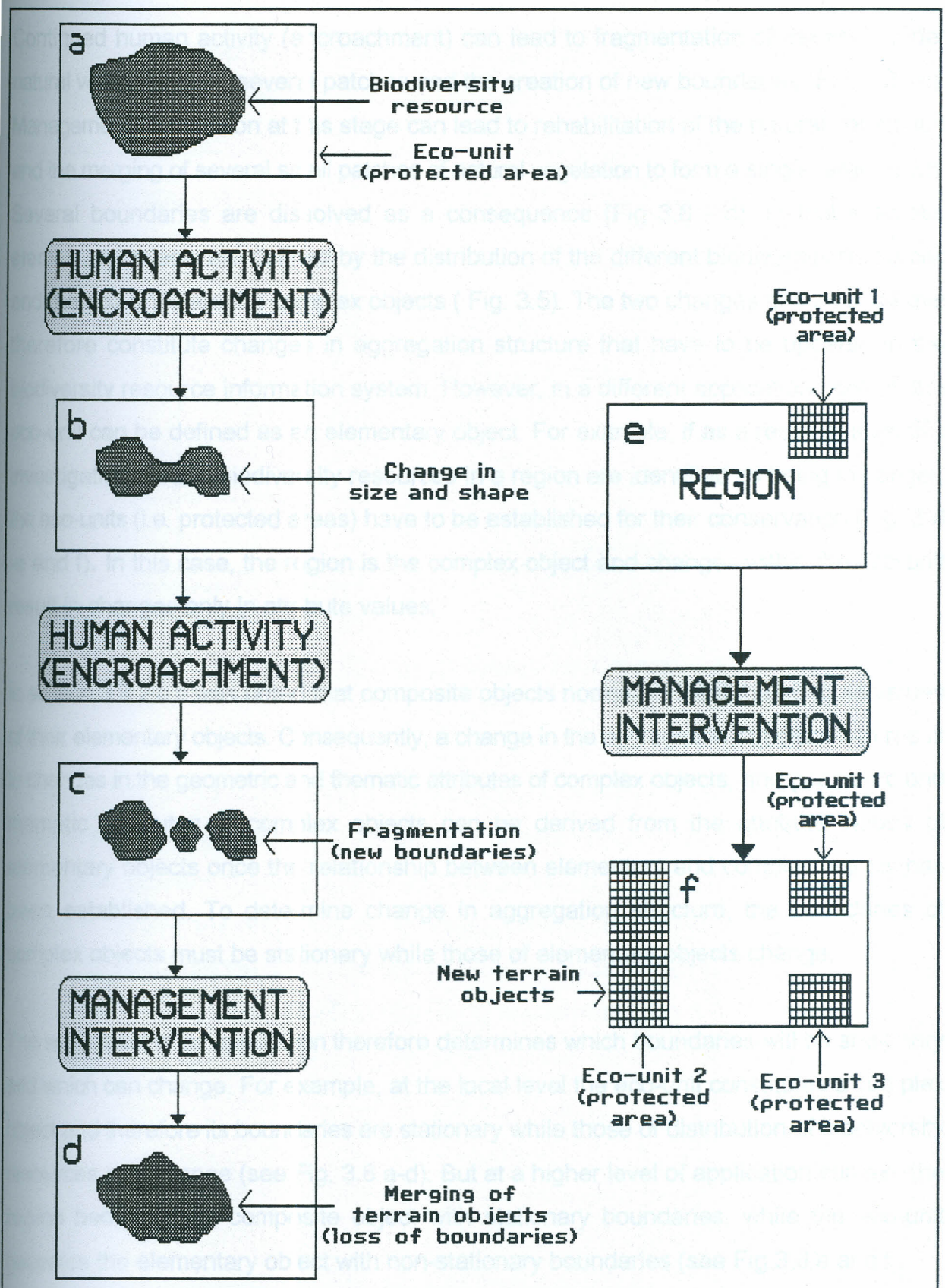


Fig. 3.8 Changes in Geometrical Characteristics and Aggregation Structures of Biodiversity Resources

Continued human activity (encroachment) can lead to fragmentation of the area under natural vegetation into several patches and the creation of new boundaries (Fig. 3.8 - c). Management intervention at this stage can lead to rehabilitation of the natural vegetation and the merging of several small patches of natural vegetation to form a single large patch. Several boundaries are dissolved as a consequence (Fig 3.8 - d). In this example, elementary objects are defined by the distribution of the different biodiversity resources and the eco-units are the complex objects (Fig. 3.5). The two changes described above therefore constitute changes in aggregation structure that have to be updated in the biodiversity resource information system. However, in a different application context, the eco-unit can be defined as an elementary object. For example, if as a result of scientific investigation certain biodiversity resources in a region are identified as being in danger, the eco-units (i.e. protected areas) have to be established for their conservation (Fig. 3.8 -e and f). In this case, the region is the complex object and changes within the eco-unit result in changes only in attribute values.

Second type of Change in Geometric Characteristics

In section 3.3.2 c it was noted that composite objects normally inherit the attribute values of their elementary objects. Consequently, a change in the aggregation structure can result in changes in the geometric and thematic attributes of complex objects, and geometric and thematic attributes of complex objects can be derived from the attribute values of elementary objects once the relationship between elementary and complex objects has been established. To determine change in aggregation structure, the boundaries of complex objects must be stationary while those of elementary objects change.

The scale level of an application therefore determines which boundaries will be stationary and which can change. For example, at the local level the eco-unit constitutes a complex object and therefore its boundaries are stationary while those of distribution of biodiversity resources can change (see Fig. 3.8 a-d). But at a higher level of application context, the region becomes the composite object with stationary boundaries, while the eco-unit becomes the elementary object with non-stationary boundaries (see Fig.3.8 e and f).

Change in position, shape and size including topology are illustrated in fig 3.9. The dry

season, animal biodiversity resources tend to concentrate near water sources (Fig. 3.9 - a) and are more dispersed during the wet season (Fig. 3.9- b)

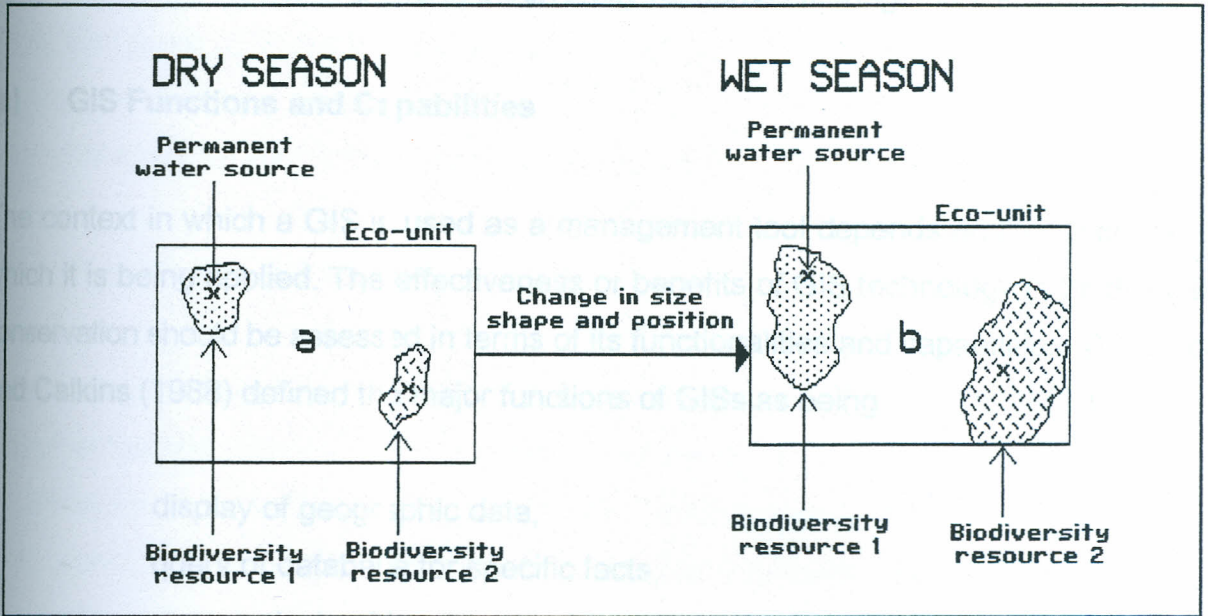


Fig. 3.9 Second type of Change in Geometric Characteristics of Biodiversity Resources

One of the aims of this study was to define relevant terrain objects in biodiversity resource management and to establish the relationships between elementary and complex objects. This should facilitate the optimization of data collection for inventory and monitoring of change in biodiversity resources by deriving geometric and thematic attribute values of complex objects from the geometric and thematic attribute values of elementary objects. Optimization of data collection will contribute to economies in the KWS operations and in the overall effectiveness of the supporting information supply system.

3.5 Need and Benefits of a GIS in Biodiversity Resource Management

The needs and benefits of a GIS in biodiversity resources management are:

(a) GIS Functions and Capabilities

The context in which a GIS is used as a management tool depends on the discipline in which it is being applied. The effectiveness or benefits of GIS technology in biodiversity conservation should be assessed in terms of its functionalities and capabilities. Dickinson and Calkins (1988) defined the major functions of GISs as being:

- display of geographic data,
- query of database for specific facts,
- map analysis with reference to a problem or problems, and
- spatial modelling, including spatial statistics, for broad analysis of geographic data.

The capabilities include:

- providing a general capability to support an ongoing decision process,
- identifying and describing spatial patterns,
- providing a complete spatial referencing system for an area (e.g. automated system to produce printed maps),
- finding the solution to specific problems or needs, and
- compiling a complete spatial database for a specific area or region.

(b) The Need for GIS as a Management Tool by the KWS

The primary responsibility of the department of biodiversity in KWS is the management of

spatial information on biodiversity resources. This involves dealing with all matters related to the acquisition, processing, storage, communication and use of geographic information. Given the nature of its responsibilities, the department in particular and the organization in general should take advantage of the now widely recognized potential of a GIS as an appropriate tool for the capture, storage, analysis and display of spatial information.

(c) **Benefits of a GIS to KWS**

In assessing the benefits of a GIS for the Kenya Wildlife Service, the fundamental issue is whether the new technology will increase the capacity of the organization to effectively and efficiently meet its objectives. In considering effectiveness, it is necessary to consider what impact the new technology will have on the processes and functioning of the organization, while in considering efficiency one should examine whether the technology will contribute to maximizing the ratio of output to input by the organization. In essence, what is needed is a cost-benefit analysis of introducing GIS technology in an organization. However, the traditional approach to such an analysis is not appropriate in this case because we are dealing with an open-ended system. It is possible to identify benefits of the new technology but not easy to express them in financial terms. Although the initial costs of a GIS are relatively easy to assess and are generally up-front, benefits are difficult to measure and usually arise well into the life of the system. Based on the analysis of the processes and functions of KWS, several areas that could benefit from the GIS have been identified. The type of benefit is indicated in brackets:

(i) **Data Management [Effectiveness and Efficiency]**

Spatial data collection is one of the most expensive considerations in many organizations. These data generally have a long life span and need to be kept in an archive and maintained; this is an added cost. Data required for biodiversity conservation are acquired at three scale levels (satellite, airborne and ground truth). These data are used by KWS

at all management levels (national, regional and local). To maximize data usage (by sharing) and to minimize on cost of data collection, KWS needs a tool that can integrate multi-source and multi-scale data and make it available for decision making at different levels in its management hierarchy. GIS is one such tool that can benefit KWS in this respect.

A data model is usually required for organizing spatial data in a GIS. Such a model is derived through semantic data modelling. During this process, entities and their semantics are identified. The resulting data model ensures that there is no duplication of entities. An object-based approach to data modelling makes it possible to generalize data acquired at a lower level for use at a higher level in the management hierarchy. GIS therefore provides a tool that enables efficient data sharing and thus minimizes cost of data collection. Since the efficiency of data collection is maximized, staff will have more time for data analysis and actual biodiversity management, which should lead to an increase in their effectiveness.

(ii) **Map Benefits [Efficiency and Effectiveness]**

KWS currently has more than 55 protected areas under its direct jurisdiction, with a possibility of more to be established. Given this scenario, KWS is a heavy user of topographic, land cover, land use, soil, geologic and geomorphic maps. All these are paper-based maps that have to be collected from different sources and maintained in high standard and good condition. This is done by maintaining multiple map sets at both the headquarters and the protected area level; it is time-consuming and therefore costly. The time factor involved in handling maps was illustrated by Palmer (1991) who demonstrated that: of the time spent working with maps, up to 45% can be taken up searching for maps (which may be wrongly filed or being used by other personnel), and a productivity gain of up to 2:1 for using GIS as a 'simple' map management tool is feasible. The ratio could be up to 4:1 if associated attribute data are also in digital format. The use of a GIS in KWS as a map delivery system could therefore provide substantial benefits in reducing map search-

and-replace time and in reducing the need to maintain and store multiple map sets.

(iii) **Analysis and Structuring of Problems** [Effectiveness]

Biodiversity resources are embedded in complex environments. One of the tasks of the Department of Biodiversity at KWS is to model these environments to gain an insight into the processes involved so as to assess threats to these resources. By simulating the processes in the environment, the department can:

- develop testable hypotheses and formulate specific research questions to be answered. The formulation of an answerable question is often obtained in an iterative manner by 'trial and error' (De Man, 1988). Consequently, a GIS should facilitate such a heuristic dialogue.
- predict the consequences of different management interventions and provide management with alternative solutions from which to choose.

(iv) **Intangible Benefits** [Effectiveness and Efficiency]

There are also other factors that would be of clear benefit to KWS but impossible to translate into cash value. These form intangible benefits and include:

- better informed decisions and planning by targeting resources more accurately, based on assessment of need,
- more rigorous data management,
- improved analytical procedures through the ability to link models and analyze spatial patterns,

- provision of relevant, timely and better information,
- ability to integrate data, facilitating consistent and easier access to the data, and
- indirect benefits which may arise well into the life of the GIS implementation.

3.6 Data Quality

Different types of information are required for management decision support in biodiversity conservation. This information is normally extracted from data available for each individual area. Although the terms 'data' and 'information' are often used interchangeably, a subtle distinction does exist: data refer to any factual material available, while information refers more specifically to data of a particular nature and in a particular form that make them useful for decision making, for whatever purpose (Conyers and Hills, 1984). The value of information therefore depends on the nature, form and quality of the data from which it is extracted, and the interpretation context. This study dealt with spatial data as they relate to terrain objects and geographic information systems.

A GIS is a tool that could be used in improving the quality of management decisions in biodiversity conservation if the data collected, stored and processed are sufficiently reliable, up to-date and error-free. Burrough and Frank (1995) noted that in application areas such as resource appraisal and environmental modelling, errors are not simple and may be both spatial and related to different scales. These errors relate to the description of both the geometric and thematic components of spatial objects (see Molenaar 1996) and influence the quality of data held in a GIS. The magnitude of these errors is a function of: the observation system used in data acquisition, the inference rules used in data extraction (whether they are certain or not; this is especially significant when classifying digital satellite data (see Middelkoop and Janssen, (1991)), and the semantics of the system

under observation, i.e. how well are the classes defined (whether they are fuzzy or not). Geostatistical methods and methods for dealing with vague phenomena (fuzzy logic) are proving to be useful in dealing with the problem of spatial data quality (Burrough and Frank, 1995).

For the three main sources of spatial data for biodiversity resources (i.e. remotely sensed satellite images, aerial photographs and ground truth observations), the main distinctions among them are their spatial and spectral resolutions. In many applications that require spatial information, it is better to combine data from all the three sources. However, in combining data from multiple sources, it is important to consider inherent errors associated with the original data and those associated with the processing techniques, as these have a bearing on the quality of information that can be extracted. Although there are many sources of possible errors in data stored in a GIS (see Burrough, 1986), the importance attached to each type of error varies according to the context in which the spatial data are used. Each application has a subset of errors that are important and need to be minimized. The quality of spatial data should therefore be viewed in the context in which they are used.

In biodiversity resource management, five aspects of data quality are relevant:

- (1) precision, i.e. how specific different terrain objects are defined; management at the local level require specific definition of terrain objects while at the national level, a more general definition is required,
- (2) accuracy, i.e. how close to reality the data are,
- (3) timeliness, i.e. information being available when required,
- (4) relevance, i.e. how the information matches management requirements and
- (5) completeness, i.e. the availability of all information required to support management decisions at different levels.

These quality aspects have implications for the biodiversity resources information model and management of biodiversity resources. In biodiversity conservation management decisions at the local level are based on collected data and at higher levels on derived data. As described in section 3.3.2 c, derived data in this study are based on the concept of aggregation hierarchies. The quality of management decisions therefore depends on the precision and accuracy of the collected data and any uncertainties in these data are compounded and accumulate in the derived data. It is therefore important to quantify uncertainty in collected data so that users of derived data can evaluate their fitness for use in any given application context.

A common approach to evaluating geographic data is to compare it with reference data by way of confusion matrices from which errors of omission, errors of commission and overall accuracies can be assessed (see Story and Congalton, 1986). In addition to precision and accuracy, the three other quality aspects (timeliness, relevance and completeness) determine the quality of management decisions. Effective biodiversity management decisions can only be made when all the relevant information is available. Because data collection is expensive and time consuming, it is important that the process of data collection is optimized to ensure that only the relevant data is collected.

3.6.1 Quality Issues Associated with Remotely Sensed Satellite Data

3.6.1.1 Data Acquisition and Preprocessing

There are three main types of inherent error associated with satellite data acquisition (radiometric, geometric and atmospheric (Lillesand and Kiefer, 1994)). Since SPOT-HRV satellite data processed at level IB, radiometrically normalized and geometrically corrected for systematic deformation were used in this study, these types of positional errors inherent in satellite data were not be considered. However, because the positional accuracy of individual pixels is important when monitoring change in land-cover types, the root mean

square (RMS) error normally introduced during the image-to-map registration process was considered.

3.6.1.2 Data Processing

Thematic information is normally extracted from remotely sensed data through the process of classification (see Mather, 1987; Lillesand and Kiefer, 1994). This is an automatic process in which each pixel in a remotely sensed image is associated with a label describing a real-world object. The assumption here is that, because real-world objects reflect electromagnetic energy in characteristic ways that can be recorded as unique patterns, which can then be classified and assigned labels corresponding to and continuous with specific map units. However, in practice this is rarely the case as not all pixels in a class will have been correctly assigned to a corresponding map unit, and not all pixels in a map unit will belong to the corresponding class. In land-cover mapping, this is caused mainly by spectral confusion caused by mixed pixels present at the boundary of two or more classes, resulting in spectral reflectances that are a mixture of different characteristic reflectance (see Ioka and Masato, 1986; Janssen et al., 1990). These identification errors also arise because the pixels in a class will rarely occupy a range of grey-scale values that do not overlap with the ranges of other classes (Lark, 1995). These errors can be separated into: errors of commission, when a pixel is erroneously included in a class to which it does not belong, and errors of omission, when a pixel is erroneously excluded from a class to which it belongs. These errors determine the quality, in terms of precision and accuracy, of the final classified image. The uncertainty in the final classified image resulting from these errors can be estimated using error matrices (Mather, 1987; Kenk, et al. 1988).

Error matrices are used to:

- (1) show which errors of omission and commission are most common (Aronoff,

1982). This allows decisions to be made about the production and interpretation of the map. Depending on the intended use of the final map, it may be preferable to combine those classes with a high level of confusion into one broad general class. The general class here is less precise, but more confident predictions of classes at any given site can be made (i.e. higher accuracy).

- (2) estimate various probabilities and conditional probabilities, each of which corresponds to the probability of the map user drawing the correct conclusion from the map (or making a particular type of error) when using it to make a particular prediction (Lark, 1995). Lark (1995) defined seven sets of probabilities that can be estimated from the error matrix. These relate to the user's (i.e. average extent of the errors of omission), the producer's (i.e. average extent of the errors of commission) or the overall map accuracy. The objective of mapping determines which of these accuracies should be maximized through manipulating the procedure of discriminant analysis (Lark, 1995).

Recent studies have shown that, by incorporating ancillary data during image classification, more specific classes can be defined (higher precision) with a high level of accuracy (Hutchinson, 1982; Kenk *et al.*, 1988; Middelkoop and Janssen, 1991; and Niemann, 1993;). This study addresses the problem of data quality in the context of classifying land-cover from digital satellite data (see Chapter 7).

3.6.2 Quality Issues Associated with Data from Aerial Photographs

Land-cover maps produced using aerial photographs as a data source can introduce both inherent and interpretational errors into a GIS, and therefore into the subsequent analysis. Inherent errors relate mainly to map scale and map unit boundaries. Scale determines the

level of generalization in a map and generally leads to labelling errors, especially if there are very small map units. Land-cover is mapped as a series of discrete units with sharp boundaries. These polygon-based data imply homogeneity of land-cover type per map unit, but that does not normally occur, especially with natural vegetation. In reality, natural land-cover represents a heterogeneous and continuous surface of change within which boundaries between different cover types are lines of transition rather than the abrupt changes seen in cartographic products. The boundaries between different cover types are therefore fuzzy, so that repeated interpretation of aerial photographs results in varying object boundaries (Molenaar, 1996). This introduces a measure of uncertainty in positioning the boundaries (edges) between different cover types. Middelkoop (1990) developed a method that involves overlaying the results of several interpretations of the same photograph to evaluate the magnitude of the uncertainty in spatial objects that is a consequence of fuzzy boundaries. The overall quality of a map based on aerial photographs is also influenced by human errors introduced during photo interpretation (relating to differences in the abilities of different observers to predict vegetation structure from aerial photographs), map compilation (relating to the number of sample points on which extrapolation is based) and the digitizing process.

3.6.3 Data Quality in a GIS

The abstractions in a GIS do not contain all possible information about a given geographic area on the Earth's surface. The type of information contained in an abstraction is context-dependent and therefore by implication subjective. The fact that models do not contain all information about a given terrain object means that inherent errors are introduced into the system from the outset. Further inherent and processing errors are introduced into a GIS by the very nature of data abstraction (refer to sections 3.6.1 and 3.6.2).

3.6.4 Implications of Data Quality in Decision Making

Because of the inherent and processing errors in a GIS, information extracted from these databases will have a certain amount of associated uncertainty. Because there is no affordable or practical way to completely eliminate this uncertainty, decision makers have to allow for it. However, this is possible only if the level of uncertainty in the information is quantified. Quantifying uncertainty allows decision makers to:

- (i) set tolerance levels within which uncertainty will be acceptable for making different types of decision,
- (ii) understand the basis for their decisions. It is expected that knowledge of uncertainty will definitely lead to better decisions in the long term,
- (iii) know which parts of the analysis are most uncertain, and which uncertainties are apt to adversely influence decisions, and
- (iv) identify information gaps, and decide whether it is wise to acquire more information before decisions are made.

Concepts of data quality as they relate to biodiversity management are discussed in detail by; Aronoff (1982), Story and Congalton (1986), Ioka and Masato (1986), Mather (1987), Kenk, et al. (1988), Janssen et al. (1990), Middelkoop and Janssen (1991), Niemann (1993), Lillesand and Kiefer (1994), Burrough and Frank (1995), Lark (1995), Molenaar (1996). Up to date, issues of data quality have not received adequate attention in biodiversity management due to the fact that in most cases primary data have been the main source of information to support management decisions. However, with increased use of modern information technology in the management of biodiversity resources and changing management structures that are increasingly relying on derived information, there is an urgent need to address the issue of data quality in resource management. This is because of the multiplier effect as data is transformed and generalized. This study examined issues of data quality in biodiversity management and defined methodology for addressing them.

Chapter 4 Study Area

4.1 Introduction

As stated in chapter 1, the general objective of this study was to develop a mechanism for the provision of information for the effective and efficient management of biodiversity in Kenya. The whole country therefore formed the study area. Kenya Wildlife Service is the institution mandated by an act of parliament to manage all biodiversity resources in the country. In this chapter, we discuss the history and the current status of biodiversity resources management in Kenya.

4.2 History of Wildlife Conservation in Kenya

Traditionally, wildlife resources have provided food and material for shelter and fuel for different ethnic communities in many parts of Africa. The rate of recruitment by most plant and animal species was generally higher than the rate of harvesting, and most species were in no danger of extinction. A significant change occurred at the end of the last century following the division of the continent into different European colonies and the arrival of many white settlers and commercial wild-animal hunters. In Kenya, the combined effect of commercial hunting and the devastating effects of settlement, such as the destruction of vast areas of animal habitats, posed a real threat to the survival of many animal species. Recognition of this threat to wildlife prompted the conservation movement and the establishment in Britain in 1903 of the Society for the Preservation of the Fauna of the Empire. This was the predecessor of the Kenya Wildlife Society, which was created in 1955. Later, the society adopted its current name of the East African Wildlife Society.

The concerns of many nature conservationists about the accelerating decline of many wild-animal species triggered the first efforts towards wildlife conservation, when the colonial government in Kenya established game reserves and introduced controls on hunting in

1898. A game department to manage wildlife was established in 1907, and its main objective was to regulate hunting. The wildlife policy at that time was geared towards the exploitation of wildlife as a food resource, which led to the slaughter of large numbers of the already dwindling species to feed the military forces during the first and second world wars.

The first serious attempt to develop a wildlife policy geared towards protection was in 1945, when the colonial legislature adopted the National Parks Ordinance Number 9 (a form of legislation used during colonial rule). In 1946, Nairobi National Park was established. This was followed by Tsavo National Park (1948) and Mt Kenya National Park (1949). By 1963, 10 National Parks and Game Reserves had been established, and by 1993 there were 25 National Parks, 22 Game Reserves and five Marine Parks. Another five established since then brought the total number of protected areas to 57 (table 4.1), occupying about 5% of the Kenya's land and water surface.

Table 4.1. List of Protected Areas in Kenya (Source Kenya Wildlife Service (KWS))

Nr.	Name	Status	Surface (ha)	Year of est.
1	Aberdare	NP ¹	76,618	1950
2	Amboseli	NP	39,206	1974
3	Central Island, Turkana	NP	500	1983
4	Chyulu	NP	47,090	1983
5	Hell's Gate	NP	6,800	1984
6	Kisumu Impala	NP	100	1992
7	Kora	NP	178,780	1989
8	Lake Nakuru	NP	18,800	1967
9	Longonot	NP	5,200	1983
10	Malka Mari	NP	87,600	1989
11	Meru	NP	87,044	1966
12	Mount Elgon	NP	16,923	1968
13	Mount Kenya	NP	71,759	1949
14	Nairobi	NP	11,721	1946
15	Ndele Island	NP	420	1986
16	Oi Donyo Sabuk	NP	1,842	1967
17	Ruma	NP	12,000	1983
18	Saiwa Swamp	NP	192	1974
19	Sibilo	NP	157,085	1973
20	South Island, Turkana	NP	3,800	1983
21	Tsavo East	NP	1,174,700	1948

22	Tsavo West	NP	906,500	1948
23	Arawale	NR ¹	53324	1974
24	Bisanadi	NR	60600	1979
25	Bonjoge	NR	2,100	1992
26	Boni	NR	133900	1976
27	Buffalo Springs	NR	13,100	1988
28	Dodori	NR	87,739	1976
29	Kakamega	NR	4,468	1985
30	Kammarok	NR	8,774	1983
31	Kerio Valley	NR	6,570	1983
32	Lake Bogoria	NR	10,705	1970
33	Losai	NR	180,680	1976
34	Marsabit	NR	208,800	1949
35	Masai Mara	NR	151,000	1974
36	Mwea	NR	6,803	1976
37	Nasolot	NR	19,400	1979
38	Ngai Ndethya	NR	21,209	1976
39	North Kitui	NR	74,500	1979
40	Rahole	NR	127,000	1976
41	Samburu	NR	16,50	1985
42	Shaba	NR	23,910	1974
43	Shimba Hills	NR	19,251	1968
44	South Turkana	NR	109,100	1979
45	Tana River Primate	NR	16,900	1976
46	Arabuko Sokoke	NAR ¹	4,332	1979
47	Nandi North	NAR	3,434	1978
48	South-Western Mau	NAR	43,032	1961
49	Uaso Narok	NAR	1,575	1981
50	Kisite/Mpunguti	MP ¹	3900	1978
51	Mombasa	MP	1000	1986
52	Ras Tenewi	MP	35,000	1991
53	Watamu	MP	3,200	1968
54	Kiunga	MNR ¹	25,000	1979
55	Malindi	MNR	21,309	1968
56	Diani Chale	MNR	300	1955
57	Maralal	S ¹	500	1974

MP¹ National Marine Park, NP¹ National Park S¹ Sanctuary NR¹ National Reserve (formerly game reserves),
 NAR¹ Nature Reserve, MNR¹ Marine Nature Reserves.

Until 1976, national parks were managed by a Board of Trustees under the National Park Service, while Game Reserves were managed by the Game Department. The 1976 Wildlife Conservation and Management Act brought the management of national parks under the Department of Wildlife Management and Conservation in the central government.

In the period between the 1970s and late 1980s, there was a rapid decline in the numbers of certain wildlife species, notably elephants and rhino, mainly through poaching (Cobb, 1976; Mbugua and Stevens, 1977; Ottichilo et al., 1981; Van Wyngaarden, 1985; Kenya

Wildlife Service, 1990; and Mwenje International Associates Ltd, 1980). In reaction to this decline, the government in 1989, through an act of parliament, established a parastatal organization, the Kenya Wildlife Service, with a mandate to deal with the problem of poaching, in addition to managing wildlife. By 1994, poaching in most protected areas had been brought under control and Kenya Wildlife Service could concentrate on the other aspects of its mandate.

4.3 Nature Conservation in Kenya in the 1990s: Where do we stand?

Many of the current nature conservation challenges in Kenya are a result of the wildlife conservation policies of the last 90 years, most of which were not designed to cope with changing circumstances outside protected areas. Previously, wildlife conservation was based on the 'protected area' concept, in which specific areas were designated by legislation for the protection and conservation of environmental resources.

The basic principle of protected areas involves setting aside representative areas of unique and unspoiled parts of the country as public parks for the benefit and quiet enjoyment of the people, and for the detailed study of nature. This concept was first conceived in the United States of America in 1872 and led to the establishment of the Yellowstone National Park as the world's first protected area (Nash, 1982). When applying this concept in Kenya, the emphasis was on wildlife conservation, focussing mainly on the large mammals. The network of protected areas in Kenya is dominated by areas where these mammals are predominant.

In the 1980s, there was growing international concern about loss of biodiversity in the tropics. IUCN (1990) described biodiversity as the living organisms in all their variety (plants, animals, fungi and microbes) that exist on the planet Earth. This implies that conservation of biodiversity is a cumulative process, i.e. conservation at protected area level contributes to the conservation of a country's biodiversity. This in turn contributes to

the conservation of regional, continental and, finally, planetary biodiversity. Depending on the spatial scale, biodiversity can be viewed at three different levels: genetic diversity, species diversity and ecosystem diversity. The three are related in a nested hierarchic structure, i.e. ecosystems are made up of species composed of genetic material. This study will be restricted to species and ecosystem diversity.

Generally, conservation refers to either preservation or controlled use. The term may be used to describe the systematic protection of natural resources (flora and fauna) or the care of the environment (management). Tivy (1994) distinguished two viewpoints of natural resource conservation: the *sustainable yield* of those products for which there is the greatest demand and which would give the maximum return on capital invested, and the protection and preservation of wildlife, i.e. *nature (biodiversity) conservation*. Protected areas fall under the second. Wise maintenance and utilization of wildlife resources are central to the modern concept of conservation. This concept entails the principles of planning resource management on the basis of accurate inventory, and the need to protect resources from degradation and extinction.

4.4 The Functional Structure of KWS

The functional structure of KWS has had to change in order to effectively implement its mission. Until 1995, there were only two levels in the organizational structure (national and local (park) levels). The establishment of policy and development of conservation programmes were done centrally at the national level, while implementation of conservation programmes was at the local level. In this structure, there was little horizontal interaction within the organization at the local level, although many conservation problems involve more than one local area and need coordinated efforts in finding solutions. There also was no mechanism by which the impact of the different biodiversity resource conservation and management programmes could be monitored at the national level.

The new functional structure consists of three levels: the national level to deal with overall policy issues, regional level to deal with regional biodiversity issues and local level to deal with local issues. At the national level, there are three levels of authority responsible for making policy decisions regarding the future direction of KWS (Fig. 4.1). These are:

- (1) A Board of Trustees, as the highest level, determines general policy and establishes the long-term objectives for the organization,
- (2) The Directorate, headed by a director is responsible for preparation of policy recommendations for the board and the execution of the boards policy decisions, and providing resources to ensure that the objectives of the organization are met, and
- (3) the different Departments headed by Deputy Directors are charged with various operational responsibilities geared towards achieving the overall goals of the organization according to the policies of the board. Each department has its own specific objectives. Of relevance to this study is the Department of Biodiversity.



Fig. 4.1 The Internal Organizational Hierarchy of Kenya Wildlife Service (Source: KWS, 1995)

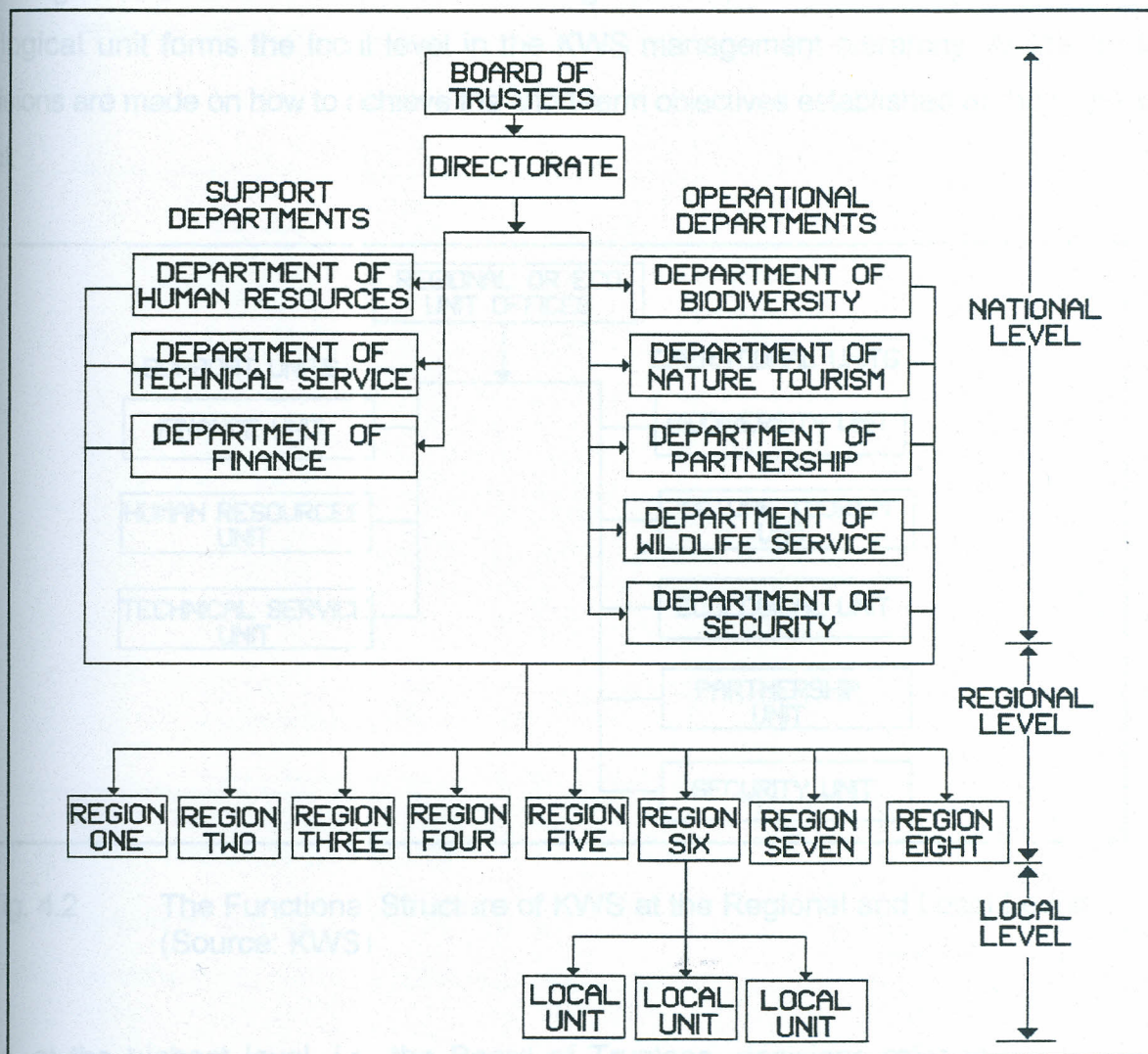


Fig. 4.1 The Internal Organizational Hierarchy of Kenya Wildlife Service (Source: KWS, 1996)

At the national level, KWS also has links with external agencies and organizations. For effective management, KWS has divided the country into eight regions. Each region is headed by an assistant director and consists of eight functional units (Fig. 4.2). The biodiversity, partnership and ecological units are directly responsible for biodiversity conservation. At the regional level, decisions are made on how to translate the organization's long-term objectives and plans into implementable programmes within the functional units. Short-term objectives are established at this level.

Each region is divided into a number of ecological units, each headed by a warden. An ecological unit forms the local level in the KWS management hierarchy. At this level, decisions are made on how to achieve the short-term objectives established at the regional level.

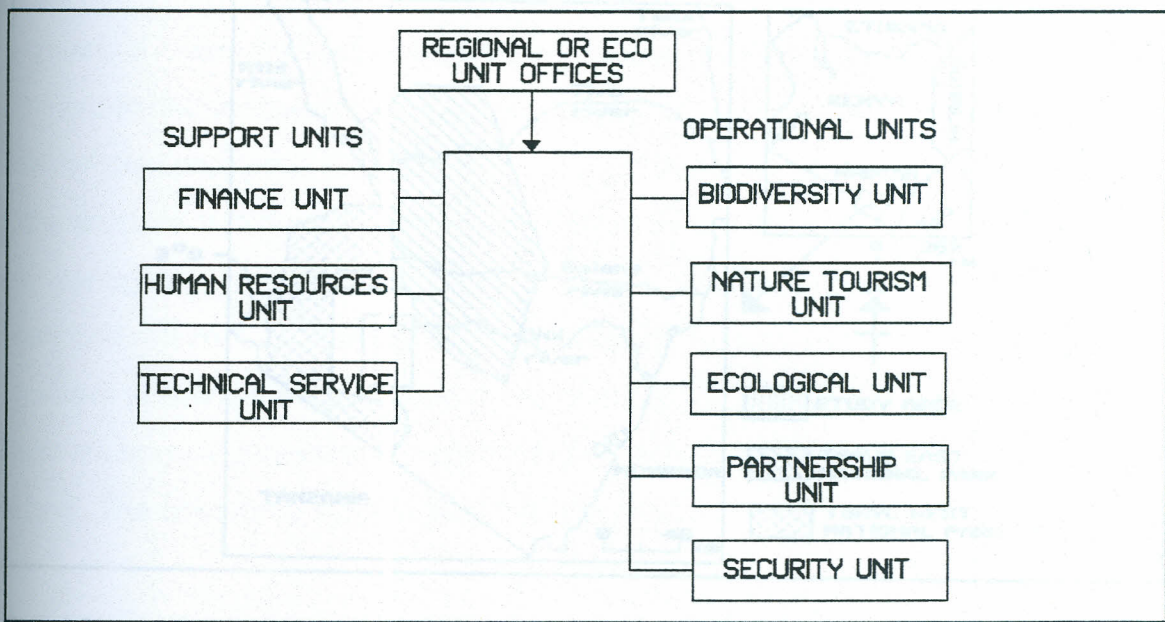


Fig. 4.2 The Functional Structure of KWS at the Regional and Local Levels (Source: KWS)

Thus, at the highest level, i.e. the Board of Trustees, decisions refer to biodiversity conservation in general and become more specific down the organizational hierarchy. On the other hand, information flows upwards in the hierarchy from the local level through the regional levels to the national level.

4.5 The Case Study Area

The study area covers approximately 660 km² and is located in southeastern Kenya in the buffer zone between Tsavo East and Tsavo West national parks. The Taita hills to the north of the area are the dominant feature and greatly influence the climate of the area. Elevation ranges from

approximately 680 m to about 1920 m above mean sea level (amsl). The northern part is steeply dissected, while the central and the southern parts are characterized by gently undulating plains (Fig. 4.3).

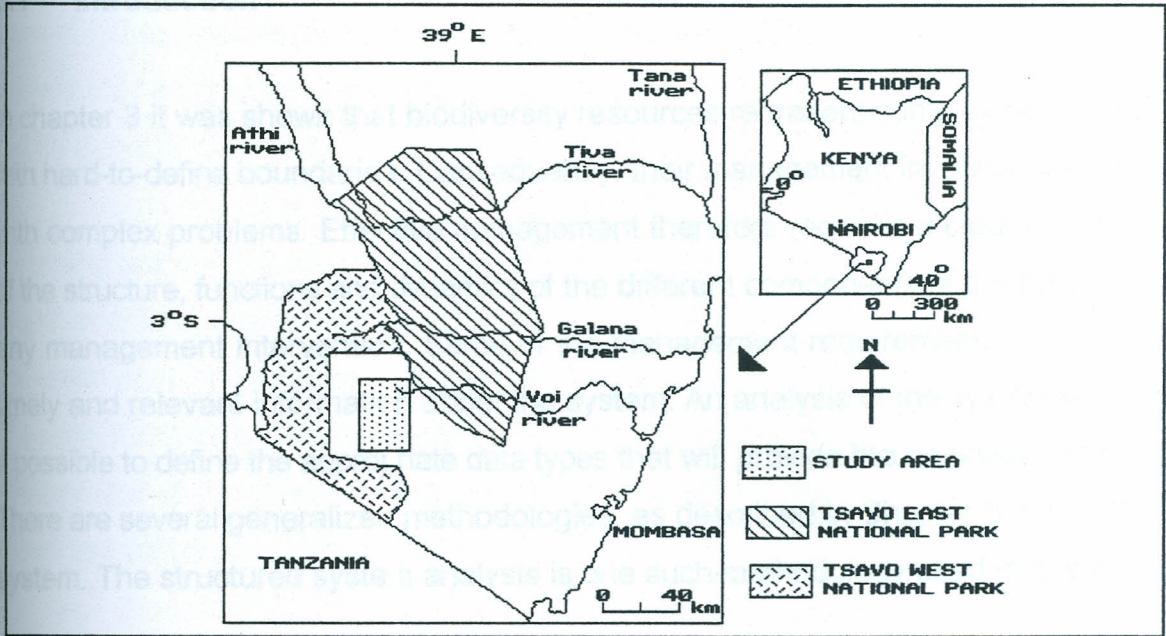


Fig. 4.3 The Case Study Area

Rainfall varies from an average of 400 mm per annum in the south to an average of 1200 mm in the north. The variation in rainfall is reflected in the variation in natural vegetation and land use.

Only in the last year has land cover and land use in part of the case study area been studied at a semi-detailed level (RLE 3, 1994). The study area has traditionally served as the buffer zone for Tsavo East National Park. It was initially used mainly by foraging wild animals and pastoralists' herds. Currently, the buffer zone is also being populated by small-scale farmers.

Chapter 5 A systems Approach to Defining Information Requirements for Effective Management of Biodiversity Resources in Kenya

5.1 Introduction

In chapter 3 it was shown that biodiversity resources represent complex natural systems with hard-to-define boundaries. Consequently, their management involves having to deal with complex problems. Effective management therefore requires a clear understanding of the structure, functions and dynamics of the different components of the system prior to any management intervention. Some of the management requirements are, adequate, timely and relevant information about the system. An analysis of the system would make it possible to define the appropriate data types that will provide the necessary information. There are several generalized methodologies, as described in Chapter 3, for analyzing a system. The structured system analysis is one such methodology used in this study.

This chapter presents a system's approach to the management and conservation of biodiversity resources. The different hierarchical levels at which biodiversity resources in Kenya could be viewed and managed are defined in the internal organization hierarchy of Kenya Wildlife service (see Figs. 4.1 and 4.2). In section 5.2, processes involved in biodiversity management and conservation and their data requirements are analysed. Section 5.3 describes the linkage between different management levels in biodiversity resources and internal organizational hierarchy of KWS with specific reference to the department of biodiversity. This department has the overall responsibility in the management of biodiversity resources. The information requirements for decision support at each level in the management hierarchy was identified using a structured systems approach to analyze the biodiversity resources system. This made it possible to determine data types necessary to provide the required information (section 5.4).

Good quality information is crucial for management decision support in biodiversity

resources management and conservation. The types of information required are determined by the level in the management hierarchy at which the decisions are made, and such information can be extracted only from appropriate data sources. Because data collection is expensive, there is a need to rationalize the process by setting priorities. These priorities provide a basis for designing and developing an information system that will meet the needs of the organization it serves. For this study, the organization is Kenya Wildlife Service.

A planning approach was used to develop a management decision support system (see Avison and Fitzgerald, 1988), emphasising development of a complete biodiversity information plan for the whole organization. This ensures that the system to be developed will enable KWS to meet its objectives for biodiversity management and conservation. The development of the system must be well structured. Figure 5.1 summarizes the main procedures followed in this study.

There are many methods for structured system development (see Avison and Fitzgerald, 1988; Paresi, 1995). In this study, the System Development Methodology (SDM) was used (Cap Gemini Publishing, 1991). Although SDM was originally designed for use in business applications, it was adapted for use here because: it meets the basic criteria for a well-structured system development method (see IBM, 1984; Avison and Fitzgerald, 1988; Hawryskiewicz, 1991), it is not dependent on any single technique but allows different techniques to be applied at various stages in the system development process, and it allows computer-assisted software engineering (CASE) tools to be used in system development. In this study, the systems development workbench was used as a CASE tool (Cap Gemini Publishing, 1991).

The SDM is divided into seven phases: information system planning, definition study, system design, detailed system design, implementation, installation and conversion, and operation and control. These phases describe the sequence of activities to be undertaken

during system development and the expected products at the end of each phase. This study was restricted to the first five phases only.

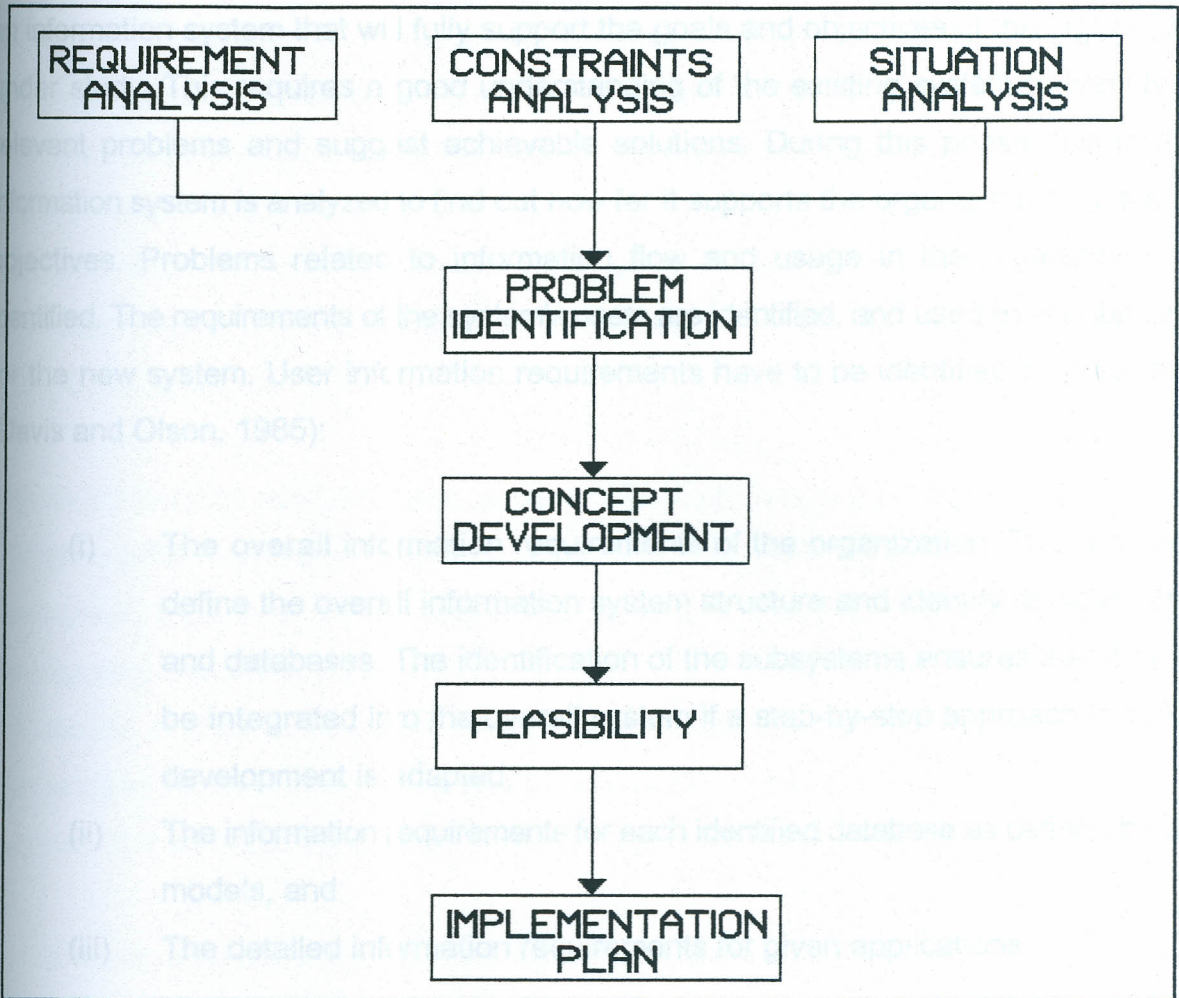


Fig. 5.1 Scheme for Developing a Biodiversity Information System Plan for KWS

5.2 Phase One: Analysis

The first step towards building a full information system should be to identify the information requirements at each management level. This can be done through an analysis of the processes involved in biodiversity management and conservation and their data requirements. The main consideration is to determine whether or not the current

information system meets user needs and to identify areas that require refinement.

The objective of this phase is to provide a basis for the development and maintenance of an information system that will fully support the goals and objectives of the organization under study. This requires a good understanding of the existing system to identify the relevant problems and suggest achievable solutions. During this phase, the existing information system is analyzed to find out how far it supports the organization's goals and objectives. Problems related to information flow and usage in the organization are identified. The requirements of the system's users are identified, and used to set objectives for the new system. User information requirements have to be identified at three levels (Davis and Olson, 1985):

- (i) The overall information requirements of the organization. This is used to define the overall information system structure and identify its subsystems and databases. The identification of the subsystems ensures that they can be integrated into the overall system if a step-by-step approach to system development is adapted,
- (ii) The information requirements for each identified database as defined by data models, and
- (iii) The detailed information requirements for given applications.

Products of this phase were: requirements analysis report, situation analysis report and constraints analysis report. These reports provided details on the status of the present biodiversity information system, its associated problems and a framework for its future development or maintenance. The results from the requirements analysis are provided in section 5.2.1.

5.2.1 Requirements Analysis

The key department for information determination was selected from KWS's seven departments (section 4.3). In this study, the department of biodiversity was selected for analysis, which involved carrying out an information search. The main strategy for obtaining information about a system is either through direct contact with personnel using questionnaires, interview and meetings, or by using indirect approaches that include: synthesis from the characteristics of the used system, gleaning from the existing information system, and discovering by experimentation from an evolving system (IBM, 1984; Davis and Olson, 1985).

The direct contact approach was used in this study based on International Business Machine's (IBM) information system planning technique (IBM, 1984). This technique, uses three basic tools (i.e. review documents related to the organization, interviews with management and matrices) to: define the organization's processes, data and information architecture, analyze current system support, and set architectural priorities for the system. This leads to the description of a new conceptual information system and its subsystems. A choice is then made as to which subsystem should be developed first.

In this study, interviews were conducted with various executives selected from the three management levels of the organization. These included the director, three deputy directors, two senior wardens, four senior research officers and three park wardens. Other interviews were conducted with staff of the computer department and local residents living in the buffer zones of the Tsavo, Amboseli and Nairobi National Parks. Interviews with the executives were carried out in two stages. For each executive, a set of key questions relating to his or her area of responsibility was prepared in advance. These formed the basis for discussion. During the first stage of each interview, the questions were put to the interviewee and the responses recorded. The responses were summarized and the results analyzed. During the second stage of the interview, the results and conclusions from the

initial interview were presented to the interviewee for confirmation and possible further clarification. The interviews with staff in the computer section were mainly in the form of discussions and explanations regarding the tasks they were performing, and the procedures and tools used in these tasks. Interviews with the local people provided a general picture of their activities in relation to the protected areas. More information was gathered by reviewing literature. This included the organization's long-term development plan, annual work plans and half-yearly progress reports.

5.2.2 Results

An information system is supposed to assist an organization to meet its objectives and goals. Therefore a good starting point for information analysis of any organization is to determine its objectives and goals. These help to define what type of information is required and from what type of data this information can be extracted. The main objectives of KWS are:

- (1) To conserve the natural environments of Kenya and their biodiversity resources for the benefit of present and future generations and as a world heritage.
- (2) To sustainably use the wildlife resources of Kenya for the economic development of the nation, and for the benefit of the people living in wildlife areas.
- (3) To protect people and property from injury or damage caused by wildlife.

Table 5.1 shows the relationship between the management hierarchy in KWS and information requirements for decision support.

Table 5.1 Relationship Between Management Hierarchy and Information Requirements for Decision Support at KWS

Management decision level and process	Data type	Coverage	Level of detail	Quality Parameters ¹		Sources
				Derived data	Collected data	
National level - Develop biodiversity policy - Develop long term objectives and goals	Qualitative	Global and National	Generalized, Scale 1:1,000000	High average accuracy	Completeness Relevance	Primarily from external sources but also from internal sources
Regional level - Develop short term objectives - Develop implementable programmes - Model biodiversity resource processes - Monitor trends on biodiversity resources - Predict effect of management interventions	Quantitative	Regional	Semi-detailed to detailed Scales 1:250000 1:100000 1:50000	High accuracy	High accuracy High precision Timeliness Completeness Relevance	Internal and external sources
Local level - Implement programmes on biodiversity resources - Monitor programmes on biodiversity resources	Quantitative and qualitative	Local	Detailed Scale 1:50000 1:25000 1:10000	High local accuracy	High accuracy High precision Timeliness Completeness Relevance	Internal sources

¹Quality Parameters

- Precision - How specific are the object classes based on user needs, (i.e., spatial resolution).
- Accuracy - How close to reality are the data, (i.e., the reliability of the data) as determined by user needs.
- Timeliness - Information being available when required.
- Relevance - How the information matches the objectives of the users.
- Completeness - All required information should be available, up to date and devoid of redundancy.

5.3 The Link Between the Management Hierarchy and the Internal Organizational Hierarchy in the Department of Biodiversity of KWS

In this study as stated earlier, the process of information determination focused on the department of biodiversity. The main objectives of this department at the time of this study were to:

- collect, store, analyse and maintain data on biodiversity resources,
- disseminate information on biodiversity resources,
- identify threats to biodiversity resources,
- develop programmes for biodiversity conservation,
- implement programmes on biodiversity conservation, and
- monitor biodiversity conservation programmes.

To meet these objectives, the department had three hierarchical functional units, i.e. national, regional and local (Fig. 5.2). Each of these units corresponds to a specific level in the internal organization hierarchy of KWS.

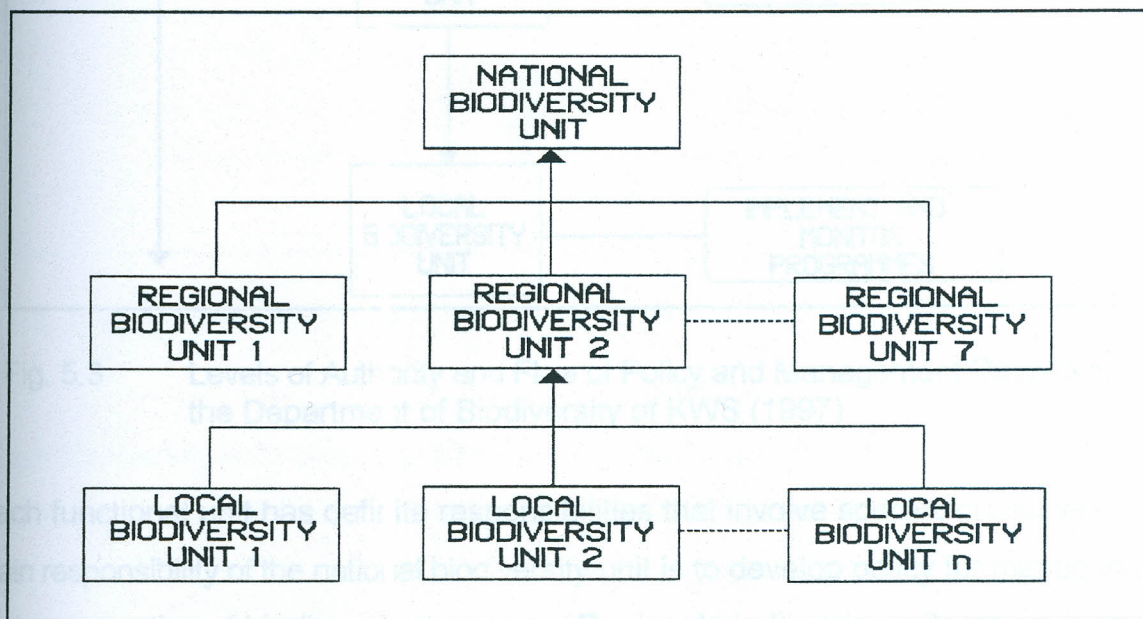


Fig. 5.2 Functional Units in the Department of Biodiversity at KWS (1997)

In this department, the national biodiversity unit is at the top of the hierarchy and corresponds to the national level in the organization hierarchy. At a lower level, there

are seven regional biodiversity units that correspond to the regional level in organization hierarchy. At the lowest level, each region consists of several local biodiversity units that correspond to the local level in the organization hierarchy.

Levels of authority coincide with the functional units in the department (Fig. 5.3). The head of a given local biodiversity unit reports to the head of a specific regional biodiversity unit, who in turn reports to the head of the national biodiversity unit. Policy and management decisions flow downwards from the national biodiversity unit to the regional biodiversity units and then to the local biodiversity units.

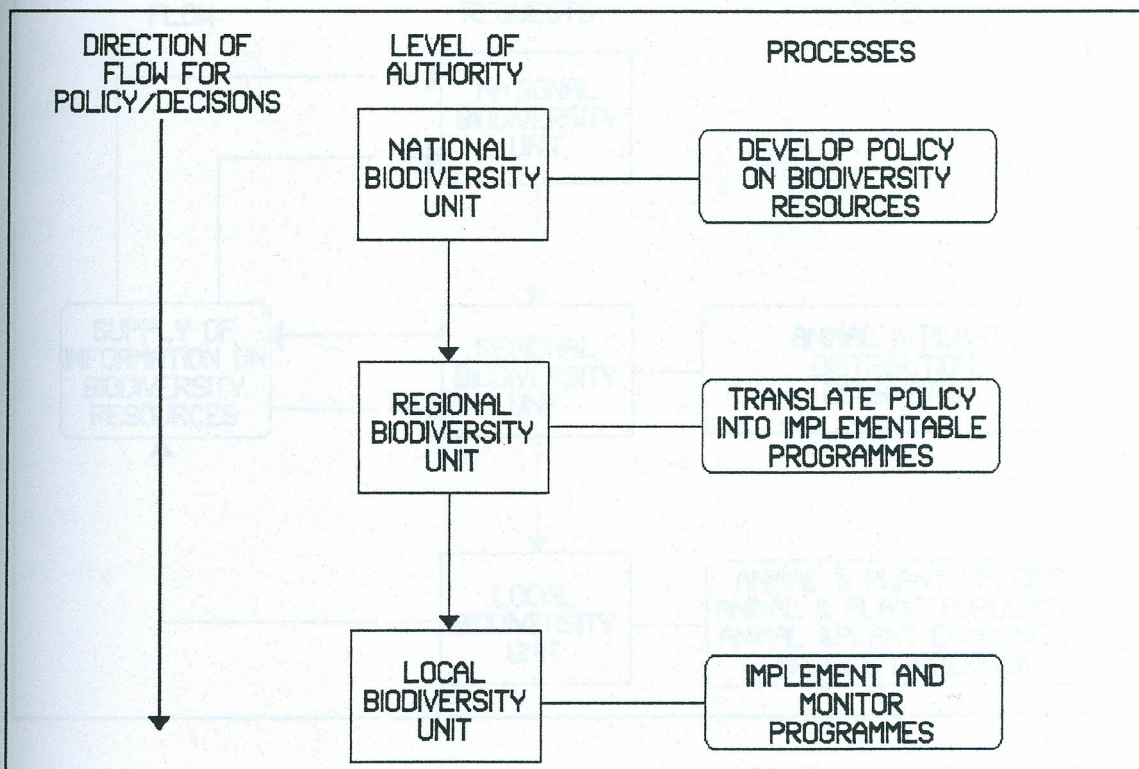


Fig. 5.3 Levels of Authority and Flow of Policy and Management Decisions in the Department of Biodiversity of KWS (1997)

Each functional unit has definite responsibilities that involve specific processes. The main responsibility of the national biodiversity unit is to develop policy for management and conservation of biodiversity resources. Regional biodiversity units translate these policies into implementable programmes for the management and conservation of biodiversity resources, while local biodiversity units implement and monitor the impact of these programmes. The different biodiversity units therefore represent different decision making contexts, each of which requires different levels of information

abstraction. The local biodiversity unit usually requires directly surveyed data; the regional and national biodiversity units require derived survey information.

Figure 5.4 illustrates the flow of information within the department and the different data types. Requests for information from the national biodiversity unit are made to a specific regional unit, while requests from the regional units are made to specific local units. Responses to requests for information can be provided by either regional or local units, depending on the level of detail required.

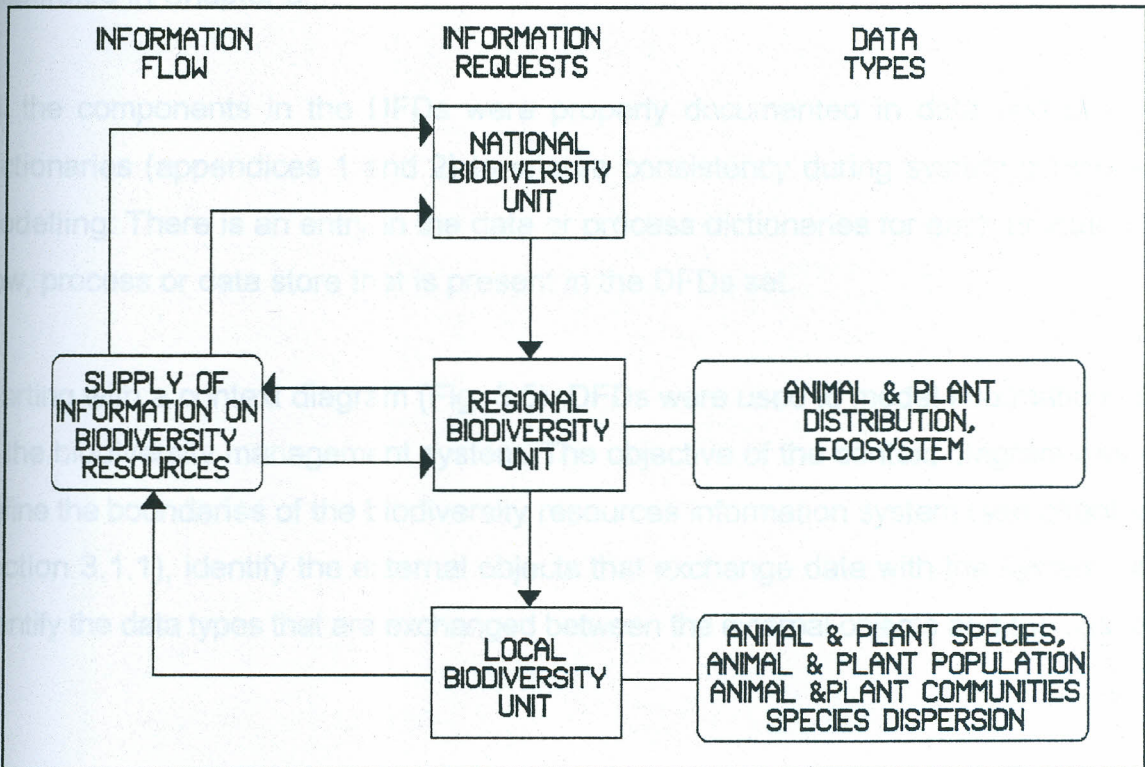


Fig. 5.4 Information Flow in the Department of Biodiversity of KWS (1997)

Local biodiversity units deal with biodiversity resources at the species, population and community levels and therefore require information at finer spatial scales, while regional and national biodiversity units deal mostly with biodiversity resources at the ecosystem and biome levels and therefore require information at more coarse spatial scales.

The different functional units in the department of biodiversity correspond to spatial units; thus they can be linked through aggregation hierarchies. This linkage forms the basis for a management decision support model for biodiversity resources.

5.4 Defining Primary Data Types for a Biodiversity Resources Management Decision Support System: Information Modelling

The main objective of information modelling was to identify and define the basic data types for a biodiversity decision support system. For this, we used data flow diagrams (DFDs) as a tool to model biodiversity resources management system components, i.e., processes, data used and produced by these processes, any external entities that interact with the system, and information flow. The basic concepts of DFDs are elaborated in Chapter 3.

All the components in the DFDs were properly documented in data and process dictionaries (appendices 1 and 2) to ensure consistency during system component modelling. There is an entry in the data or process dictionaries for each unique data flow, process or data store that is present in the DFDs set.

Starting with a context diagram (Fig. 5.5), DFDs were used to model information flow in the biodiversity management system. The objective of the context diagram was to: define the boundaries of the biodiversity resources information system (see chapter 3 section 3.1.1), identify the external objects that exchange data with the system, and identify the data types that are exchanged between the external objects and the system.

Fig. 5.5 Context Diagram For the Biodiversity Resources Management System for Kenya Wildlife Service

In the context diagram, only one function is defined, i.e., biodiversity conservation. This is a global definition that includes all processes involved in biodiversity management and conservation. This diagram was then elaborated in terms of the top-level processes in Figure 5.6. Four functions were identified:

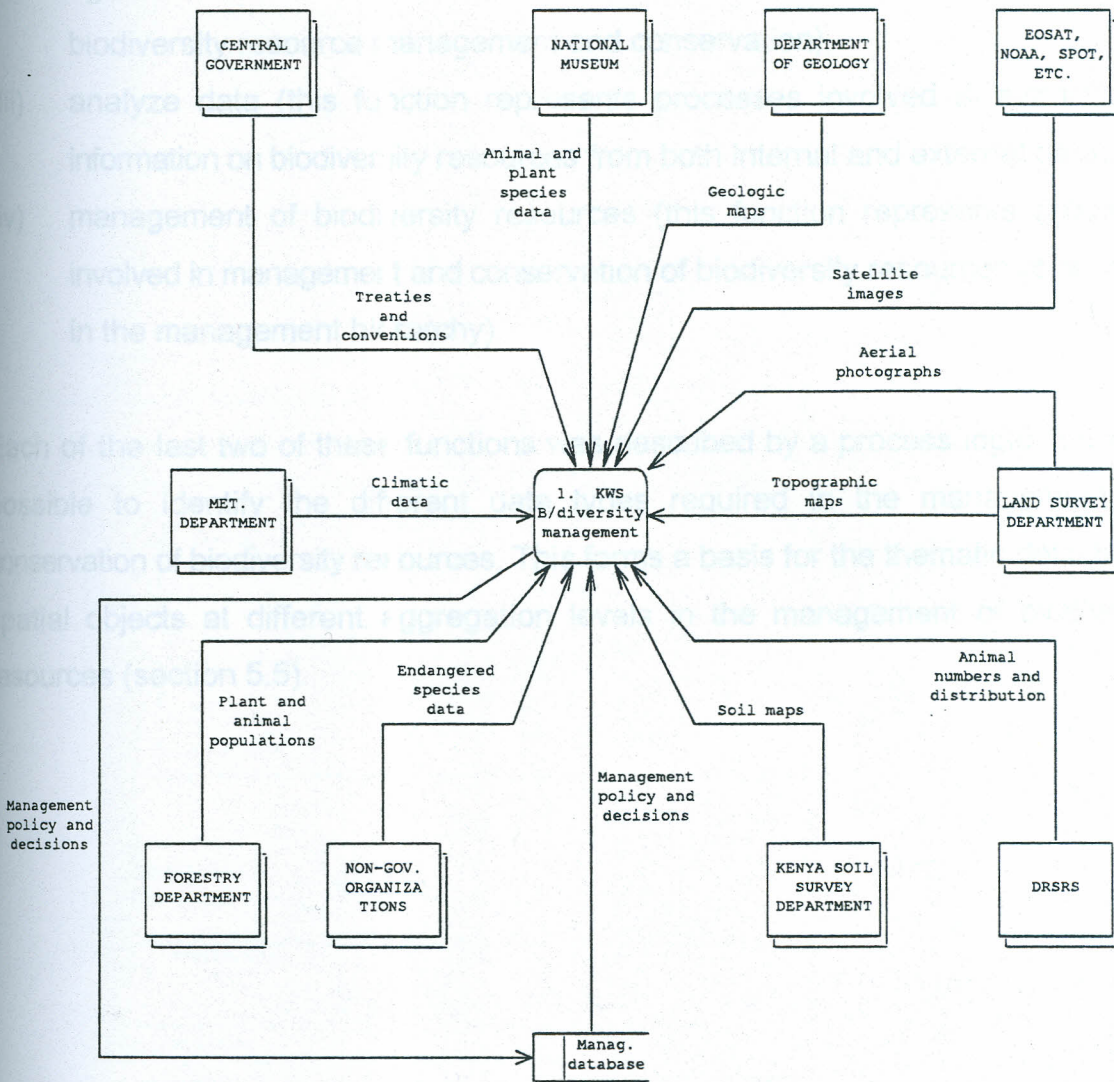


Fig. 5.5 Context Diagram For the Biodiversity Resources Information System for Kenya Wildlife Service

In the context diagram, only one function is defined, i.e., biodiversity conservation. This is a global definition that includes all processes involved in biodiversity management and conservation. This diagram was then elaborated in terms of the top-level functions in Figure 5.6. Four functions were identified:

- (i) acquire internal data (this function represents processes involved in acquisition of data on biodiversity resources by KWS),
- (ii) acquire and transform external data (this function represents processes involved in acquisition by KWS of data on biodiversity resources collected by external agencies and their standardization and harmonization for application in biodiversity resource management and conservation),
- (iii) analyze data (this function represents processes involved in extraction of information on biodiversity resources from both internal and external data), and
- (iv) management of biodiversity resources (this function represents processes involved in management and conservation of biodiversity resources at all levels in the management hierarchy).

Each of the last two of these functions was described by a process logic, making it possible to identify the different data types required in the management and conservation of biodiversity resources. This forms a basis for the thematic definition of spatial objects at different aggregation levels in the management of biodiversity resources (section 5.5).

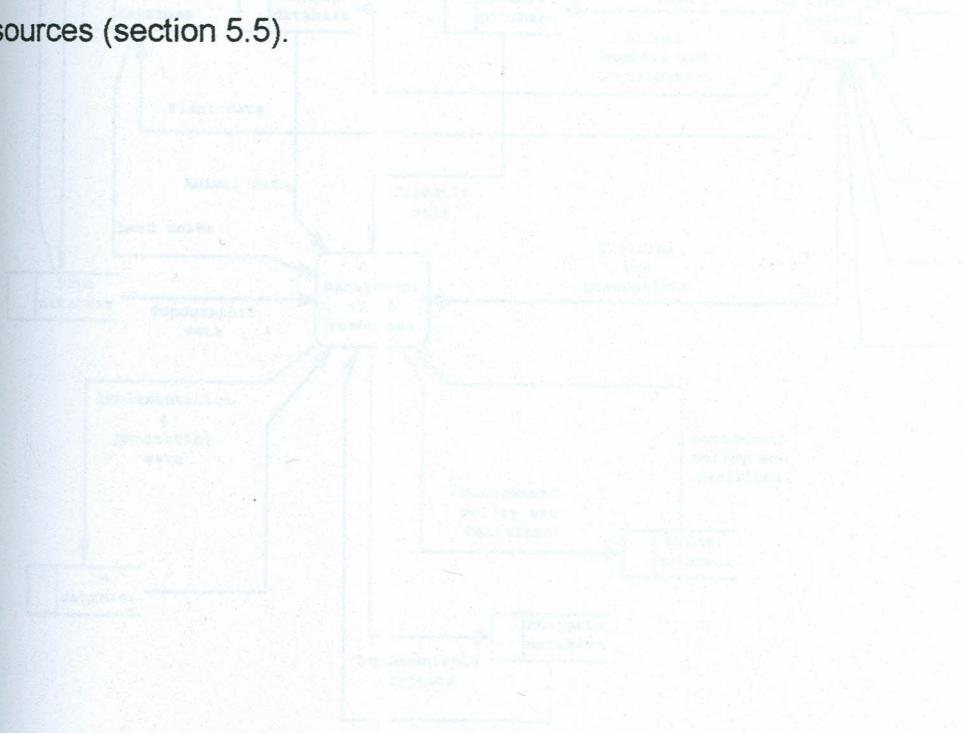


Fig 5.5 Top-level Functions of the Biodiversity Resources Management System for KWS

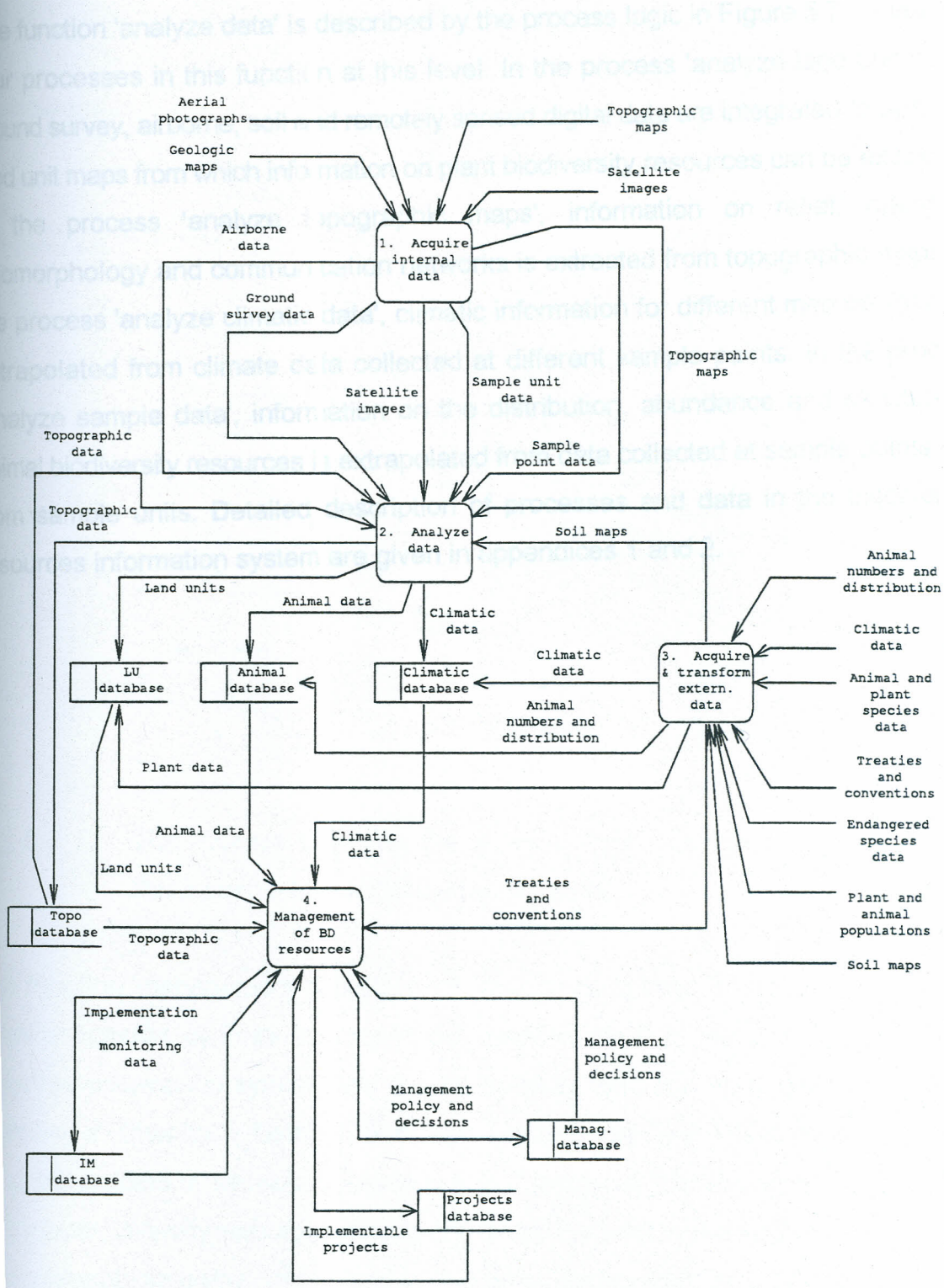


Fig. 5.6 Top-level Functions of the Biodiversity Resources Information System for KWS

5.5 The Process Logic for Data Type Identification and Analysis

The function 'analyze data' is described by the process logic in Figure 5.7. There are four processes in this function at this level. In the process 'analyze land unit data', ground survey, airborne, soil and remotely sensed digital data are integrated to produce land unit maps from which information on plant biodiversity resources can be extracted. In the process 'analyze topographic maps', information on relief, drainage, geomorphology and communication networks is extracted from topographic maps. In the process 'analyze climatic data', climatic information for different map polygons is extrapolated from climate data collected at different sample points. In the process 'analyze sample data', information on the distribution, abundance and structure of animal biodiversity resources is extrapolated from data collected at sample points and from sample units. Detailed description of processes and data in the biodiversity resources information system are given in appendices 1 and 2.

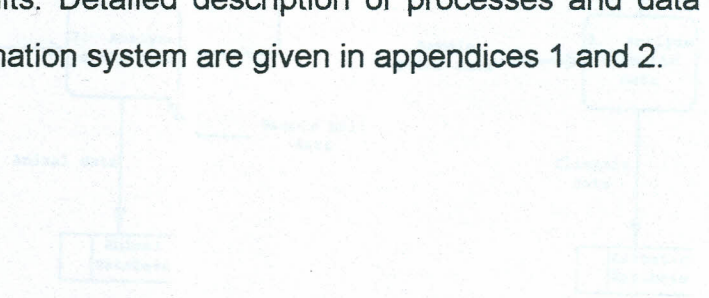


Fig. 5.7 The Process Logic for the 'analyze data' Function of the Biodiversity Resources Information System for KVE

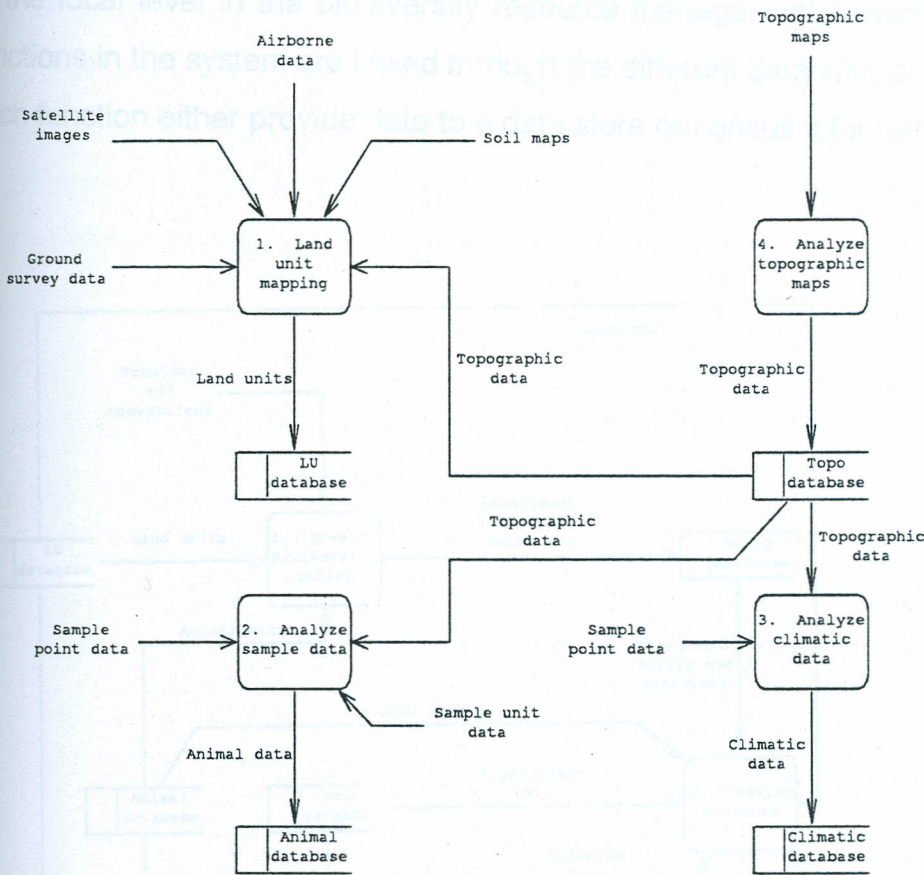


Fig. 5.7 The Process Logic for the 'analyze data' Function of the Biodiversity Resources Information System for KWS

The function 'management of biodiversity resources' is described in Figure 5.8. This function consists of three processes that provide the link between the biodiversity resource information system and the biodiversity resource management hierarchy identified in Chapter 3. Using treaties and conventions, land unit and animal data as input, the process of 'develop biodiversity policy' produces information on management policy for biodiversity resources. This is at the national level in the biodiversity resource management hierarchy. Using land unit, animal, topographic and climatic data, plus biodiversity resource management policy, the process of 'develop projects' produces a set of implementable projects in the management and conservation of biodiversity resources. This is at the regional level in the biodiversity resource management hierarchy. Using land unit, animal, climatic data, and a set of implementable projects

as input, the process of 'implement projects' produces data on the implementation and monitoring of the impact of management intervention on biodiversity resources. This is at the local level in the biodiversity resource management hierarchy. The different functions in the system are linked through the different data stores. The processes in each function either provide data to a data store or consult it for data.

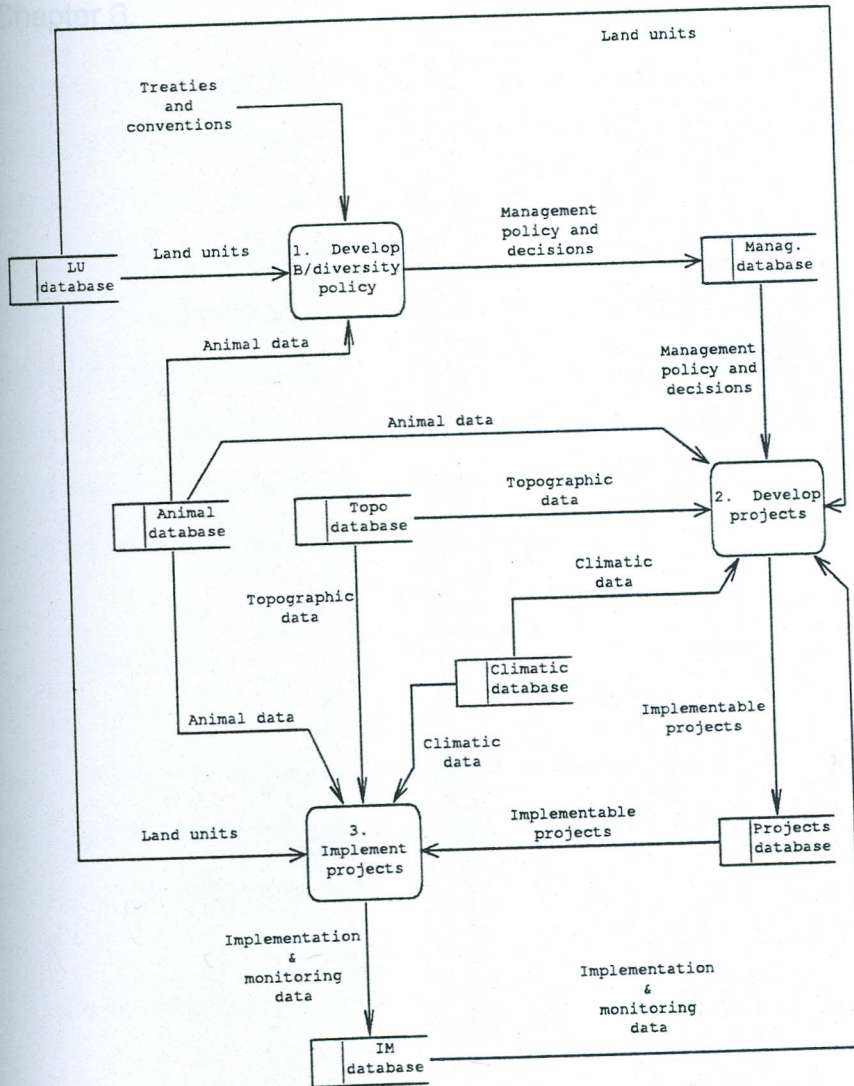


Fig. 5.8 The Process Logic for the 'management of biodiversity resources' Function of the Biodiversity Resources Information System for KWS

5.6 Summary

In this chapter, The basic data types that are needed to provide information for decision support for effective management of biodiversity resources in Kenya have been identified. This has been done by analyzing biodiversity resources as a natural system. The data types identified form a basis for defining a data model for representing the data in a database and for defining a database structure. This is considered in detail in Chapter 6.

6.1 Database

There were three stages in developing the database. The first stage was to develop the data model for the database. This was followed by defining the database structure and finally the database design.

6.1.1 Database Model

Based on the functional analysis of biodiversity conservation described in Chapter 5, general-purpose classes of data used by many applications and groups of users were identified that are inter-related and together describe a coherent part of biodiversity resources. They were then used to define a conceptual data model for the biodiversity resources information system. The database consists of five systems, i.e., land cover, animal, climate, socio-economic and topographic data.

Chapter 6 Implementation of the Biodiversity Resources Information System

6.1 Introduction

The main data types required to support decisions essential for effective management of biodiversity resources have been identified in Chapter 5. This Chapter describes how a database to support multi-level management decisions in biodiversity conservation was designed and implemented. Because information to support these multi-level management decisions is to be extracted from the same data, their (data) usage has to be contextual. Several models for context transformation are described and a number of programmes have been written to implement them. The tools used include the Arc/Info GIS software, Arc View software and an Access database management system with programming in SQL. Test data for the implementation of the models for context transformations are from Tsavo Ecosystem. A key component of the biodiversity resources information system is the database.

6.2 Database

There were three stages in developing this database. The first stage was to define a data model for the database. This was followed by defining the database environment and finally the database design.

6.2.1 Database Model

Based on the functional analysis of biodiversity conservation described in chapter 5, general-purpose classes of data used by many applications and groups of classes of data that are inter-related and together describe a coherent part of biodiversity resources were identified. They were then used to define a conceptual database model for the biodiversity resources information system. The database consist of five components, i.e., land cover, animal, climate, socio-economic and topographic sub-

databases (Fig. 6.1). These database components and associated computer software (Arc/Info and Access) constitute the biodiversity information base similar to the one described in Chapter 2 section 2.2.2.

6.2.2 Database Environment

The conceptual database model defined above (Fig. 6.1) was implemented using the Arc/Info geographic information system software in combination with the Access database management system software. The objective of implementing the database model was to test its suitability as a source of information to support decisions for the different levels of biodiversity management as defined in section 5.3. The Arc/Info software has capabilities for manipulating, analyzing and displaying spatial data in digital form. The software organizes geographic data using a relational and topological model, as described in chapter 3, making it possible to handle both geometric and thematic data.

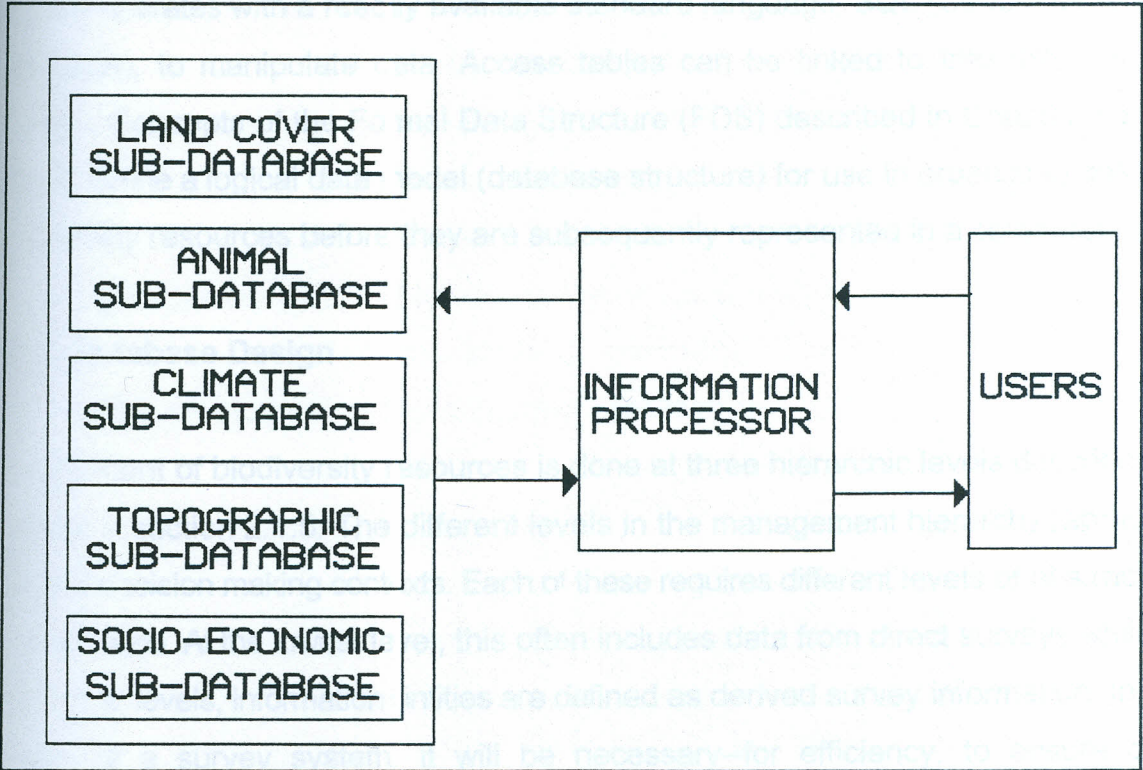


Fig. 6.1 A Conceptual Database Model for the Biodiversity Resources Information System for KWS.

Chapter 2 section 2, it was established that information required to support decisions in biodiversity conservation is contextual in the sense that specific information is needed for certain decisions at different levels in the biodiversity resources management hierarchy. The different decisions made at each level generally require specific information, similar data acquisition procedures are needed for all the management levels. There is therefore a need for context transformation and this is possible only if there is proper topological structuring of the relevant terrain objects¹ in a GIS. The Arc/Info software provides the required topology and represents terrain features in a GIS by sets of arcs, nodes and polygons, and provides the topological relationships among connected features. In this way, the connectivity and contiguity of terrain objects is maintained. The Arc\Info software was used for spatial data capture and representation, topological structuring and maintenance.

The Access database management system was used for the capture and maintenance of thematic data. This system is fully relational, and supports one-to-many and many-to-many operations, is object-based and robust, and allows easy access to data. This software operates with a readily available standard language, SQL (Structured Query Language), to manipulate data. Access tables can be linked to Info data files in Arc/Info. Concepts of the Formal Data Structure (FDS) described in Chapter 3 were used to define a logical data model (database structure) for use in organizing data on biodiversity resources before they are subsequently represented in a computer.

6.2.3 Database Design

Management of biodiversity resources is done at three hierarchic levels described in Chapter 2 section 2.1.5. The different levels in the management hierarchy represent different decision making contexts. Each of these requires different levels of abstraction of information. At the lowest level, this often includes data from direct surveys while at the higher levels, information entities are defined as derived survey information. In the design of a survey system, it will be necessary--for efficiency, to ensure data

¹ Terrain objects are defined in section 3.2

consistency and to avoid redundancy—to attempt to carry out one survey from which all the other information at the different context levels can be derived. The data have to therefore be represented in a database in a suitable format that will allow for context transformation. The database implemented in the prototype presented in this thesis was designed to include classification and aggregation hierarchies described in Chapter 3. Given the extensive nature of the KWS information requirements and its complexity, it was necessary to initially develop a prototype database. This is a small scale version of the actual database required by the KWS. It is used to test the applicability and suitability of the designed system in providing information to support biodiversity resources management decisions at all levels in the organization. This provides a means for testing the system for faults and other design deficiencies before its full implementation.

6.3 Biodiversity Database Structures

The biodiversity resources database implemented in the prototype was realised by mapping the Formal Data Structure (FDS) model described in chapter 3 to logical data structures in an Arc/Info and Access² database environment. Data on large herbivores, landcover and watering places were used to test the applicability of the proposed biodiversity resources database in providing information for management decision support at different hierarchic levels. In this study, large herbivores, landcover and watering places are taken as superclasses. In the following sections, each of these attributes is assessed on the basis of geometric, thematic and attribute data requirement for the biodiversity resources database.

6.3.1 Large Herbivores

Methodology for acquiring data on large herbivores is described in Chapter 3. For the study area, data on large herbivores were obtained from the Department of Resource

² Although implemented in Arc/Info and Access database environments, the design of the data structures is generic hence, they can be implemented in any other database environment that contains topology.

Figure 6.2 illustrates the logical data structure for storing spatial and thematic data on animal biodiversity resources. It depicts the vertical relationship between the data items. In this structure, each object is made up of a geometric and a thematic partition and has a unique identifier. This reflects the main characteristic of the FDS model described in chapter 3. There are two basic spatial objects from which data on animal biodiversity resources are obtained : the sample point and the sample unit. Animal biodiversity occur randomly within any given sample unit (Fig.6.3). Previously, limitations imposed by technology meant that data from an animal species that was sampled more than once in any given sample unit was aggregated and treated as a single reading during analysis. However with new and affordable technology in the form of Geographical Positioning Systems (GPS), data on the same animal species from the same sample unit can be analysed separately as the coordinates of the point where they are observed can be identified. These form sample points which are within the sample unit. Sample units are area features and are represented on topographic maps and subsequently in a GIS as polygons(Fig.6.4).

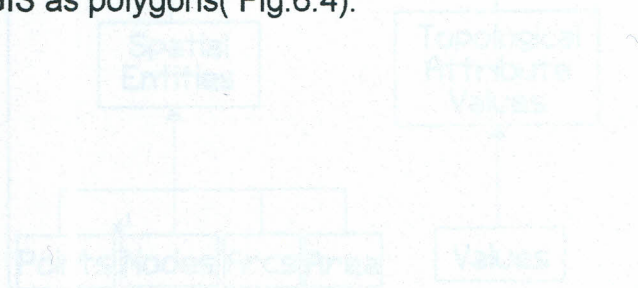


Fig. 6.2 Object (sample unit) Formation with a Logical Data Structure

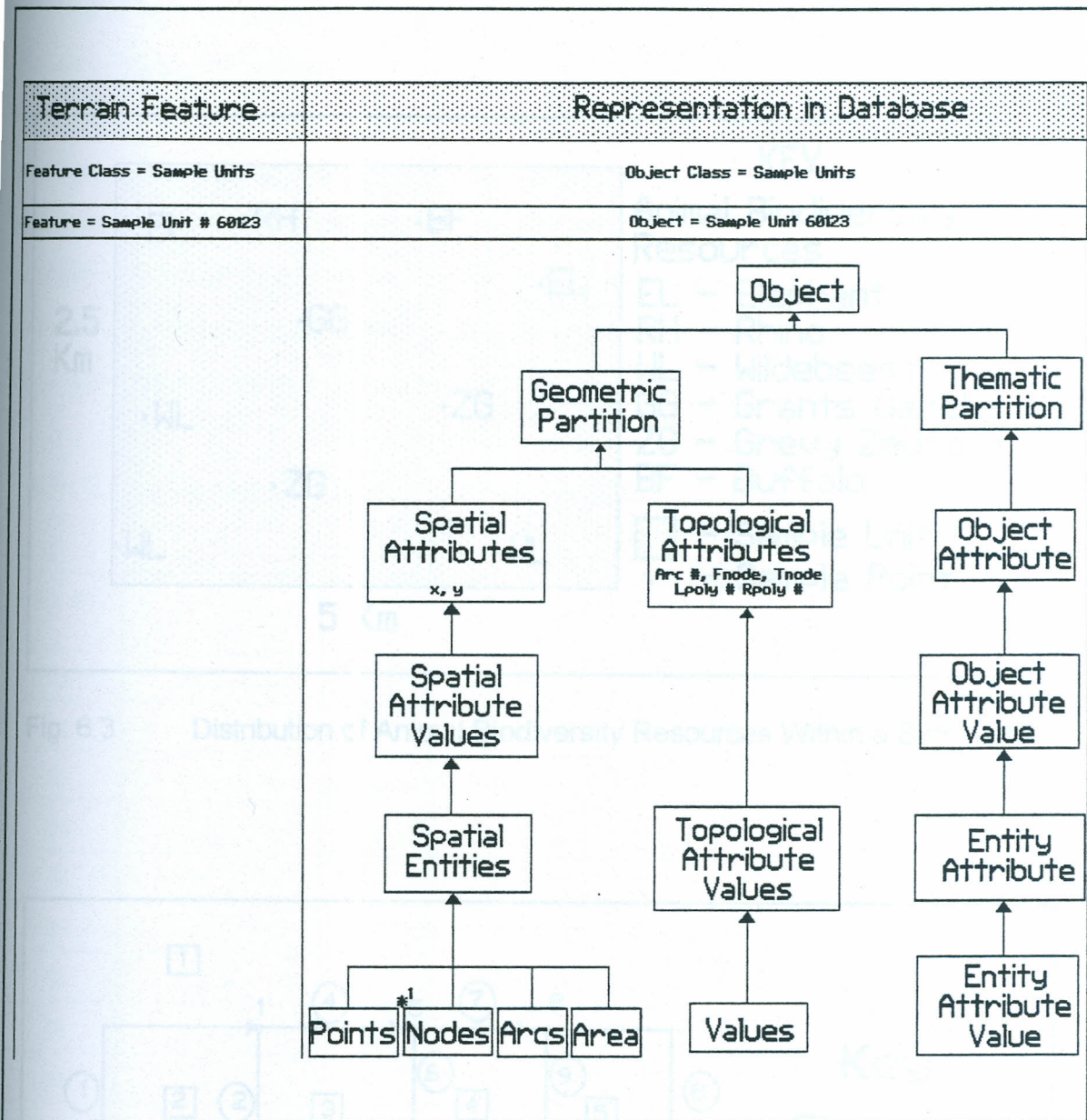


Fig. 6.2 Object (sample unit) Formation with a Logical Data Structure

Fig. 6.4 Sample Unit: Represented by Arcs and Polygons

These units are represented in the GIS by linking geographically adjacent polygons to form arcs. The topology is made of arcs (lines) and nodes (points). Each polygon is defined by a set of arcs. Each arc is defined by a set of nodes.

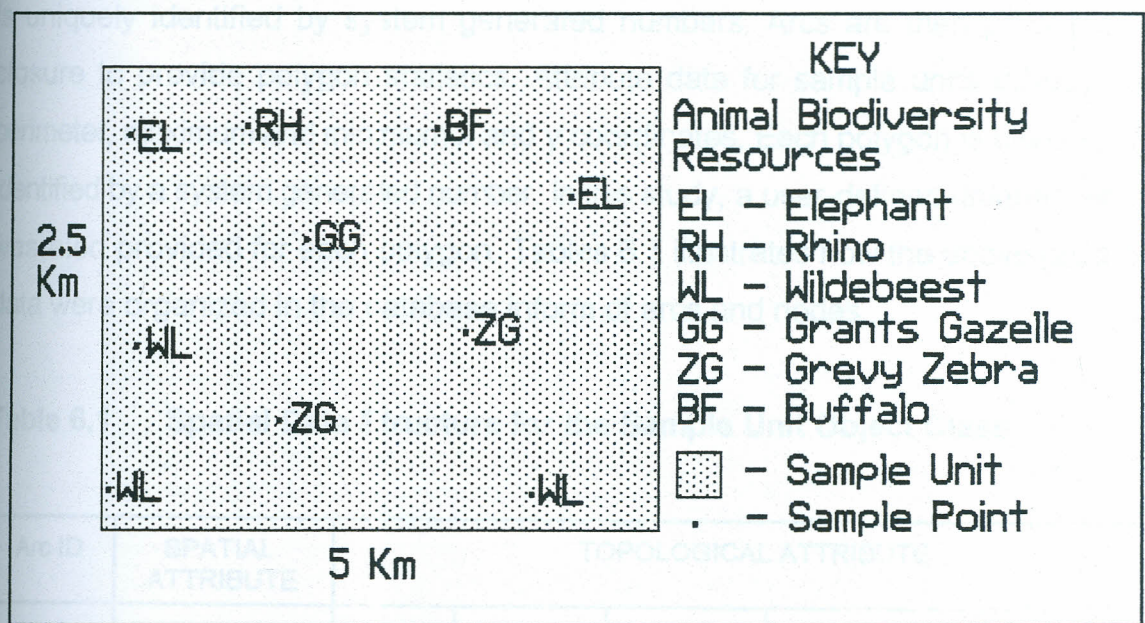


Fig. 6.3 Distribution of Animal Biodiversity Resources Within a Sample Unit

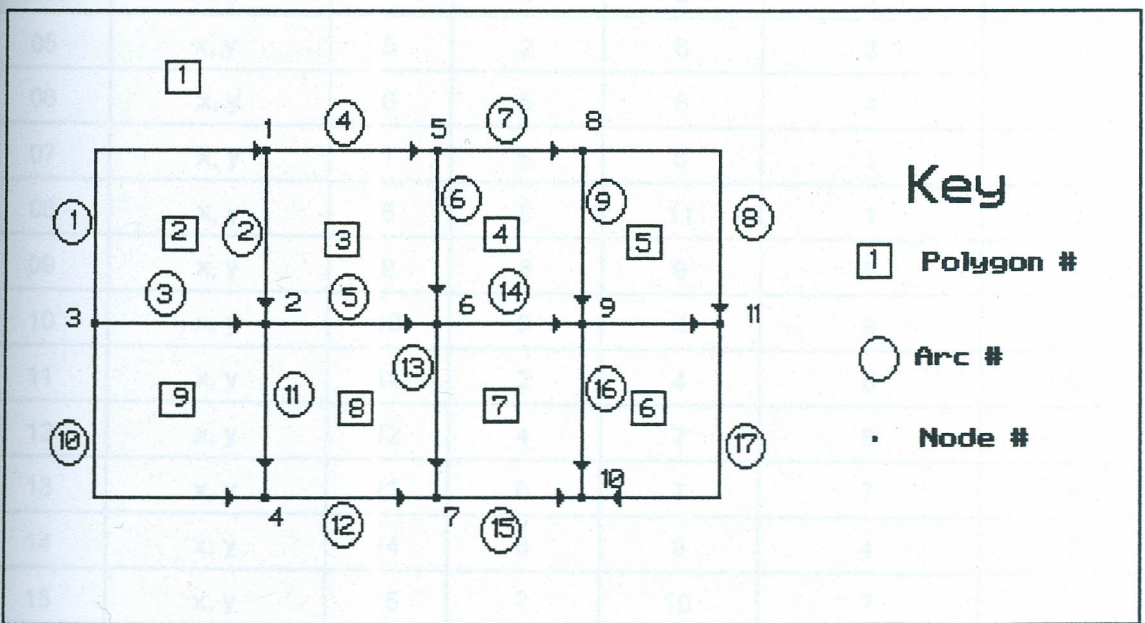


Fig. 6.4 Sample Units Represented by Arcs and Polygons

These units are represented in the GIS by linking geometrically atomic data, i.e. nodes and arcs, to form polygons. The topology is made of arcs, from-nodes (Fnode), to-nodes (Tnode), left polygon and right polygon. Each arc starts and ends at a node and is uniquely identified by system generated numbers. Arcs are then processed for closure to provide polygon statistics. Attribute data for sample units include area, perimeter, maximum and minimum x and y coordinates. Each polygon is also uniquely identified by a system generated number. In this study, a user-defined unique identifier was also provided for each polygon. Tables 6.1 illustrates how the above geometric data were organized in the database inform of arcs and nodes.

Table 6.1 Spatial Data Structure for the Sample Unit Object Class

Arc ID	SPATIAL ATTRIBUTE	TOPOLOGICAL ATTRIBUTE				
Recno	Coordinates	Arc	Fnode #	Tnode #	LeftPolyg #	RightPolyg #
01	x,y	1	3	1	1	2
02	x, y	2	1	2	3	2
03	x, y	3	3	2	2	9
04	x, y	4	1	5	1	3
05	x, y	5	2	6	3	8
06	x, y	6	5	6	4	3
07	x, y	7	5	8	1	4
08	x, y	8	8	11	1	5
09	x, y	9	8	9	5	4
10	x, y	10	3	4	9	1
11	x, y	11	2	4	8	9
12	x, y	12	4	7	8	1
13	x, y	13	6	7	7	8
14	x, y	14	6	9	4	7
15	x, y	15	7	10	7	1
16	x, y	16	9	10	6	7
17	x, y	17	11	10	1	6

Processing data on arcs and nodes produces polygons that are stored in the database as table (Table 6.2) containing information related to the polygon identity (system generated), user identity (user-defined) and associated spatial attributes.

Table 6.2 Polygon Data for the Sample Unit Object Class

Poly ID		User ID	Spatial attributes	
Recno	Intern #	SampleUnit #	Area (M ²)	Perimeter (M)
1	2	60121	25,000	20,000
2	3	61122	25,000	20,000
3	4	62123	25,000	20,000
4	5	63124	25,000	20,000

Tables 6.3 illustrates how thematic data were organized in the database. Data from the geometric and thematic partition were stored in different tables. The unique identifier for each sample unit was used to link data from its geometric partition (digitally captured in an Arc/Info database environment) with that from its thematic partition (digitally captured in an Access database environment). This is consistent with the FDS rules described in Chapter 3.

Table 6.3 Thematic Data Structure for the Sample Unit Object Class

ID				Coordinates		
CENSUS #	SAMPLE UNIT#	FLIGHT #	DATE	Dir	x	y
9605	60121	A001	02/23	E	439999.9	-295000.1
9605	60123	A001	02/23	E	444999.9	-285000.1

Continued

Table 6.3 continued

Entity Attributes					Object Attributes				
Species	C ₁	C ₂	C _n	C _{n+1}	SH (M)	SW (M)	SUL (M)	SUS (M)	TC
EL	11	7	21	4	400	0.224	5,000	5,000	43
RH	3				400	0.244	5,000	5,000	3

ID - Unique Identifiers, Species - Species Code (e.g. EL = Elephant, Rh - Rhino), C₁ - first count of EL, C₂ - Second count of EL in same Sample Unit, C_n - nth count of EL in the same Sample Unit, Date - Date of survey, SH - Survey Height, DIR - Survey Direction, SW - Strip Width, SUL - Sample Unit Length, SUS - Sample Unit Spacing, TC - Total count of a species in a given unit, M - Metres

The superclass 'large herbivores' consists of three classes (based on feeding habits i.e. browsers, mixed feeders and grazers) and subclasses (Individual herbivore species) as shown in Fig 6.5)). In this study, 21 data subclasses were determined in the case study area. Thematic data for the 'large herbivore' superclass were collected at the subclass level. They consisted of species name and the number observed per sample unit.

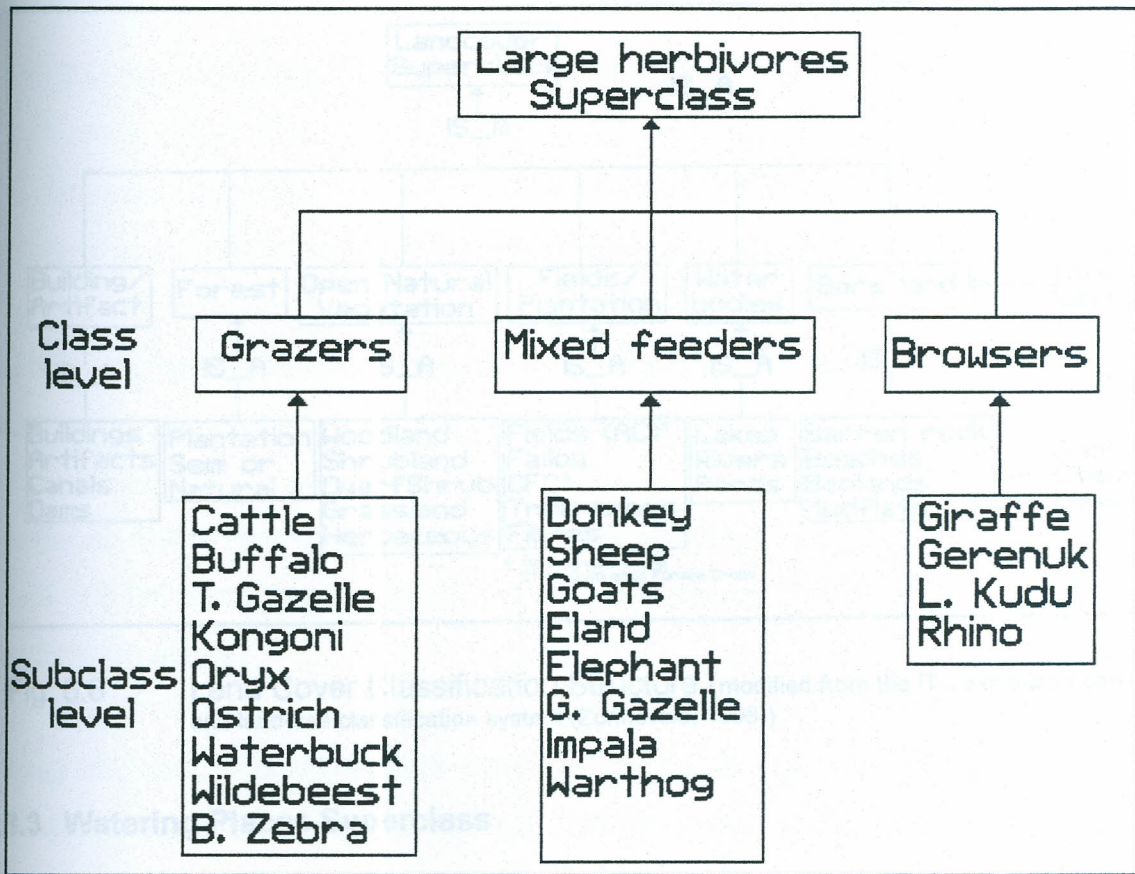


Fig. 6.5 Large Herbivore Classification Structure

6.3.2 Land Cover Superclass

Land cover data for the study area were acquired through analysis of remotely sensed data, sample aerial photographs and ground sampling as outlined in chapter 3. Figure 6.6 illustrates the hierarchic structure of land cover data. The different land cover types (sub-classes) are stored in a GIS as polygons with polygon topology such as Fnode, Tnode, left and right polygons. Each polygon is given a unique identification. The classification hierarchy is stored in a relational database environment using a table. The attributes in such table include: unique identification, area, circumference, specific land cover type, and general land cover type.

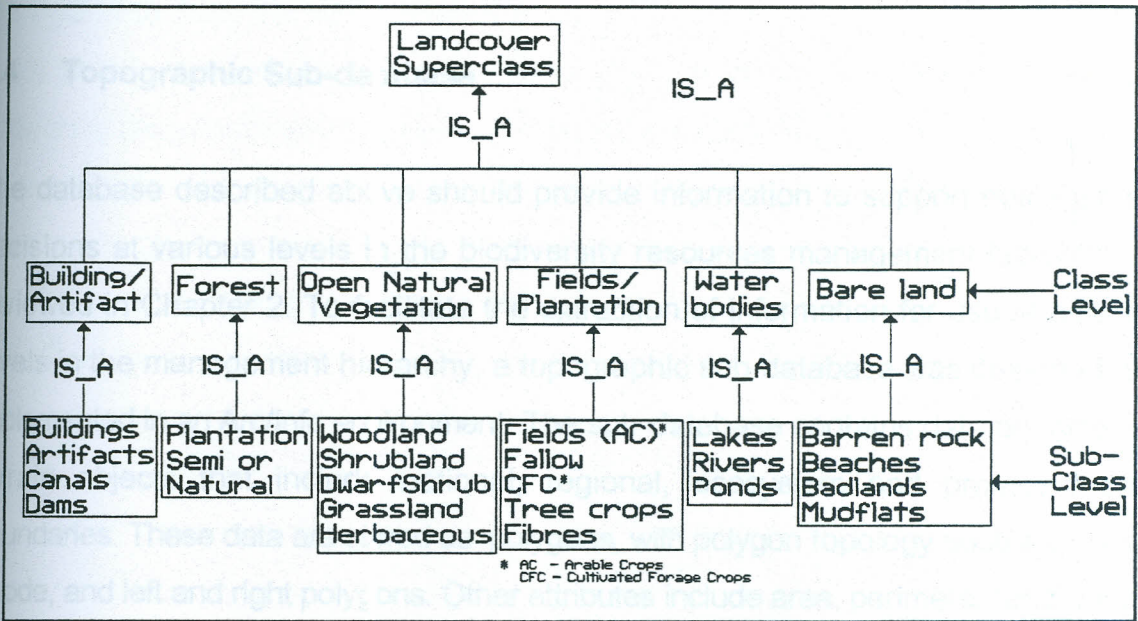


Fig. 6.6 Land Cover Classification Structure (modified from the ITC world land cover and land-use classification system (Zonneveld, 1988))

6.3.3 Watering Places Superclass

Data on watering places in the study area were extracted and digitally captured from 1:100,000 topographic maps produced by the Department of Survey, Kenya, and georeferenced to the UTM grid. Fig. 6.7 illustrates the hierarchic structure for watering places data. There are five main watering places for which data were stored in the data base; rivers and streams, dams and ponds, lakes, water holes, and swamps and marshes. Data on linear features (i.e. rivers and streams) were represented in the database by arcs made up of three atomic data items consisting of the line segment, a Fnode and a Tnode. Each arc (a river or stream) is uniquely identified by a system generated reference number plus a user provided reference code. Lakes, dams, swamps and marshes are represented in the database as polygons with polygon topology such as from-node, to-node, left and right polygons. Water holes and ponds are represented in the database as points using their x and y coordinates. The logical data structure for storing spatial and thematic data on watering places was similar to that of animal biodiversity resources (Fig. 6.2) only that the entity attributes and object

attributes were different.

6.4 Topographic Sub-database

The database described above should provide information to support management decisions at various levels in the biodiversity resources management hierarchy as reviewed in Chapter 2. To facilitate the extraction of information for use at different levels in the management hierarchy, a topographic sub-database was designed and implemented in an Arc/Info environment. The sub-database contains data on different terrain objects that include national, regional, ecosystem and protected area boundaries. These data are stored as polygons, with polygon topology such as Fnode, Tnode, and left and right polygons. Other attributes include area, perimeter, and unique identification codes.

Through the concept of aggregation described in Chapter 3 section 3.3.2, sample units as elementary objects are aggregated into ecological units which are composite objects (Fig. 6.8). These are then represented on a map and subsequently in a GIS as ecologic unit map polygons (= Eco-Unit_Mpolygon). At a higher level, ecological units are

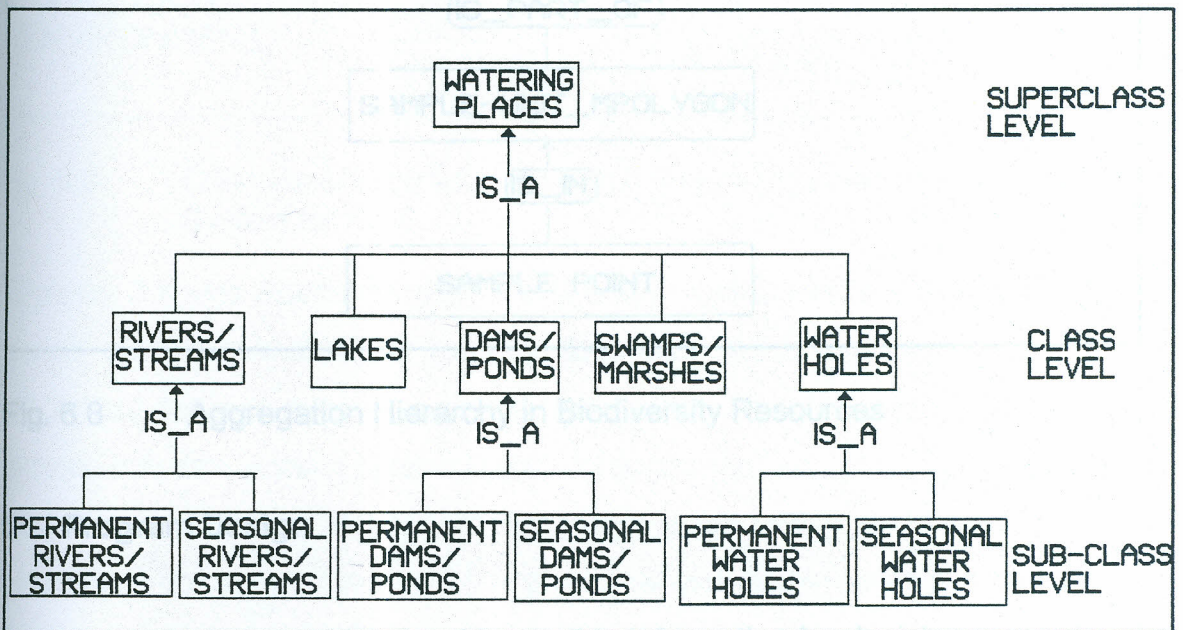


Fig. 6.7 Watering Places Classification Structure

aggregated to form region map polygons (Region_Mpolygon) which in turn are aggregated to form the national map polygon (National_Mpolygon). The top three levels in this biodiversity resources hierarchy correspond to the three levels in biodiversity resources management as discussed in Chapter 2 section 2.1.5. Each Eco-Unit and Region in the country was assigned a unique code. To facilitate the formation of composite objects such as region or national object classes from elementary objects (i.e. eco-units object classes) each Eco-Unit was assigned a regional and a national code. This makes it possible to expand the hierarchy to cater for the supra-region and continent as may be necessary.

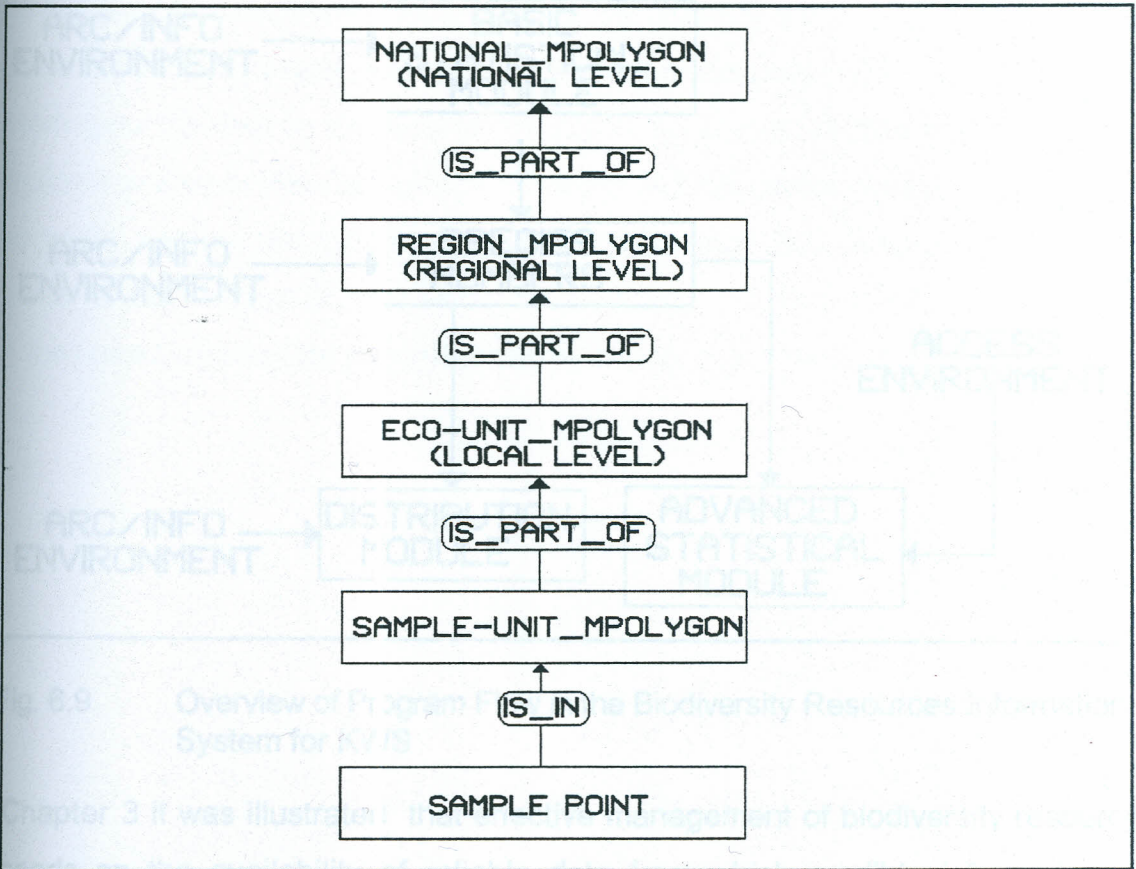


Fig. 6.8 Aggregation Hierarchy in Biodiversity Resources

6.5 Program Design

A computer program was designed to provide information for decision support at the

different levels in the biodiversity resources management hierarchy. This program consists of some four main modules including modules for data quality control, basic statistical analysis, distribution and advanced statistical analysis. Fig. 6.9 illustrates an overview of the program flow of the main modules and the environment under which they operate in the biodiversity resources information system.

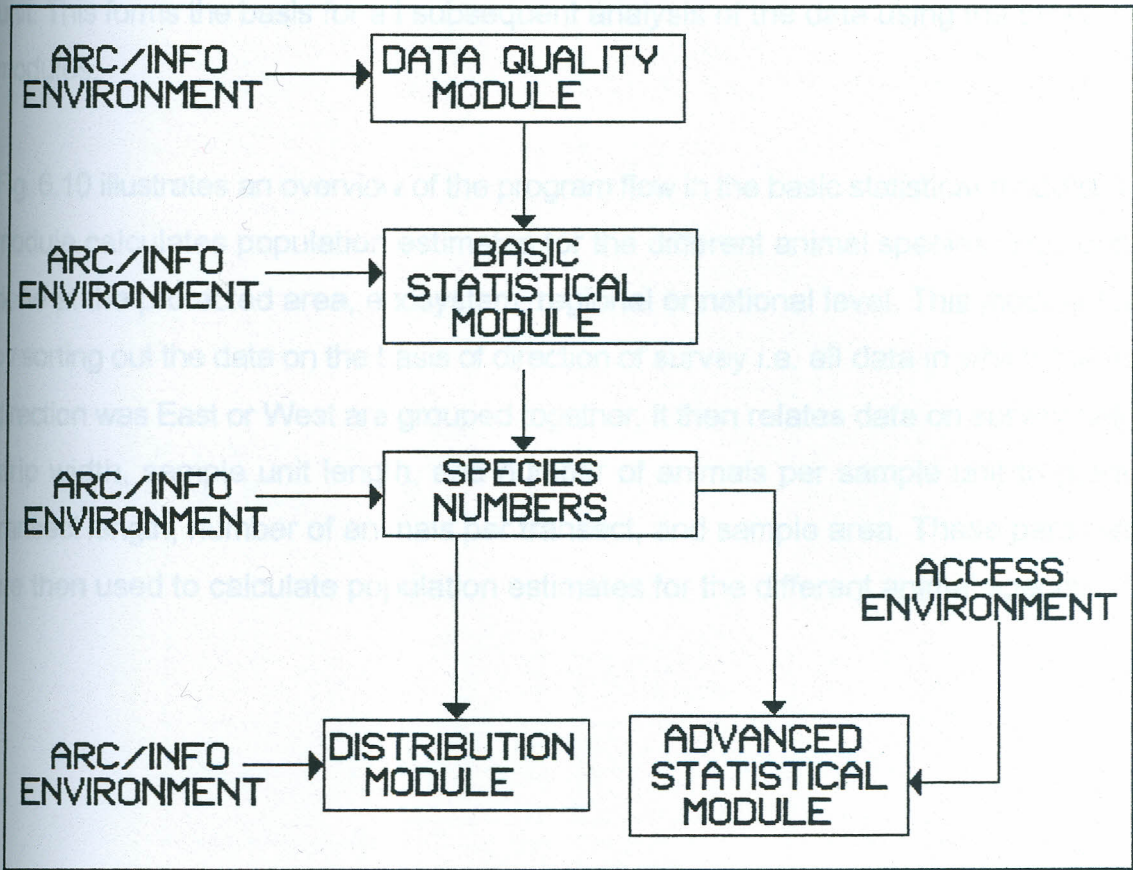


Fig. 6.9 Overview of Program Flow in the Biodiversity Resources Information System for KWS

In Chapter 3 it was illustrated that effective management of biodiversity resources depends on the availability of reliable data from which credible information for management decision support can be extracted. Also described was how errors are introduced into data at the collection stage and during data entry into the database. To minimize the occurrence of such errors during the acquisition stage, data should be collected in a consistent manner by applying consistency rules and use of reliable methods and techniques. The data quality module in the biodiversity resources

information system checks for errors that may be introduced into the data during data entry. This module checks for consistency in data of the three observers in any SRF survey, typing errors in species codes, abnormal herd sizes and compares visual versus photo counts of large herds of herbivores seen during a survey. The product here is an ASCII file containing data on sample units, date of survey, direction, strip width, survey height and number of animals of any given species seen in the sample unit. This forms the basis for all subsequent analysis of the data using the other three modules.

Fig. 6.10 illustrates an overview of the program flow in the basic statistical module. This module calculates population estimates for the different animal species. This can be done at the protected area, ecosystem, regional or national level. This module starts by sorting out the data on the basis of direction of survey i.e. all data in which the flight direction was East or West are grouped together. It then relates data on survey height, strip width, sample unit length, and number of animals per sample unit to produce transect length, number of animals per transect, and sample area. These parameters are then used to calculate population estimates for the different animal species.

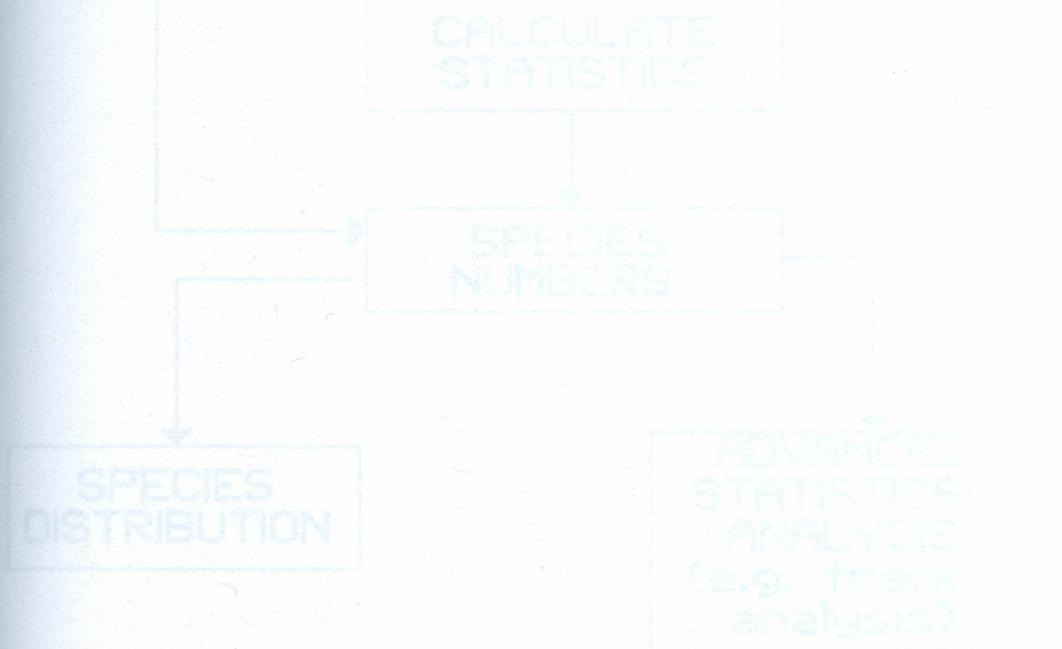


Fig. 6.10 An Overview of the Program Flow in the 'basic statistical module'

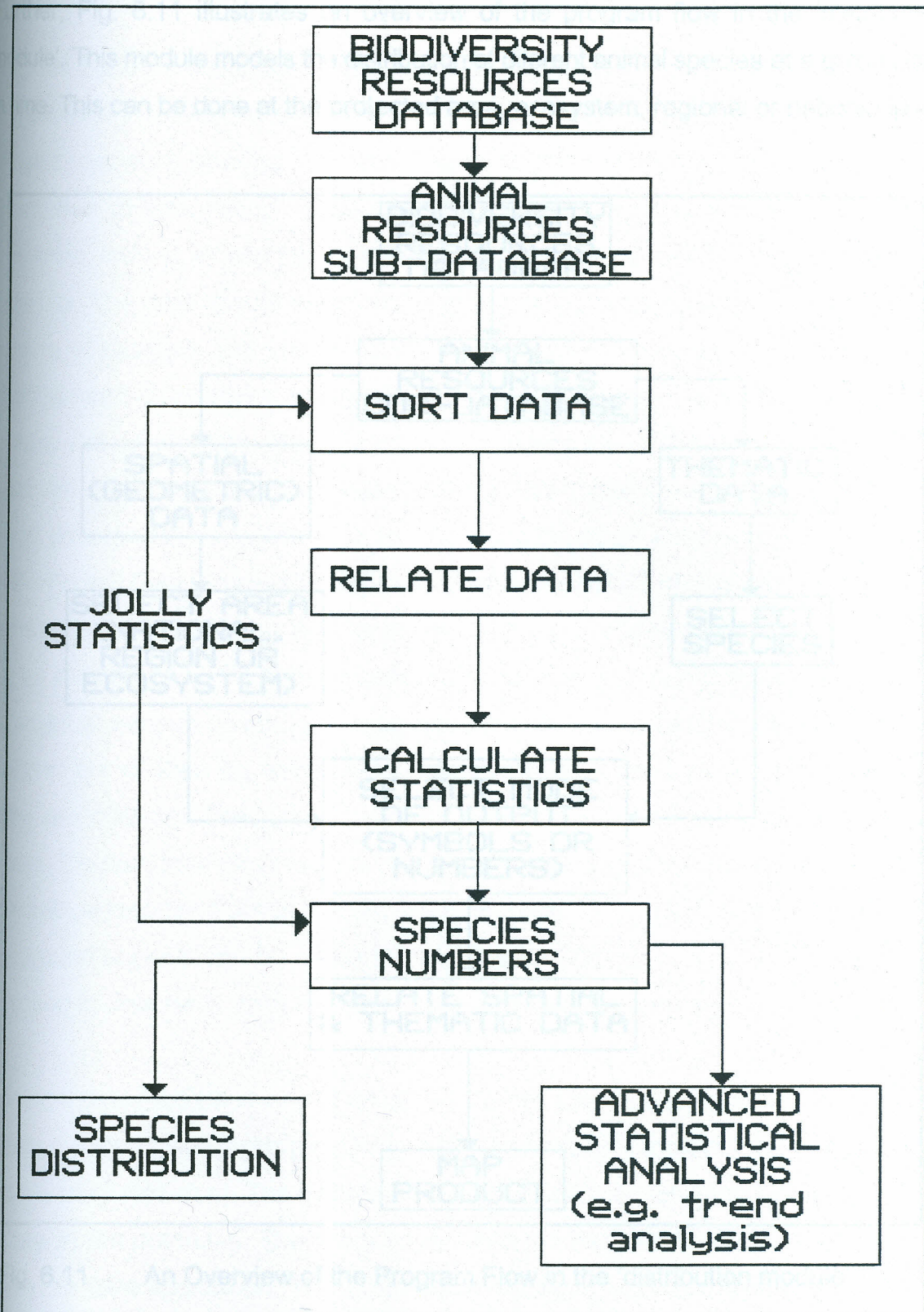


Fig. 6.10 An Overview of the Program Flow in the 'basic statistical module'

Summary

Further, Fig. 6.11 illustrates an overview of the program flow in the 'distribution module'. This module models the distribution of different animal species at a given point in time. This can be done at the protected area, ecosystem, regional or national level.

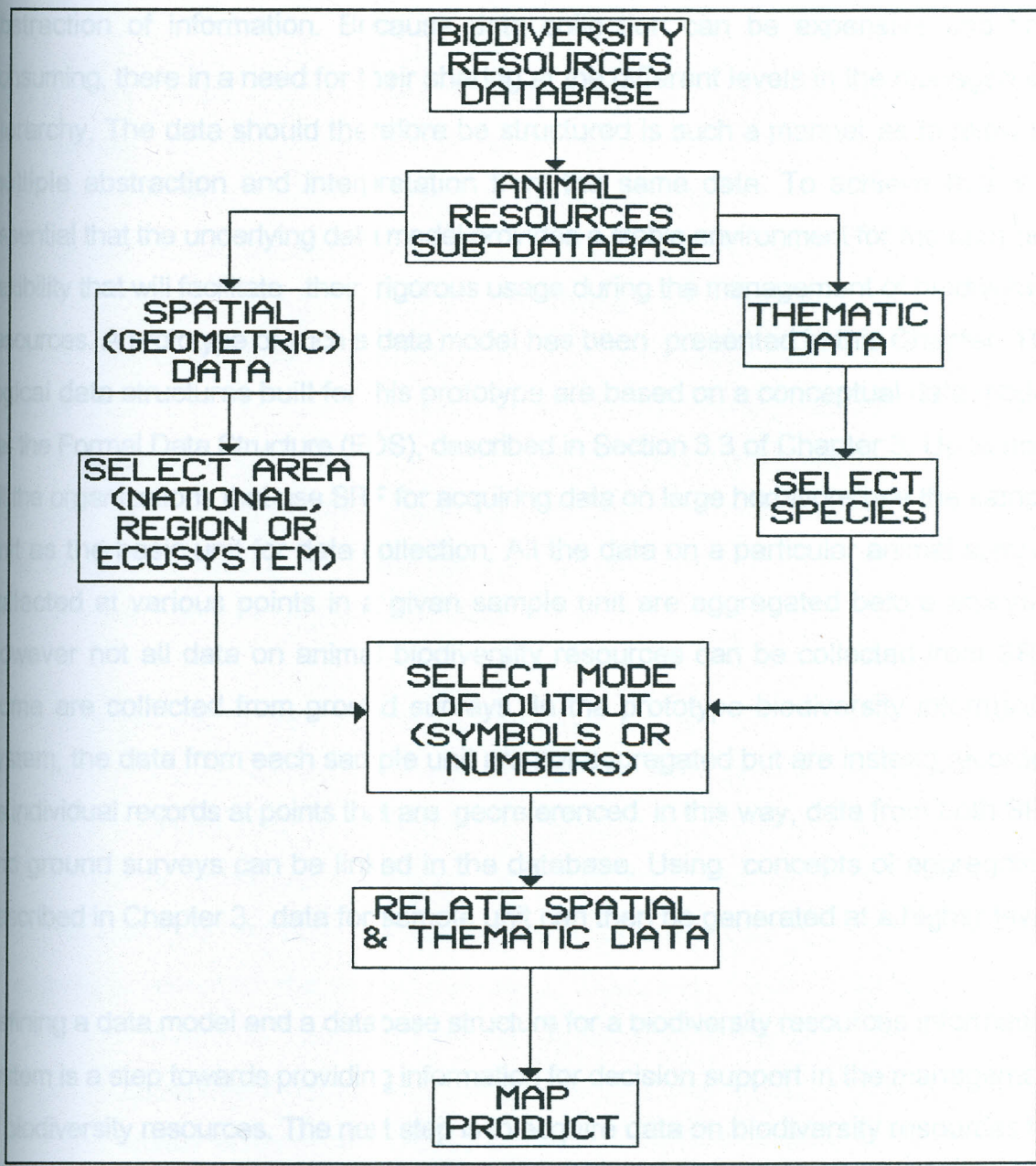


Fig. 6.11 An Overview of the Program Flow in the 'distribution module'

6.6 Summary

Chapters 1 and 2 it was shown that there is a hierarchic structure in the management of biodiversity resources and that the different levels in the hierarchy represent different decision-making contexts. Each of these requires different levels of abstraction of information. Because data collection can be expensive and time consuming, there is a need for their sharing at the different levels in the management hierarchy. The data should therefore be structured in such a manner as to allow for multiple abstraction and interpretation from the same data. To achieve this, it is essential that the underlying data model provides a stable environment for the data and flexibility that will facilitate their rigorous usage during the management of biodiversity resources. A prototype of such a data model has been presented in this Chapter. The logical data structures built for this prototype are based on a conceptual data model, i.e. the Formal Data Structure (FDS), described in Section 3.3 of Chapter 3. Up to now, all the organizations that use SRF for acquiring data on large herbivore use the sample unit as the basic unit for data collection. All the data on a particular animal species collected at various points in a given sample unit are aggregated before analysis. However not all data on animal biodiversity resources can be collected from SRF. Some are collected from ground surveys. In the prototype biodiversity information system, the data from each sample unit are not aggregated but are instead recorded as individual records at points that are georeferenced. In this way, data from both SRF and ground surveys can be linked in the database. Using concepts of aggregation described in Chapter 3, data for sample unit can then be generated at a higher level.

Defining a data model and a database structure for a biodiversity resources information system is a step towards providing information for decision support in the management of biodiversity resources. The next step is to acquire data on biodiversity resources for storage in the database. There are many methods that can be used in biodiversity resources data acquisition. The methods in this study are described in detail in the following Chapter 7.

Chapter 7: Data Acquisition: Integrating Remotely Sensed and Ancillary Data in a GIS to Acquire Data on Plant Biodiversity Resources

7.1 Introduction

Land cover maps are the main source of data on plant biodiversity resources. Traditionally, land cover maps are compiled by extracting data from aerial photographs and ground surveys. Since the advent of remote sensing from space, reflectance data in a digital format has also become available for mapping land cover, but one of the main constraints to using remotely sensed data is their scale. When used alone, only general land cover classes can be extracted from these data, and these classes do not contain sufficiently detailed information to support biodiversity management decisions at the regional and local levels. This chapter describes a method that integrates remotely sensed and ancillary data in a GIS to produce land cover maps that contain sufficient information, on plant biodiversity resources, to support management decisions at national, regional and local levels.

The large geographic extent of many protected areas, and the corresponding high cost of inventory and monitoring have necessitated the development of accurate and cost-effective methods and tools for mapping and monitoring land cover. Conventional ground survey techniques of obtaining land cover information although more accurate, involves intensive field work, are slow and expensive because many locations must be sampled to represent the diversity of many landscapes. Aerial photo interpretation is a less intensive technique, but involves greater uncertainty because of reliance on subjective assessment rather than quantitative data. Remotely sensed digital satellite data and spatial analysis techniques provide timely and relatively inexpensive land cover information. In recent years, computer-aided classification of satellite digital data has proved useful for inventorying and monitoring land cover over large and varied landscapes (Tucker et al., 1985; Cibula, 1987; Franklin and Hiernaux, 1991; Niemann, 1993; Huising, 1993; Janssen, 1994). However, satellite data quality in terms of

reliability and accuracy is sometimes unsuitable for certain management applications. Overall, accuracies have varied from 50% to 90%, depending on topography, land cover type, classification hierarchies and image acquisition date (Shimoda et al., 1988; Niemann, 1993; Jansen et al., 1990). Anuta (1977) and Hutchinson (1982) concluded that spectral data alone are inadequate descriptors of many terrain phenomena and must be augmented by information from other sources. In this Chapter, a combination of techniques are used to illustrate how remotely sensed data can be used to extract information that is sufficiently accurate to support management decisions on plant diversity resources at national, regional and local levels.

Satellite data used to map land cover are digitally classified based on their spectral characteristics of the image. The classes are then assigned labels that represent different land cover types. It is sometimes difficult to identify classes on the basis of their spectral characteristics, resulting in misclassification and the lower overall accuracy of the information extracted, especially in areas of very pronounced relief variation (Franklin, 1989).

There are several ways to improve information extraction from satellite data for land cover mapping. One of the most promising approaches is through the integration of remotely sensed and ancillary data using spatial analysis techniques. As observed by Hutchinson (1982), ancillary data can be incorporated in image classification during: pre-classification scene stratification, post-classification sorting, and classification modification through prior probabilities. This involves human intervention and judgement, and the effects are reflected in the overall accuracy of the final land cover map, which determines its fitness for use in a given context. Ancillary data can be used to improve land cover classification accuracy only if their relationship with an image class is known. Most of these data are readily available in the form of thematic maps (soil, topography, geology and climate). Various studies have applied the three approaches of incorporating ancillary data with varying results. For instance, Middelkoop and Janssen (1991), using ancillary data and knowledge as prior probabilities in a knowledge-based classification of satellite images, obtained an

improvement in the overall accuracy of 4% to 20% with respect to results based on only spectral information. In an earlier study, Benson and DeGloria (1985) used expert knowledge to visually interpret TM data to discriminate different land cover types, and obtained a low overall accuracy of 56% compared with the minimum classification accuracy of 85% that was considered acceptable for the study. Later, Kenk et al. (1988) assessed three approaches for improving classification accuracy, and concluded that the best results were obtained by using a combination of three spectral bands; beyond that, the choice of bands had no significance. Niemann (1993) integrated thematic mapper (TM) data, a Digital Elevation Model (DEM) and locational information data in land cover classification, and the results indicated that TM data with ancillary data are not adequate to generate the results desired in an old-growth forest inventory. Niemann (1993) used 11 features: seven TM bands and four extra bands of ancillary data. The use of ancillary data (elevation, slope, aspect, forest cover) as extra bands in digital image analysis only marginally improved the overall accuracy. On the other hand, use of context techniques yielded a more acceptable map product with ecologically significant boundaries.

Of the many available technologies and conceptual approaches to spatial data analysis, geographic information systems (GISs) have been widely recognized as the most promising tool for providing reliable information for both planning and decision making tasks (Michalak, 1993). Earlier on, Ehlers et al (1989) expounded on the integration of the capabilities of remote sensing as a data acquisition tool and the analysis and storage capabilities of GIS as a necessary development in providing information for resource management. However, extraction of this information is seldom a straightforward process since it is often (partly) based on non-formalized inference rules using a combination of different types of remote sensing data and existing object data (Molenaar and Janssen, 1994).

The specific objective of this chapter is to illustrate how sufficiently detailed data to support biodiversity resources management decisions at national, regional and local levels can be obtained by integrating remotely sensed and ancillary data in a GIS environment.

7.2 Land Cover Mapping

Figure 7.1 summarizes the main procedure followed in this study for data acquisition, starting from data collection and database development to image classification and the integration of ancillary data. The steps in the flow chart are described in subsequent sections.

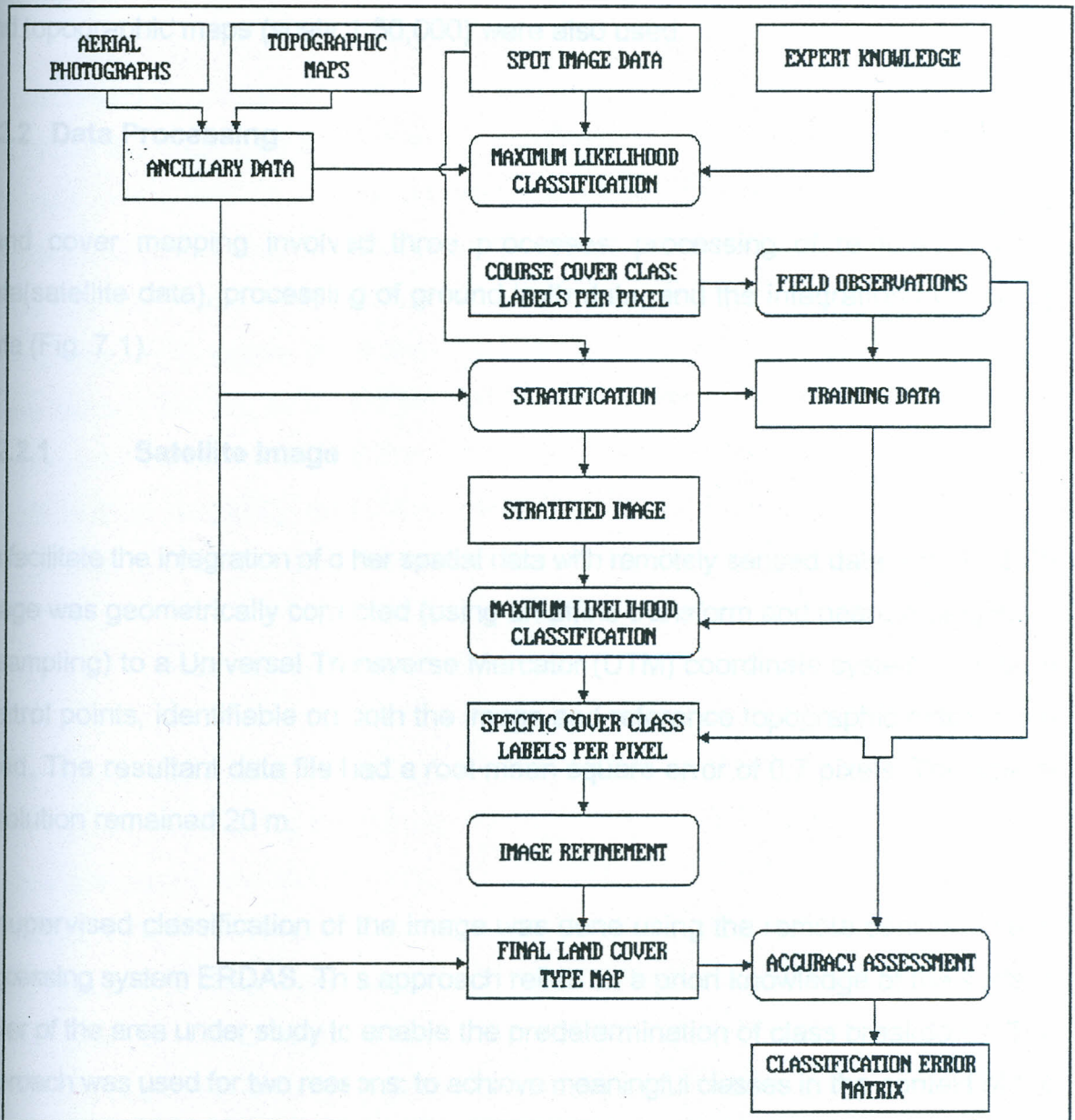


Fig. 7.1 Scheme for Integrating Remotely Sensed and Ancillary Data in Land Cover Mapping

7.2.1 Data Collection

A nearly cloud-free Spot XS image of 25 March 1992 was acquired for the study. The date corresponds to the end of the dry season, when most agricultural fields have been prepared for planting. Three spectral bands of data were available for use : band 1 (0.51-0.59 μm), band 2 (0.61-0.68 μm) and band 3 (0.79-0.89 μm). The image pixel size was 20 x 20 m. Black-and-white aerial photographs of January 1994 (scale 1:20,000) and topographic maps (scale 1:50,000) were also used.

7.2.2 Data Processing

Land cover mapping involved three processes: processing of remotely sensed data (satellite data), processing of ground truth data, and the integration of ancillary data (Fig. 7.1).

7.2.2.1 Satellite Image

To facilitate the integration of other spatial data with remotely sensed data, the Spot XS image was geometrically corrected (using an affine transform and nearest-neighbour resampling) to a Universal Transverse Mercator (UTM) coordinate system. Fourteen control points, identifiable on both the image and reference topographic maps, were used. The resultant data file had a root mean square error of 0.7 pixels. The spatial resolution remained 20 m.

A supervised classification of the image was done using the remote sensing image processing system ERDAS. This approach relies on a priori knowledge of the surface cover of the area under study to enable the predetermination of class breakdown. The approach was used for two reasons: to achieve meaningful classes in the context of the study objectives, taking into account the potential range of cover classes that can be obtained when conventional land cover techniques are used, and because good topographic maps and recent aerial photographs of the area were available. Using

these together with expert knowledge of the general relationships between the geophysical and biophysical components of the landscape, it was possible to define some possible land cover types. The result was a classified image with 20 spectral classes. These were coarse classes that formed the basis for selecting sites to be visited to collect training and test data samples.

7.2.2.2 Ground Truth Data

Procedure used to obtain ground truth data used in land cover mapping are explained in chapter 3 section 3.2.1 (b) (i). According to Huising (1993), not all land cover classes defined in the field can be recognized spectrally. Several cover classes may be generalized into a superclass. Through interpretation, the superclasses can be separated into the cover classes defined in the field. Rules have to be defined for this interpretation. Representative samples of each land cover type defined in this study were divided into two sets. One set was used for developing training statistics for the supervised classification of the image. The second set was used to evaluate classification accuracy and was augmented by 350 samples extracted from a vegetation map constructed from a survey carried out in April 1994 (RLE 3, 1994).

7.2.2.3 Integrating Ancillary Data

Any form of data other than the original image data is ancillary data. Most of these data are readily available in the form of thematic maps. The ancillary data for this study were processed and stored using the integrated land and water information system (ILWIS, 1993). Required information was extracted from aerial photographs through the process of photo interpretation as sequenced in Fig. 7.2. This process involves four phases: photo reading (detection, recognition and identification), analysis, classification and deduction (Van Zuidam, 1985; Huising, 1993). Only information relevant to the study was extracted. Using pattern recognition, it was possible to subdivide the small-scale agricultural fields into different categories, and also to distinguish between river valleys under agriculture and natural vegetation. The

delineated areas were then digitized and, using ground control points from the field, the polygons were transformed to a UTM grid and stored in the GIS. Mylar copies of 1:50,000 scale topographic map sheets of the study area with a contour interval of 50 m and a UTM coordinate system were digitized. The contour lines were then rasterized to create a raster map, which was interpolated to create a regularly spaced 20 x 20 m elevation grid. This formed the digital elevation model. Three data sets, 'elevation', 'slope gradient' and 'slope aspect,' were extracted from the DEM and stored in the GIS database.

To carry out their day to day functions, biodiversity resource managers require land cover information to be defined in a form of land cover types, which is an object-based structure. It is noted that data on a remotely sensed image are recorded on a pixel-by-pixel basis (raster structure), with each pixel representing a geographic position and therefore not readily usable by managers. A terrain object can thus consist of one or more pixels. Therefore, for remotely sensed data to be of optimal benefit to biodiversity resource managers, individual pixels have to be related to terrain objects. This requires that the position-based structure of remotely sensed data be converted into an object-based structure (Molenaar and Richardson, 1994). Molenaar and Janssen (1994) proposed two approaches for linking object and remote sensing data: spectral data, classification and segmentation results can be linked directly to already defined terrain objects, or a priori object information can be used to improve the quality of the information extraction from remotely sensed data. The second approach was used in this study.

Fig. 7.2 Scheme for Processing Ancillary Data

7.2.3 Class Hierarchies

From an ecologic perspective land cover classification is based on the concept of object. Applying this concept produces a hierarchic object class structure as described in Chapter 3. At the highest hierarchic level, object classes that are

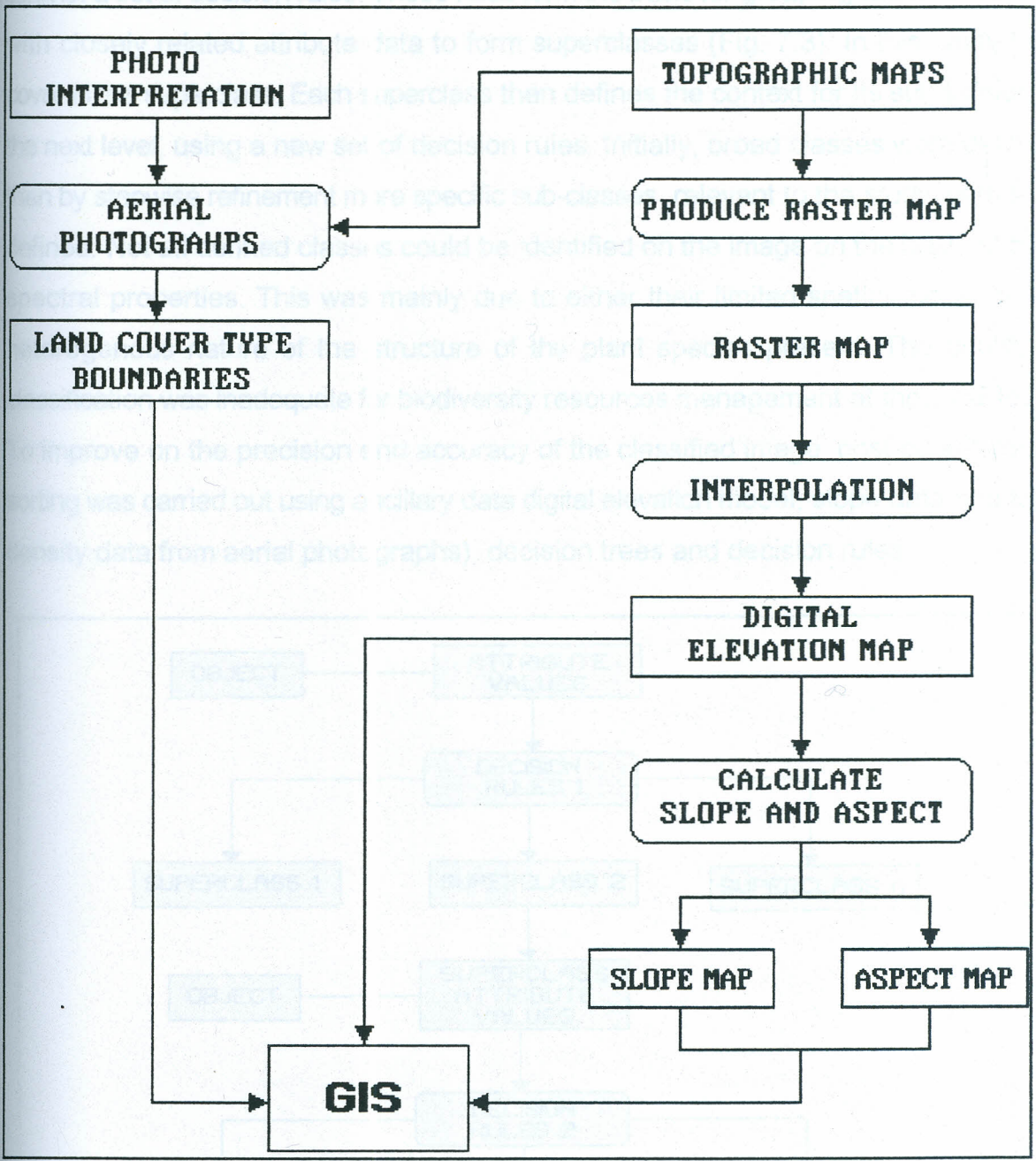


Fig. 7.2 Scheme for Processing Ancillary Data

7.2.3 Class Hierarchies

From an ecologic perspective, land cover classification is based on a hierarchy concept. Applying this concept produces a hierarchic object class structure as described in Chapter 3. At the highest hierarchic level, object attribute data are tested

against a set of decision rules. These rules form the basis for grouping together objects with closely related attribute data to form superclasses (Fig. 7.3). In this study land cover is the superclass. Each superclass then defines the context for its subdivision at the next level, using a new set of decision rules. Initially, broad classes were defined, then by stepwise refinement more specific sub-classes relevant to the study were then defined. Not all defined classes could be identified on the image on the basis of their spectral properties. This was mainly due to either their limited spatial extent or the heterogenous nature of the structure of the plant species present. The quality of classification was inadequate for biodiversity resources management at the local level. To improve on the precision and accuracy of the classified image, post-classification sorting was carried out using ancillary data (digital elevation model, slope data and farm density data from aerial photographs), decision trees and decision rules.

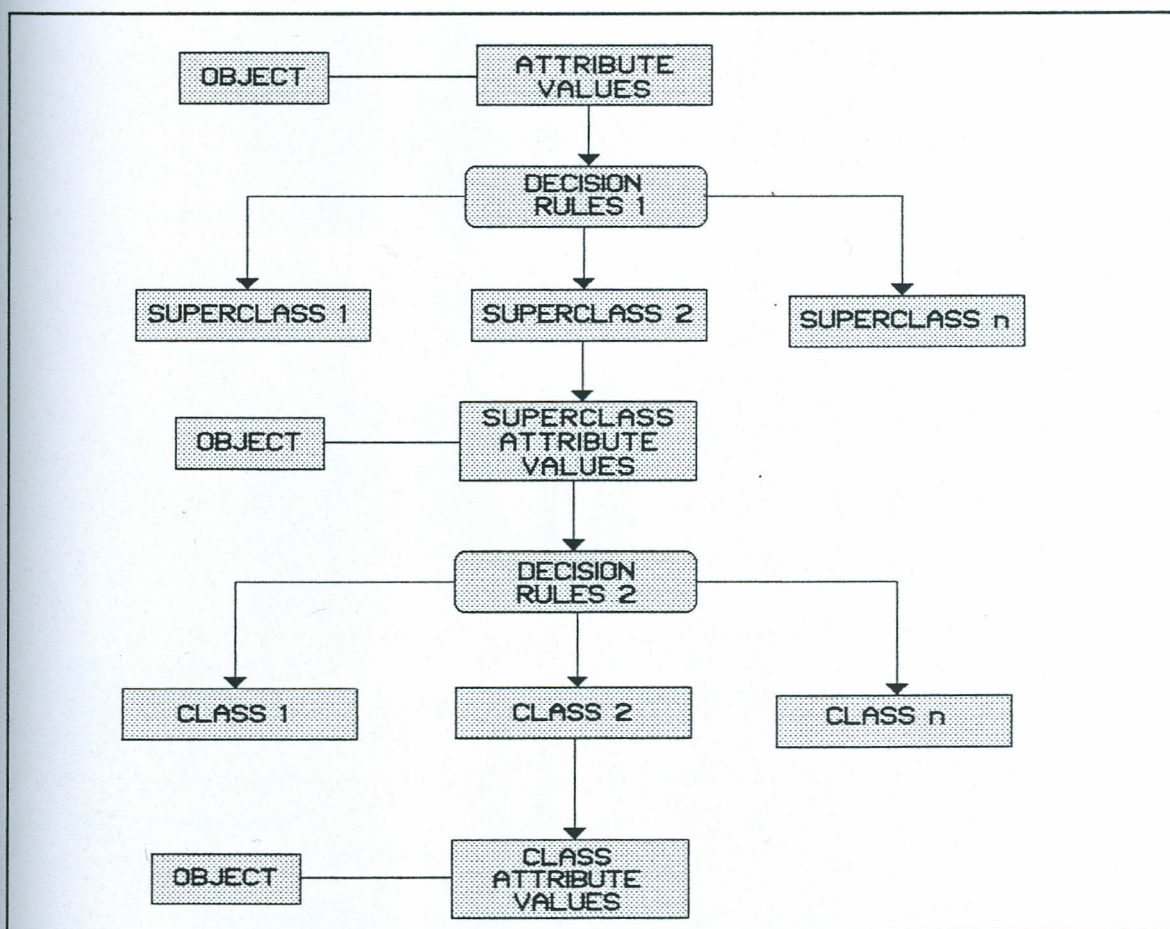


Fig. 7.3 Relationships Between Classification Tree and Class Hierarchies

The process was repeated until all the identified spatial units (or objects) had been assigned to one of the predefined classes. At each level, there was a specific set of rules which was context-dependent and had to be met before an object was assigned to a group. These rules were designed to trigger specific actions by the objects.

7.2.3.1 Decision Tree for Classifying Land Cover Types

Decision rules provide a link between ancillary data and the land cover classification process, and define the context for the next lower classification level. Different types of ancillary data are required at different levels in the classification process. For this study, a decision tree was used to define the structure for incorporating ancillary data in the classification process (Fig.7.4).

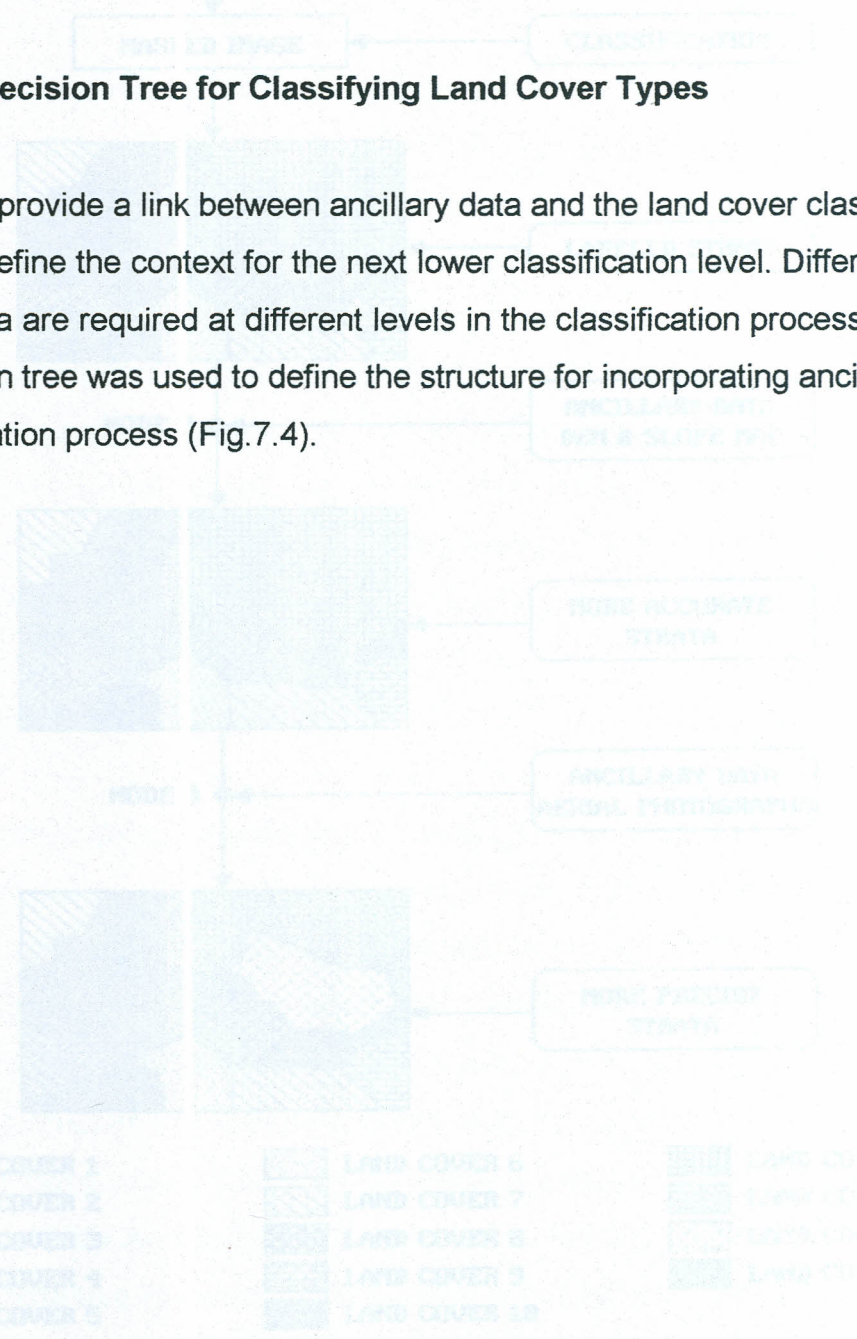


Fig. 7.4 Decision Tree used for Incorporating Ancillary Data into the Process of Image Classification for Land Cover Mapping

Decision trees consist of nodes at which more than one class assignment is possible

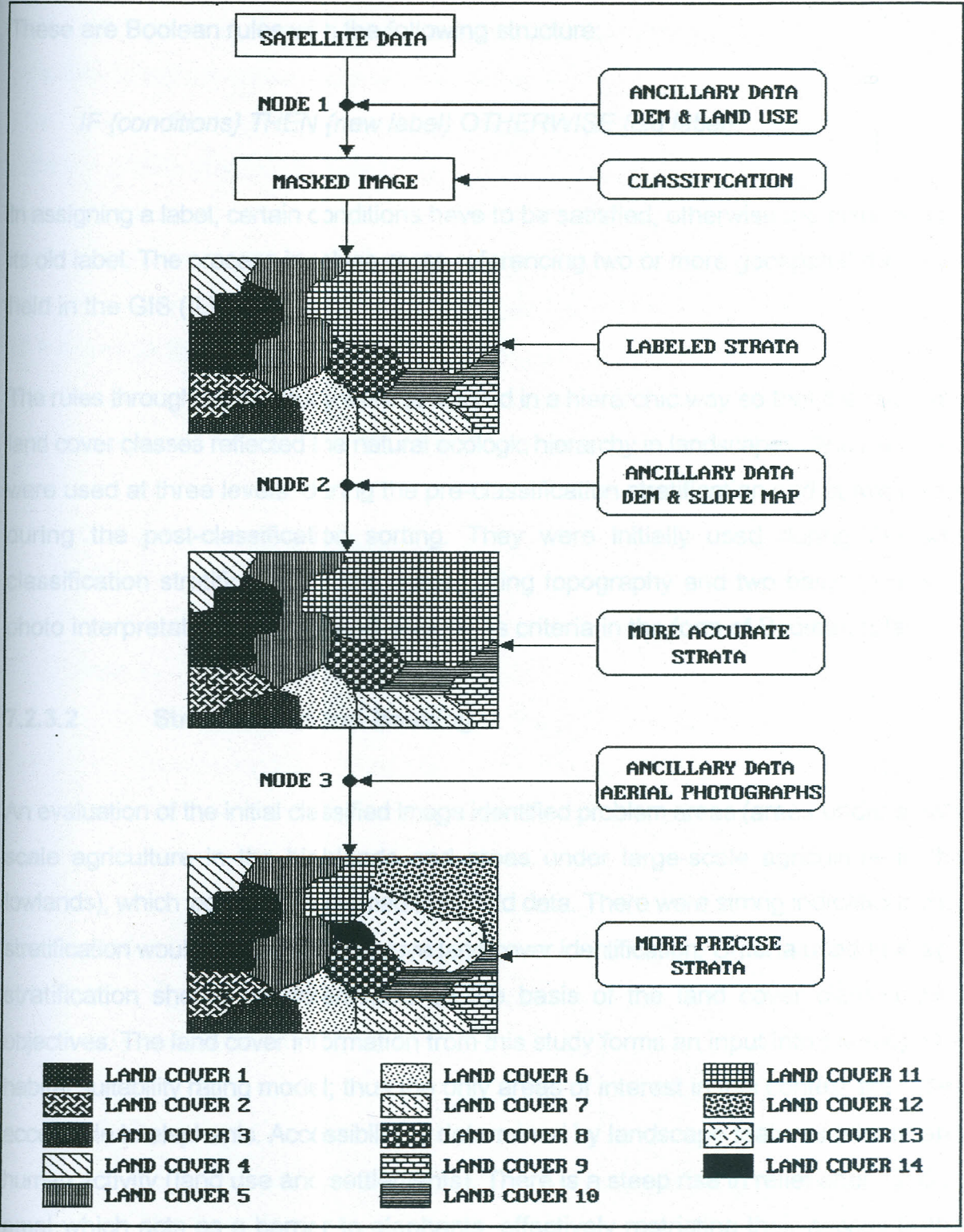


Fig. 7.4 Decision Tree Used for Incorporating Ancillary Data into the Process of Image Classification for Land Cover Mapping

Decision trees consist of nodes at which more than one class assignment is possible.

At the nodes, decision rules have to be applied to determine the appropriate class. These are Boolean rules with the following structure:

IF {conditions} THEN {new label} OTHERWISE {old label}.

In assigning a label, certain conditions have to be satisfied, otherwise the pixel retains its old label. The process involves cross-referencing two or more geospatial data sets held in the GIS (ILWIS).

The rules throughout the study were structured in a hierarchic way so that the resultant land cover classes reflected the natural ecologic hierarchy in landscapes. Ancillary data were used at three levels: during the pre-classification stratification and at two levels during the post-classification sorting. They were initially used during the pre-classification stratification of the image, using topography and two basic factors of photo interpretation, 'pattern' and 'shape', as criteria in the form of Boolean rules.

7.2.3.2 Stratification and Masking

An evaluation of the initial classified image identified problem areas (areas under small-scale agriculture in the highlands and areas under large-scale agriculture in the lowlands), which were also confirmed from field data. There were strong indications that stratification would significantly improve land cover identification. Criteria used in image stratification should be determined on the basis of the land cover classification objectives. The land cover information from this study forms an input into the elephant habitat suitability rating model; thus the only areas of interest in this context are those accessible to elephants. Accessibility is determined by landscape features (slope) and human activity (land use and settlements). There is a steep rise in relief after 1200 m amsl which acts as a barrier to elephants, effectively restricting their access to the higher elevations. In the study area, there are also large-scale agricultural farms whose management strategy includes the exclusion of elephants.

Using information from the DEM, the image was stratified into two parts: above and below 1200 m amsl. On the basis of pattern, shape and field observations, it was possible to extract areas under large-scale agriculture from aerial photographs. The main crop on the large-scale farms was sisal at various stages of its life cycle. The different growth stages produced different spectral responses on the image. Since it was not the objective of this study to distinguish the different growth stages of the crops, all growth stages were classified together and assigned the same land cover type, which was then stratified and excluded from the supervised classification process of the image that followed. The cover type was later reincorporated into the final classified image. Stratification was done using Boolean decision rules and the elevation and land unit data held in the GIS, and had the following structure:

Use georeferenced image, land unit map (LUM) and digital elevation model (DEM).

Rule 1

IF a pixel is <1200 m amsl on the DEM, THEN retain the value of the corresponding pixel on the image, OTHERWISE assign the corresponding pixel on the image a value of zero. New image is stratified image one.

This resulted in an image where only the pixels in the area below 1200 m amsl retained their original digital values and all other pixels were assigned a value of zero. The second rule was applied to this stratified image.

Rule 2

IF a pixel on the LUM is classified as sisal plantation, THEN assign the corresponding pixel on the image a value of zero, OTHERWISE retain the original image value.

This resulted in a stratified image that excluded all areas above 1200 m amsl and the

sisal plantations. A supervised classification of the image was then carried out using the maximum likelihood classifier and resulted in a classified image with more specific classes.

7.2.3.3 Stratified Re-classification

Ancillary data were next used in post-classification sorting. Decision rules were targeted towards improving the classification accuracy of the one class (forest) and two sub-classes (forest along river valley and bushland on steep slopes) with the most spectral overlap. The spectral reflectance of 'bushland on steep slopes' is often confused with that of 'forest'. Although both are dominated by evergreen woody species, the species are different owing to their geographic locations. The cover type 'forest' occurs on the upper foot slopes of the Taita hills at an elevation of >1000 m amsl. This area not only receives more rainfall, but considerable soil moisture also seeps in from the higher ground, enough to support a low tropical montane forest. The hill slopes, on the other hand, lie between 850 and 1000 m amsl, are steep sided (16° slope) and receive less rainfall that can support only dense bush vegetation. Because of the steep slope, there is less evidence of human impact on this land cover type. Decision rules 3 and 4 were designed to separate the two sub-classes, and also to distinguish 'bushland on steep slopes' from other bushland cover types.

Use classified image, elevation map (DEM), slope map and distance from river map.

Rule 3

IF a pixel on the image is classified as 'forest', 'forest along river valley' or 'bushland on steep slopes', and is at an elevation of >1000 m amsl, THEN assign the cover type 'forest', OTHERWISE retain the original cover type.

Rule 4

IF a pixel on the image is classified as 'bushland on steep slopes', 'undegraded bushland' or 'forest', is at an elevation of between 850 and 1000 m amsl, and has a slope of $>16^\circ$, THEN assign the cover type 'bushland on steep slopes', OTHERWISE retain the original cover type.

Rule 5

IF a pixel on the image is classified as 'forest' or 'forest along river valley' or 'bushland on steep slopes', is below 1000 m amsl, has a slope of $>4\%$ and is < 200 m away from a river, THEN assign the cover type 'forest along river valley', OTHERWISE retain the original cover type.

The next set of decision rules (6 to 8) were designed to subdivide and update the land cover superclass 'fields', using information extracted from aerial photographs of January 1994. Two basic factors of photo interpretation, 'pattern' and 'shape', were used as criteria for extracting information stored in a GIS in the form of a detailed land unit map of fields and settlements. Ancillary data were used here not only to delineate more precise cover classes of the class 'fields', but also to update object boundaries on the image.

Use classified image and land unit map.

Rule 6

IF a pixel on the land unit map is marked small-scale agriculture $<30\%$ cover, THEN assign the corresponding pixel on the classified image the cover type 'low-density small-scale agriculture'; IF marked small-scale agriculture $30-60\%$ cover, THEN assign the corresponding pixel on the classified image the cover type 'medium-density small-scale agriculture'; and IF marked small-scale agriculture $>60\%$ cover, THEN assign the corresponding pixel on the classified image the cover type 'high-density small-scale agriculture', OTHERWISE retain the original cover type.

Rule 7

IF a pixel on the land unit map is marked 'small-scale agriculture along river valley', THEN assign the corresponding pixel on the classified image the cover type 'small-scale agriculture along river valley', OTHERWISE retain the original cover type.

Rule 8

IF a pixel on the land unit map is marked 'permanent settlement', THEN assign the corresponding pixel on the classified image the cover type 'settlement', OTHERWISE retain the original cover type.

By applying decision rules 6, 7 and 8, it was possible to determine the current extent of the land cover class 'field' and the class 'settlement'. At this stage, ancillary data were incorporated into the classified image to produce more precise and accurate classes.

7.2.3.4 Mapping Land Cover Classes and Subclasses to Actual Land Cover Types

On the basis of field information, six land cover classes were identified (Table 7.1). On the basis of structure, the class 'open natural vegetation' was divided into two sub-classes, ie, 'woodland' and 'bushland'. Bushland was further subdivided into five sub-classes on the basis of landscape processes and soil types. On the basis of relief, the class forest was divided into two sub classes, while fields were divided into four cover sub-classes on the basis of farm density and relief. In total, 15 land cover classes and sub-classes were defined. During pre-classification stratification of satellite digital data, one cover class, ie, plantation, was defined and assigned the label 'sisal'. Of the remaining fourteen, ten could be distinguished on the basis of their spectral properties in remotely sensed data, and by using field information they were assigned names of actual land cover types.

Table 7.1 Mapping Land Cover Classes and Subclasses to Land Cover Types

Super-class	Class	Sub-class	Label	Land cover type (sub-class)
Water body	Dam		1	Water
Plantation	Sisal crop		14	Sisal crop
Open natural vegetation	Woodland		8	Woodland
	Bushland	Bushland (undegraded)	5	Undegraded bushland
		Bushland (degraded)	4	Degraded bushland
		Dense bushland on limestone	6	Dense bushland on limestone
		Bushland on limestone	7	Bushland on limestone
	Bushland on steep slope	9	Bushland on steep slopes	
Natural forest			3	Forest along river valley
			10	Forest
Fields	<30% cover		12	Low-density small-scale agriculture
	30-60% cover	Medium-density small-scale agriculture	11	Medium-density small-scale agriculture
	> 60% cover	High-density small-scale agriculture	13	High-density small-scale agriculture
	> 60% cover	High-density small-scale agriculture	2	High-density small-scale agriculture
Buildings	Settlements		15	Settlements

Different field densities could not be segregated spectrally from remotely sensed data, while buildings could not be identified at all owing to the predominant use of dry plant material for roofing. Using information on field and building density from aerial photographs, it was possible to map the field and building land cover classes onto their

actual land cover types.

7.2.4. Classification Accuracy

Land cover information extracted from remotely sensed data is now fundamental to a variety of applications, including land use mapping and monitoring, land use planning, ecologic monitoring of both natural vegetation and agricultural ecosystems, mapping of habitat suitability, and land evaluation. Planners and decision makers who use this information should be made aware of its accuracy. In this study, classification accuracy was assessed at three stages, i.e. after: classification based on image spectral data, classification based on image data and ancillary data extracted from topographic maps (elevation, slope, aspect), and classification based on image data and ancillary data extracted from topographic maps and aerial photographs. The data used in the accuracy assessment and the data used for training statistics were collected simultaneously.

Classification accuracy was assessed at these three stages (using the ERDAS image processing software) by building a $k \times k$ confusion matrix with test pixels. This is a square array in which the column and row for each position indicate the actual class of a number of pixels, and the class to which those pixels have been assigned following classification. The main features of these matrixes, and the merits associated with their use, are discussed elsewhere in literature (Story and Congalton, 1986; Mather, 1987; Kenk et al., 1988;). Test pixels are chosen as a sample of all available pixels in the image being classified, and numerous combinations of pixels are possible. It is likely that the distribution of accuracy values could be summarized by a conventional probability distribution such as the hypergeometric distribution (Mather, 1987). This makes it possible to evaluate the confidence limits for each classification accuracy value. A lower confidence limit associated with each value was calculated using Equation 1, provided by Jensen (1986):

$$s = P - [z\sqrt{(PQ/N) + 50/N}] \quad (\text{Equation 1})$$

where

s = lower degree of accuracy at the given confidence level

z = (100-r)/100th point of the standard normal distribution

r = confidence level

P = % of correctly classified pixels

Q = % of incorrectly classified pixels [(100 - P)%]

N = total number of test pixels.

7.3 Results

After each classification (Fig. 7.2), an accuracy assessment was carried out using the independent test data. The initial classification using training statistics from all defined land cover types resulted in a low overall classification accuracy (35.6%). Spectrally, it was not possible to: distinguish settlements on the image, subdivide the class 'fields' into the different sub-classes defined, or separate forest along river valleys from forest at higher elevations and bushland on steep hill slopes. A second classification followed using the class 'fields' instead of the three sub-classes defined. The cover class 'settlements' was excluded at this stage. After classification, a majority filter was applied to the image. The key to the land cover superclass and classes distinguished is as already shown in Table 7.1. Table 7.2 shows the results of the overall accuracy assessment of the image. Only five of the 11 sub-classes had accuracy results above the threshold of 70% considered acceptable in this study for use in the management of biodiversity resources at the local level (Table 7.2). The initial overall classification accuracy was 59.72%, with a 95% lower confidence limit of 56%. The results show a considerable spectral overlap between the land cover types 'forest along river valley', 'forest' and 'bushland on steep slopes'.

If classification was 100% correct, then all cells off the main diagonal would be filled with zeroes (Table 7.2). Values off the diagonal below a column heading indicate errors of commission (erroneously including pixels from another class). Values off the diagonal along a row heading indicate errors of omission (erroneously excluding a pixel

from a class).

PROD andUSR are two estimates of overall classification accuracy from the original matrix (Story and Congalton, 1986). PROD is the averaged probability in percent that an assessment pixel will be correctly classified. It indicates the average extent of the errors of omission. USR is the averaged probability in percent that a pixel from the classified image actually represents that class on the ground, ie, the reliability of the classification. It reflects the average extent of the errors of commission.

Table 7.2 Accuracy Assessment Results from the Classified Image Using the Maximum Likelihood Classifier and a Majority Filter

labels for land cover types (see Table 7.1).

	1	2	3	4	5	6	7	8	9	10	11	PROD
1	5	0	0	0	0	0	0	0	0	0	0	83
2	0	18	4	0	0	0	0	0	0	1	0	64
3	0	3	4	0	0	0	0	0	0	3	0	15
4	0	1	1	70	8	1	1	1	3	0	16	88
5	1	3	12	7	74	1	3	3	8	31	0	71
6	0	0	0	0	2	33	2	0	0	0	0	91
7	0	0	0	0	2	1	17	0	3	0	0	68
8	0	0	0	2	7	0	1	29	0	0	7	80
9	0	0	0	0	10	0	1	2	24	4	0	48
10	0	5	16	0	1	0	0	0	18	24	0	36
11	0	0	0	0	0	0	0	1	0	0	11	27
USR	100	78	60	75	51	89	74	63	61	36	91	

Numbers 1-11 are the labels for the defined land cover types.

PROD = producer accuracy, USR = user accuracy.

Average producer accuracy = sum of producers accuracies (671) / number of classes (11)= 61%

Average user reliability = sum of users accuracies (778) / number of classes (11)= 71%

Overall accuracy = sum of diagonal (309)/assessment pixel total (509) = 60%

Lower 95% confidence limit = 56.0%

* averages are weighted by class size.

The incorporation of decision rules 3, 4 and 5 resulted in improved precision in predicting areas under 'forest', 'bushland on steep slopes' and 'forest along river valleys', and the improved reliability of the classification, as confirmed by the increase in the overall classification accuracy to 72%, an increment of 12% (Table 7.3).

Although the application of decision rules 3, 4 and 5 improved the overall classification accuracy by 12%, there were still low classification accuracies for sub-classes 3 and 11, and one sub-class (settlements) was not distinguished at all (Table 7.4). From field observations, there were three distinct categories of agriculture cover classes, depending on the level of intensity, whose categories were determined by the percentage cover of agricultural plots. Newly settled land had a lower percentage cover by plots than areas that had been settled for longer periods. The next step was to test whether the integration of higher spatial resolution ancillary data could aid in: separating different agriculture categories according to intensity, distinguishing settlements, and determining the actual extent of agriculture in river valley bottoms.

Table 7.3 Accuracy Assessment Results from the Classified Image Reclassification Using Decision Rules 3, 4 and 5

Labels for land cover types (see Table 7.1).

	1	2	3	4	5	6	7	8	9	10	11	PROD
1	5	0	0	0	0	0	0	0	0	0	0	83
2	0	21	0	0	0	0	0	0	0	1	0	75
3	0	0	16	0	0	0	0	0	0	0	0	41
4	0	1	1	70	8	1	1	1	0	0	16	88
5	1	3	8	7	87	1	3	3	3	28	0	83
6	0	0	0	0	2	33	2	0	0	0	0	91
7	0	0	0	0	2	1	17	0	3	0	0	68
8	0	0	0	2	7	0	1	29	0	0	7	80
9	0	0	0	0	4	0	1	2	39	4	0	69
10	0	5	12	0	1	0	0	0	11	37	0	58
11	0	0	0	0	0	0	0	1	0	0	11	27
USR	100	95	100	70	61	89	74	74	83	56	91	

Overall accuracy = 72%

Numbers 1-11 are the labels for the defined land cover types.

- Average producer accuracies (PROD) = 69%
- Average user reliability (USR) = 82%
- Overall accuracy = 72%
- Lower 95% confidence limit = 69%

By applying decision rules 6, 7 and 8, it was possible to merge more recent information on the actual extent of the land cover class, 'field' and sub-class, 'settlement' into the classified image. The next stage involved the fusion of the classified image with the

image containing the class 'plantation'. Comparison of cover types showed no significant difference between the land cover types 'dense bushland on limestone' and 'bushland on limestone'. In most cases, the former was embedded in the latter. As a result, the two sub-classes were merged. This resulted in the improved precision of the final classified image with a total of 14 land cover types (Table 7.5). There was also improved reliability regarding the information content of the classified image, with an overall classification accuracy improvement of 25% (Table 7.4).

Table 7.4 Accuracy Assessment Results from Final Classified Image
Labels for Land Cover Types (see Table 7.1).

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	PROD
1	6	0	0	0	0	0	0	0	0	0	0	0	0	0	86
2	0	29	0	0	1	1	0	0	0	0	1	2	0	0	88
3	0	0	7	0	0	0	0	0	0	0	0	0	0	0	50
4	0	0	0	30	4	1	0	0	0	0	0	0	0	0	67
5	0	0	5	3	33	2	1	5	1	0	0	2	0	0	62
6	0	0	0	2	0	14	0	0	0	0	0	0	0	0	64
7	0	0	1	2	5	0	19	0	0	0	0	2	0	0	91
8	0	0	0	3	2	2	0	28	1	1	0	0	0	0	80
9	0	0	0	0	2	0	0	0	15	0	0	0	0	0	75
10	0	3	0	2	3	0	0	1	0	31	0	1	0	0	94
11	0	0	0	0	1	0	0	0	0	0	20	0	0	0	87
12	1	1	0	1	1	1	0	0	1	1	2	41	0	0	80
13	0	0	0	0	0	0	1	1	1	0	0	3	12	0	100
14	0	0	0	0	0	0	0	0	0	0	0	0	0	14	100
USR	100	85	100	86	64	88	66	76	100	76	96	82	67	100	

Numbers 1 to 14 are the labels for the defined land cover types.

- Average producer accuracy (PROD) = 80%
- Average user reliability (USR) = 84%
- Overall accuracy = 85%
- Lower 95% confidence limit = 82%

Table 7.5 Final Land Cover Types

Label	Land cover type
1	Water
2	Small-scale agriculture along river valley
3	Forest along river valley
4	Degraded bushland
5	Undegraded bushland
6	Bushland on limestone
7	Woodland
8	Bushland on steep slopes
9	Forest
10	Medium-density small-scale agriculture
11	Low-density small-scale agriculture
12	High-density small-scale agriculture
13	Sisal crop
14	Settlement

7.4 Discussion

The specific aim of this study was to illustrate how data, that is detailed enough, to support biodiversity resources management decisions at national, regional and local levels can be obtained by integrating remotely sensed and ancillary data in a GIS environment. The results show that by integrating remotely sensed data with ancillary data in a GIS environment, it is possible to produce a land cover map that is sufficiently accurate for use at the local level as a source of information for management decision support. Generally, maps with a reliability of 70% or more are acceptable as sources of information to support management decisions at the local level. The overall accuracy of a land cover map based on a supervised classification approach using only the spectral properties from remotely sensed data was low (35.6%). The assumption in this approach is that the land cover types defined have homogeneous terrain, structural and spatial characteristics, and this forms the basis for selecting pixels used in training statistics. Structural and spatial variability is inherent in natural vegetation, even on homogeneous terrain. Even in modified land cover types like sisal plantation, variability is still present because of the different growth stages of the crop.

To optimize remotely sensed data as an information source for decision support in the management of biodiversity resources at all levels, a new approach to land cover

classification is developed, i.e. the object-based approach as described in Chapter 3. In this approach, the use of remotely sensed data is optimized by linking the data directly to the object information stored in a GIS (Ehlers et al., 1989). The linkage also makes it possible to use knowledge of the history and dynamics of terrain objects to improve classification (Molenaar and Janssen, 1994).

By using the object-based concept in classifying land cover it was possible to identify the hierarchical structure of the land cover types (Table 7.1), which are then stored in a GIS as described in Chapter 6, and can be used to derive information to support biodiversity management decisions at the regional level, (i.e. elephant habitat suitability rating models - Chapter 8), and at the national level, (i.e. inventory of biodiversity resources).

A method has been demonstrated that integrates readily available ancillary data and remotely sensed data to produce a land cover map suitable for use to support decisions at all levels of biodiversity resources management. Ancillary data made it possible to stratify the image prior to classification, resulting in an overall classification accuracy of 60%. The classified image then provided a base on which progressive refinements were applied through the use of decision rules. This resulted in a 25% increase in overall accuracy (final accuracy was 85% up from 60% see Tables 7.2 and 7.4), while the number of mapable land types increased from 11 to 15. This study has demonstrated a method that increases the quality of image classification in two ways: by producing more precise classes relevant to the application discipline, and by producing a more reliable classification.

The design of the decision rules was determined by the critical factors required for management of biodiversity resources at the local level. These factors provided a means for evaluating mapping results, and had to be defined at the beginning. They included not only defining the elementary terrain objects but also describing their geometric structure, thematic content, and classification and aggregation hierarchies. Although the land cover map developed is for use in a human/elephant conflict model,

the method can be applied to other human/wildlife conflicts by simply changing the critical factors. The expected overall accuracy of the final cover map will vary for different animal species, and so will the critical factors. This method can be implemented with readily available PC-based GIS software, making it a valuable tool for biodiversity resource management at local and regional levels.

Land cover types are dynamic and are constantly changing their geometric structure as well as their thematic content. The area under the class 'fields' (Table 7.1) could change as more of the class 'open natural vegetation' is cleared for agricultural use. This would result in a change in the geometric structure. On the other hand, the density of small-scale agricultural plots could change as more people settle down permanently. This would result in a change in the thematic content of the terrain object. Effective management requires that these changes (both geometric and thematic structures) be monitored. The method described in this thesis has shown that remotely sensed data can be used to establish an inventory of land cover types which, once established, can form a basis for monitoring these changes and hence play an important role in monitoring the dynamics of land cover types. Results of this study agree with that of Ehlers et al. (1989), Huising (1993) and Molenaar and Janssen (1994). This results demonstrate the power of remote sensing as a tool for monitoring the dynamics of agricultural land use.

It has been demonstrated that the final land cover map could be stored in a GIS using the format described in Chapter 6. Noting that wildlife surveys are usually done on a grid system based on the UTM, this makes it possible to incorporate the land cover data in the spatial analysis normally carried out in protected areas to determine habitat/wildlife relationships. The next chapter presents an evaluation of the prototype biodiversity information system that has been developed in the first seven chapters of this thesis.

Chapter 8.0 Evaluation of the Prototype Biodiversity Information System

8.1 Introduction

In Chapter 6, a conceptual data model for representing biodiversity resources data in a database was defined. Also defined was a database structure for the storage, retrieval, manipulation of biodiversity resources data. Subsequently, a prototype biodiversity resources information system was implemented. In Chapter 7, a method for acquiring data on biodiversity resources and deriving a classification scheme that is more accurate and reliable was elaborated. This chapter evaluates the effectiveness of this prototype biodiversity information system as a source of information for decision support at different levels in the management of biodiversity resources. Data on both animal and plant biodiversity resources are used for illustration. Section 8.2 illustrates how information can be extracted from the database to provide answers to management questions at the national and regional levels. Section 8.3 illustrates how information is extracted from the database to provide answers to management questions at the local level. Section 8.4 illustrates how solid knowledge about the forces driving different processes in biodiversity resources can be extracted from data in the database.

8.2 Distribution and Range of Animal Biodiversity Resources

In Chapter 2 we noted that at the national level, resource managers are interested in knowing what resources are available and where they occur. As described in Chapter 3, data on the distribution of large herbivore species are collected using Systematic Reconnaissance Flights(SRF). Such data are used in this study. These data were collected by the Department of Resource Surveys and Remote Sensing in the Ministry of Planning and National Development, Kenya, between 1977 and 1997. Using the data model and database structure described in Chapter 6, these data were digitally captured in the database of the prototype biodiversity information system described in Chapter 6. Species numbers and distribution modules described in the same Chapter

were then applied to the data in an Arc/info environment. The products are files containing data that have been checked and verified for accuracy and quality from which maps showing animal species distribution and home ranges can be generated. Although the elephant was used as an example in this study, maps for any other animal species can be generated from the database using the two modules. Such maps provide answers to one of the basic questions asked by biodiversity resource managers at the national and regional level: What biodiversity resources are available in the country or region, where are they found (distribution and home range) and in what quantities (abundance)?

Figure 8.1 illustrates distribution of elephants in Kenya over the last twenty years (1977-1997). This map was generated using data on district and protected area boundaries from the topographic sub-database and data on elephant numbers from the animal sub-database. The data which are stored in different thematic layers were overlaid in an Arc View environment to produce the elephant distribution maps. The same macro can be used to produce similar distribution maps for other animal species.

The distribution map (Fig. 8.1) shows that between 1977 and 1997, elephants were mainly concentrated in the South Eastern (Taita Taveta, Tana, Kwale, Kitui, Garissa, Kilifi and Lamu districts), South Western (Narok and Kajiado districts), Central (Samburu, Isiolo, Meru and Laikipia districts), North Western (Baringo and Turkana districts), North Eastern (Mandera district), and Northern (Marsabit district) parts of Kenya. A large proportion of elephants were found outside designated wildlife protection areas. Such information should makes biodiversity resources managers re-evaluate the concept of using protected areas as the focus for biodiversity resources conservation.

Scale:
1:500,000

Figure 8.2 illustrates distribution (range) of elephant over the last seven years (1990-1997). During this period, elephants were restricted mainly to the South Eastern, South Western, Central and Northern parts of the country.



Fig. 8.2 The Elephant Distribution (range) in Kenya Between 1990 and 1997

Resource distribution maps (such as Fig. 8.1 and Fig 8.2.) form the basis for classifying resources into those that have wide distribution and those that are endemic to specific areas. This can then be used as a criteria for assigning them relative importance indexes for conservation purposes. Endemic resources would get a higher importance index and hence require special attention from resource managers. At the national level, information on distribution and abundance of biodiversity resources also forms a basis for dividing the country into biodiversity management regions and ecosystems. Tsavo is one such ecosystem.

8.3 Population Trends in Large Herbivore Species in Tsavo Ecosystem

After defining regions and ecosystems, resource managers are interested in monitoring trends within the resources in each of them. From the database of the prototype biodiversity information system developed above, it is possible to provide such information by analysing changes in animal numbers over time. This analysis is illustrated below using data on large herbivore species from the Tsavo ecosystem. Large herbivore species are an important biodiversity resource that form the cornerstone of the tourism industry in Kenya. Subsequent section present procedures to generate information vital for monitoring biodiversity resources.

8.3.1 Data Analysis

In the data structures described in Chapter 5, large herbivores are at superclass level. Grazers, mixed feeders and browsers are at the class level while the individual animal species are at the sub-class level (See Fig. 6.5). At the sub-class level, trends in the population of individual species can be analysed. Analysis of population trends at the class and superclass levels require context transformation of the data. The data on different animal species have to be transformed into a common unit e.g. the animal-unit equivalence. The Tropical Livestock Unit (TLU) and Metabolic Weights (MBW) are two such units. The TLU is the scaling of body weights of different animal species using a mass of 250 Kg. A disadvantage of this approach is that large-bodied species such as

elephants, buffalo, hippopotamus tend to influence disproportionately the final TLU total when all species are combined (e.g. the TLU of an elephant is 60 X that of a gerenuk). The metabolic weight is the scaling of metabolic maintenance demands to mass ($W^{0.75}$). In this study, metabolic weights were used because their scaling is exponential and therefore tends to normalize the influence of both large-bodied and small-bodied animal species (e.g. the MBW of an elephant is only 21.5 X that of a gerenuk).

Analysis of population trends was done by querying the biodiversity resources information system in an Access database management system environment using the Simple Query Language (SQL). The queries were grouped into several modules. Box 1 illustrates an SQL used in extracting metabolic weights of all grazers in the database. This was done by first transforming population estimates for the different grazers into metabolic weights, summing them and then grouping them using time period as a criteria (per year or season).

Box 1: SQL for Extracting Metabolic Weight Density for Grazers

```
SELECT DISTINCTROW maecxx.type, maecxx.category, maecxx.CENSID,
Sum(maecxx.tmw) AS SumOfTmw, Format(Sum([tmw]/34760.2), '#.##') AS gmwd
FROM maecxx
GROUP BY maecxx.type, maecxx.category, maecxx.CENSID
HAVING (((maecxx.type)="Wildlife") AND ((maecxx.category)="Grazer"))
ORDER BY maecxx.type;
```

Boxes 2, 3, and 4 illustrate the SQL for extracting data on metabolic weight density from the prototype biodiversity resources database.

Box 2: SQL for Extracting Metabolic Weight Density for Browsers

```
SELECT DISTINCTROW maecxx.type, maecxx.category, maecxx.CENSID, maecxx.YEAR,
Sum(maecxx.tmw) AS SumOfTmw, (Sum([tmw]/34760.2)) AS bmwd
FROM maecxx
GROUP BY maecxx.type, maecxx.category, maecxx.CENSID, maecxx.YEAR
HAVING (((maecxx.type)="Wildlife") AND ((maecxx.category)="Browser"))
ORDER BY maecxx.type;
```

Box 3: SQL for Extracting Metabolic Weight Density for Mixed Feeders

```
SELECT DISTINCTROW maecxx.type, maecxx.category, maecxx.CENSID, maecxx.YEAR,
Sum(maecxx.tmw) AS SumOfTmw, (Sum([tmw]/34760.2)) AS mfmwd
FROM maecxx
GROUP BY maecxx.type, maecxx.category, maecxx.CENSID, maecxx.YEAR
HAVING (((maecxx.type)="Wildlife") AND ((maecxx.category)="Mixed Feeder"))
ORDER BY maecxx.type;
```

Box 4: SQL for Extracting Metabolic Weight Density for Livestock

```
SELECT DISTINCTROW maecxx.type, maecxx.CENSID, maecxx.YEAR, Sum(maecxx.tmw)
AS SumOfTmw, (Sum([tmw]/34760.2)) AS lmwd,
FROM maecxx
GROUP BY maecxx.type, maecxx.CENSID, maecxx.YEAR
HAVING (((maecxx.type)="Livestock"))
ORDER BY maecxx.type;
```

Data thus extracted formed the basis for analyzing animal population trends. The first step was to explore relationships between herbivore species numbers and time, on the basis of population estimates carried out over a twenty year period. Regression analysis was used to describe this relationship. This analysis was done at three hierarchic levels (sub-class, class and super class) as describes in Chapter 6 (Fig. 6.5). At the sub-class level, data on individual animal species were used. In this study, data on elephants were used to illustrate this analysis. At the class level, data on animal species were grouped on the basis of their feeding habits (i.e. grazers, mixed feeders and browsers) and at the super class level, data were grouped on the basis of food types (i.e. herbivores). For each level, the analysis was done for three spatial units (area inside the Tsavo protected areas, area outside the Tsavo protected area, and for the Tsavo ecosystem).

The first step in the regression analysis is to estimate the parameters for the model. This is done using the least-squares principle (see Cochran and Cox, 1957). The parameters in this study were the expected animal population estimate (response variable) with time (explanatory variable). The next step is an Analysis of Variance (ANOVA). The results are presented in Table 8.1. From this table we can deduce how well the regression equation explains the response variable. In this example, the

fraction of variance accounted for (R^2_{adj}) is 0.377, which means that only 37.7% of the variation in population estimates is explained by a change in time. This table can further be used to statistically test whether the expected responses (i.e. population estimate) differ with time. For this test, the F ratio was compared with the critical value of an F distribution with 1 and 9 degrees of freedom. The results were found to be significant at the 5% level. It is concluded that the expected responses do differ with time. Thus the animal population estimates differ significantly between the years at the 5% level ($P = 0.026$). These findings are useful to resource managers.

Table 8.1 A Straight Line Fitted by Least-squares Regression: Parameter estimates and ANOVA Table of Log-transformed Elephant Counts Inside the Protected Area.

Variable	Coefficient	Standard error	t	P(2 tailed)
Constant	50.116	17.382	2.883	0.018
Year	-0.023	0.009	-2.656	0.026

$Y = 50.116 - 0.023x$ Where $Y = \text{Animal population estimate}$
 $X = \text{Time (year)}$

ANOVA Table					
Source	ss	d.f.	m.s.	F-Ratio	P
Regression	0.275	1	0.275	7.053	0.026
Residual	0.275	9	0.039		

$R^2_{adj} = 0.377$

8.3.2 Animal Population Trends

At the sub-class level, population trends can be analyzed for those animal species whose population estimates differ significantly over time. In this study, elephant population estimates in the Tsavo ecosystem were used to illustrate this analysis. At the class level, the animal resources were grouped on the basis of the feeding mode (grazers, mixed feeders and browser) before analysis of trend was carried out. While at the superclass level, the animal resources were grouped on the basis of their food types. The database model described in Chapter 6 supports this grouping.

There are several models that could be used to explain the underlying trends in animal

resources over time (see Jorgensen, 1988). These include linear models, log-linear models, and quadratic models. For each model, some assumptions have to be made on how animal resources behave over time. Generally, populations of animal resources decline gradually towards a minimum, stabilize, and then recover (i.e. increase), or the populations increase towards a maximum then decline. In such a case, a quadratic model may explain the underlying trends in the resources. Because of the wide range in some population estimates, fitting quadratic models often resulted in unrealistic population estimates (i.e. negative population estimates). To make the models more realistic, the population estimates were transformed with the natural logarithm.

8.3.3 Results

The results from regression analysis and the analysis of variance are given in appendix 3. From the analysis of variance (ANOVA) tables, it could be concluded that between the period 1977 and 1997, the expected responses among animal resources population estimates in the Tsavo ecosystem differ and that population estimates for: (1) elephants, browsers, mixed feeders and total herbivores inside the protected area (i.e. Tsavo national park), (2) elephants in the whole ecosystem, and (3) browsers outside the protected area differed significantly over time at the 5% level ($P < 0.05$, F test). Trends in animal resources were analysed for these significant population estimates.

Fig 8.3 shows a quadratic model for elephant population numbers within the protected area. There was a gradual decline in elephant population numbers between 1977 and 1987. This coincides with a period of high poaching activity. The numbers then levelled-off before beginning to increase in 1991. After the formation of KWS in 1989, new protection measures were introduced. There were also special protection measures introduced for endangered species like the elephant. This could be partly responsible for the gradual increase in elephant population numbers beginning from 1991. The results indicate that there was no significant change in elephant numbers outside the protected area.

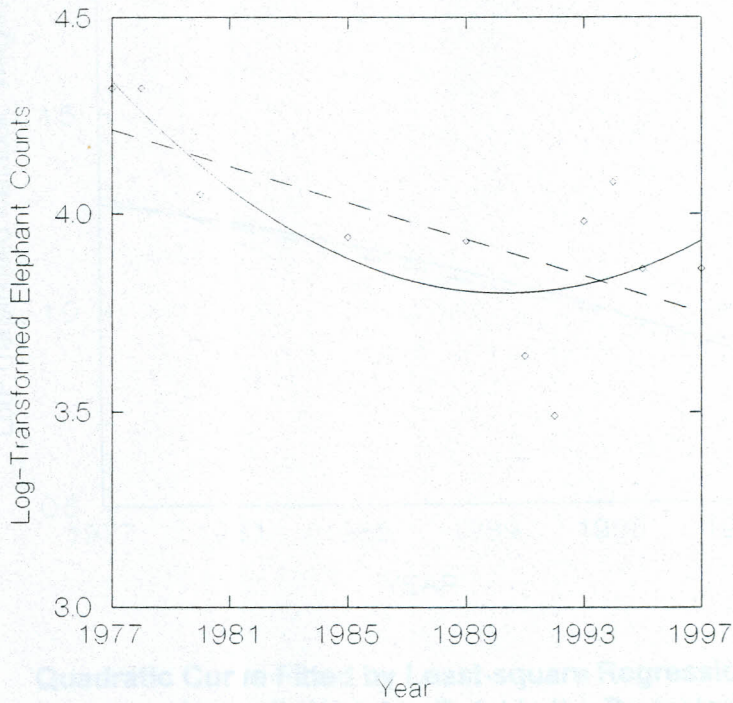


Fig. 8.3 Quadratic Curve Fitted by Least-square Regression of Log-transformed Elephant Population Estimates Inside the Protected Area.

Fig 8.4 shows a quadratic model for trends in metabolic weights of browsers outside the Tsavo protected area. There is a near constant decline in the metabolic weight of browsers during the period between 1977 and 1997. For browsers inside the protected area, there was a steady increase in metabolic weight towards a maximum between 1977 and 1985. This was followed by a gradual decline (Fig. 8.5).

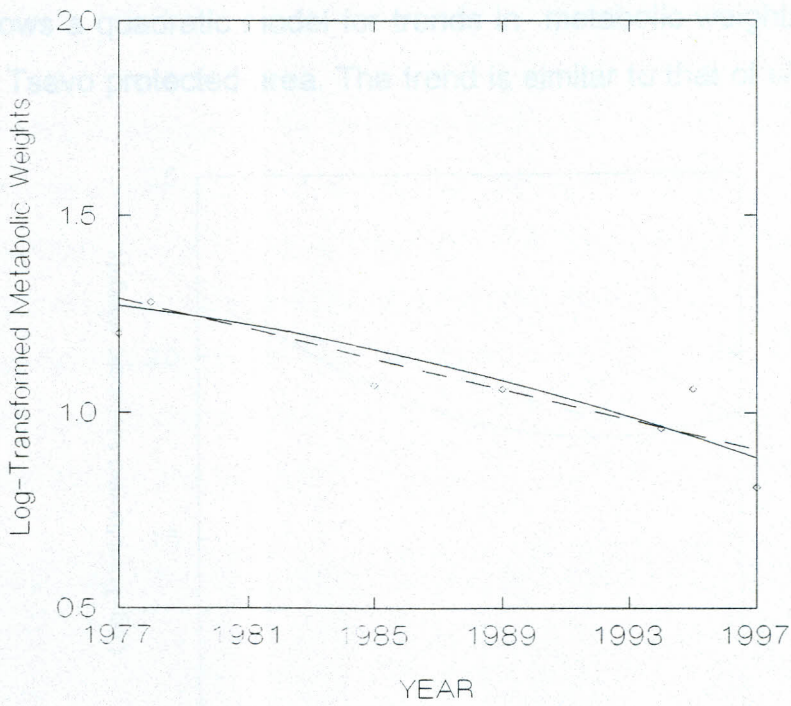


Fig. 8.4 Quadratic Curve Fitted by Least-square Regression of Log-transformed Bowers Metabolic Weights Outside the Protected Area.

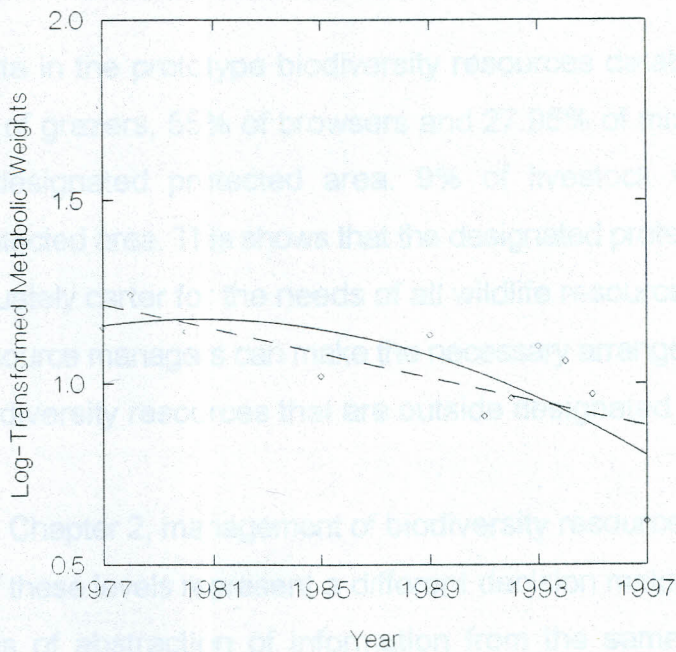


Fig. 8.5 Quadratic Curve Fitted by Least-square Regression of Log-transformed Bowers Metabolic Weights Inside the Protected Area.

Fig 8.6 shows a quadratic model for trends in metabolic weights of mixed feeders inside the Tsavo protected area. The trend is similar to that of elephants described above.

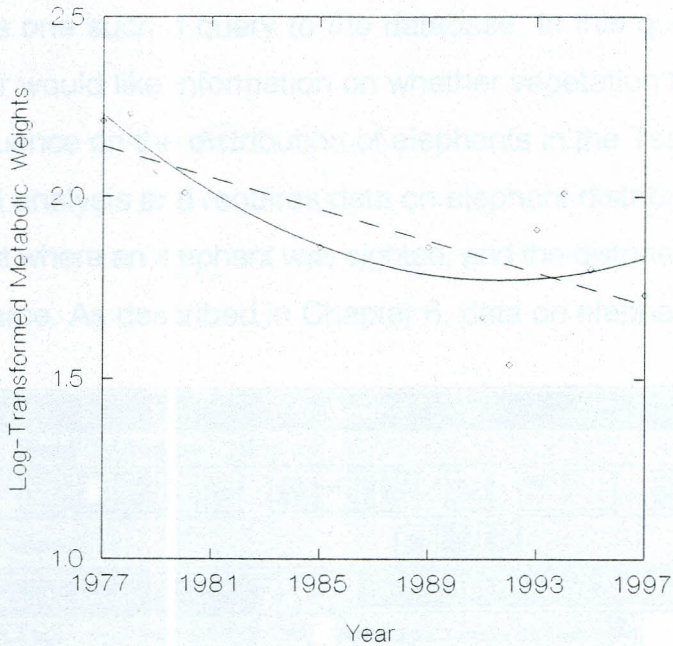


Fig. 8.6 Quadratic Curve Fitted by Least-square Regression of Log-transformed Browsers Metabolic Weights Inside the Protected Area.

Analysis of data in the prototype biodiversity resources database shows that on the average, 37% of grazers, 55% of browsers and 27.95% of mixed feeders were found outside the designated protected area. 9% of livestock were found within the designated protected area. This shows that the designated protected area in this region does not adequately cater for the needs of all wildlife resources in the area. With this information resource managers can make the necessary arrangements to also conserve the animal biodiversity resources that are outside designated protected areas.

As reviewed in Chapter 2, management of biodiversity resources is at three hierarchic levels. Each of these levels represent a different decision making context and requires different levels of abstraction of information from the same database. To provide information required for decision support in the effective management of biodiversity resources, the database structure should be able to support the different levels of information abstraction. Biodiversity resource managers should be able to query the database and extract the required information. The database describe in Chapter 6

Select all points in Tsavo ecosystem where one or more elephants were sighted during the 1997 animal census and show how many were sighted, the vegetation type where they were sighted, and the distance of that point to the nearest water source.

The results was a table containing the required data (attributes of Elpoint as illustrated in Fig 8.7. These data can be analysed statistically to extract solid knowledge that may be used by resource managers to understand the forces driving different processes and events within biodiversity resources through the use of models as illustrated in subsequent sections.

8.4 A biodiversity Resources Model

The objective of the case study was to investigate the relationship between elephant distribution in the Tsavo ecosystem (i.e. observation of an elephant) and different environmental variables. In this case study, the environmental variables used were: vegetation cover and distance to watering points. Because the elephant census data were not normally distributed, they were first transformed into present or absent values which were then assigned the numeric value 1 for present and 0 for absent for statistical analysis. The fully saturated model had the form:

$$OBS = 1/1 + \exp(a + b * scdst + c * scdst^2 + d * veg + e * veg^2)$$

Where :

OBS	=	the probability of observing an elephant based on distance to water and vegetation cover.
scdst	=	distance to watering point
veg	=	vegetation cover

This is a second order polynomial response function. The loss function used to execute the model was:

$$LOSS \ FUNCTION = Animal * \text{Log}(\text{estimate}) + (1 - Animal) * \text{Log}(1 - \text{estimate})$$

Where:

Animal = Elephant presence

Both forward and backward stepwise logit regressions (as described by Nicholls (1989)) were used to select the best fitting model. The backward selection procedure starts with a fully saturated model and from which the variable with the largest error terms is eliminated at every step until a model with only significant variables is obtained.

The forward selection starts with a single variable. Subsequently more variables are added. At each step, a test is performed to determine if the parameter estimate varies significantly from zero using the 5% one-sided significance test. Only models for which the parameters estimates are significant are retained. This selection starts with the 'null hypothesis' $OBS = 1/(1-\exp^{-a})$. In this model, no environmental variable is included and corresponds to a situation where distribution of elephants is not affected by any environmental factors. Then models that include one factor are run. This is repeated with two factors and so on. Since the chances of a deviation between a model and the next one are distributed as a Chi-Squared variable (Nicholls, 1989), the Chi-Squared test is used to evaluate whether such more complex models are significantly better than the 'null' model. This process is repeated until the models are no longer significantly different from the 'null' model.

8.5 Results

The forward selection method produced eight models (Table *.1). The best selected equation was:

$$Y = 0.033 - 0.837 * x$$

Where Y is the probability of observing an elephant
X is the distance to a watering point

This was the only equation that was significantly different from the 'null' model. According to this equation, the probability of finding an elephant during the dry season depends on the distance of the point to a permanent watering place. This equation was incorporated into the model for predicting the potential for an elephant/human conflict as described in Chapter 9.

Table 8.2 Statistical Equations Describing the Relation Between Elephant Presence and Two Environmental Factors (distance to watering points and vegetation cover)

Model	Parameter values				Loss Function
	a	b	c	d	
OBS=1/1+exp*a	-0.051 ^{ns} (0.026)				4013.485
OBS=1/1+exp(a+bscdst)	-0.052 ^{ns} (0.037)	0.001 ^{ns} (0.114)			4013.85
OBS=1/1+exp(a+bscdst ²)	0.033 ^{ns} (0.37)	-0.837* ^s (0.114)			4013.76
OBS=1/1+exp(a+b*veg)	-0.070 ^{ns} (0.097)	0.030 ^{ns} (0.151)			4013.466
OBS=1/1+exp(a+b*scdst+c*veg)	-0.072 ^{ns} (0.105)	0.005 ^{ns} (0.115)	0.031 ^{ns} (0.153)		4013.465
OBS=1/1=exp(a+b*veg+c*veg)	-0.133 ^{ns} (0.220)	0.275 ^{ns} (0.785)	-0.215 ^{ns} (0.673)		4013.415
OBS=1/1+exp(a+b*scdst+c*scdst+veg)	-0.052 ^{ns} (0.037)	0.013 ^{ns} (0.228)	-0.022 ^{ns} (0.360)		4013.415
OBS=1/1+exp(a+b*scdst+c*veg+d*veg ²)	-0.147 ^{ns} (0.241)	0.017 ^{ns} (0.120)	0.309 ^{ns} (0.821)	-0.242 ^{ns} (0.701)	4013.405

ns - not significant (95% level)

s - significant (95% level)

8.6 Summary

Management of biodiversity resources in Kenya is at three hierarchic levels as reviewed in Chapter 2. The different levels in the decision making hierarchy represent different decision making contexts. Each of these requires different levels of abstraction of information. We defined a prototype biodiversity information system in Chapter 6. The aim was to develop an information system with a database that could provide information for biodiversity resources management decision support at the different hierarchic levels. In this chapter, we have evaluated the effectiveness of the information system in providing information to support decisions in the management of biodiversity resources. Several examples have been used to illustrate how information needs at different levels in the management of biodiversity resources can be met from the prototype biodiversity information system defined in Chapter 6. In this Chapter, we have also illustrated how data from the system can be used to gain additional understanding of the dynamics of biodiversity resources.

At the local level, information is extracted from the same land cover maps and used to predict the potential for human-wildlife conflict (section 9.2.3). The elephant example is an example to illustrate how information extracted from the same data source (land cover maps) can be used to support management decisions at different levels of the biodiversity resource management hierarchy within the Tsavo Ecosystem.

A major task for biodiversity resource managers in Kenya is the conservation of wildlife (KWS, 1986); consequently, they need to evaluate the suitability of different habitats for wildlife. This involves rating Kenya's landscapes in terms of their potential to support populations of different wildlife species. Information on four variables (habitat availability, forage quality, to age quantity and availability of water) is important in evaluating the suitability of a habitat for different animals. Land cover maps are an important source of information for evaluating wildlife habitats. The arrangement of different land cover types in a landscape (i.e. spatial characteristics) may have an influence on its value as a habitat for different wildlife species. Spatial diversity indices are used to quantify the spatial characteristics of a landscape, it is possible to apply additive or multiplicative models to rate habitats (Meat et al., (1981). By this approach,

Chapter 9: Extracting Biodiversity Resource Management Information from Land Cover Maps: Habitat Suitability Rating and Human/Elephant Conflict Potential

9.1 Introduction

Understanding the spatial characteristics of plant biodiversity resources will enable the evaluation of habitat suitability and the potential for human/wildlife conflict, as well as monitoring of change. That is the thesis of this chapter. This will in turn facilitate effective management and conservation of these resources.

A method is developed for evaluating habitat suitability for wildlife (section 9.2.1 and 9.2.2) using information extracted from land cover maps that are stored in the biodiversity resources database described in Chapter 6. This is done at the regional level in the biodiversity resources management hierarchy as described in Chapter 2. At the local level, information extracted from the same land cover maps can be used to predict the potential for human/wildlife conflict (section 9.2.3). The elephant is used as an example to illustrate how information extracted from the same data source (i.e. land cover maps) can be used to support management decisions at different levels in the biodiversity resource management hierarchy within the Tsavo Ecosystem.

A major task for biodiversity resource managers in Kenya is the conservation of wildlife (KWS, 1996); consequently, they need to evaluate the suitability of different habitats for wildlife. This involves rating Kenya's landscapes in terms of their potential to support populations of different wildlife species. Information on four variables (i.e. forage availability, forage quality, forage quantity and availability of water) is important in evaluating the suitability of a habitat for different animals. Land cover maps are an important source of information for evaluating wildlife habitats. The arrangement of different land cover types in a landscape (ie, spatial characteristics) has a great influence on its value as a habitat for different wildlife species. Spatial diversity indices are used to quantify the spatial characteristic of a landscape, it is possible to apply additive or multiplicative models to rate habitats (Mead et al., (1981). By this approach,

spatial diversity indices are determined using spatial coverage, structure and mixes of plant communities, and provide a measure of habitat heterogeneity which is then used to evaluate the habitat's suitability for a given wildlife species.

A description of the spatial pattern characteristics of an area can be used for several purposes besides habitat suitability rating. It can be used for monitoring change in distribution and dispersion of biodiversity resources. Definition and descriptions of spatial characteristics of objects in an area using their aggregation hierarchies form the basis for monitoring change. Depending on the level of abstraction, change in aggregation structures could be used as an indicator of change in either the spatial extent of a terrain object or its thematic content as described in Chapter 3.

Spatial pattern characteristics of terrain objects are used to evaluate potential for human/wildlife conflicts. These conflicts are some of the major problems in and around protected areas. In resolving these conflicts, resource managers require information on the nature and magnitude of these human/wildlife conflicts. This thesis set out to develop a method for acquiring information from land cover maps on wildlife habitat suitability and for predicting the potential for human/wildlife conflicts. In this study, the elephant was used as an example.

9.2 Methods

The analysis involved four steps: selection of environmental variables and database development, evaluation of spatial characteristics, evaluation of the potential for elephant/human conflict, and verification. **These are considered in subsequent sections.**

9.2.1 Selection of Environmental Variables and Database Development

The relationship between elephants and their environment is based primarily on the need for forage and water. The main influencing variables are land cover types and distance to permanent water sources. Land cover types were mapped by integrating digital satellite data and ancillary data in a GIS as described in Chapter 7. Each 20 x

20 m pixel on the map was assigned a label representing a specific cover type.

The land cover map (Chapter 3) was used to determine the cover type for each pixel.

Information on distance to permanent water sources was extracted from topographic maps (scale 1:50,000) and field surveys. The positions of the permanent water sources were digitized using the integrated land and water information system (ILWIS, 1993) and geo-referenced to the Universal Transverse Mercator (UTM) coordinate system. These maps were then rasterized using the 'vector to raster' module of the GIS, and transformed into distance maps (in metres) using the 'spatial modelling' module. In Chapter 8, a regression model for estimating the probability of encountering an elephant, based on the distance from permanent water source (equation 1) was developed based on data from literature (Buss, 1961; Bax and Sheldrick, 1963), and from systematic reconnaissance surveys (see Chapter 3) carried out by the Department of Resource Surveys and Remote Sensing (DRSRS) between 1977 and 1997.

$$\text{OBS} = 1/1 + \exp(a + b * \text{distance}^2) \quad (\text{Equation 1})$$

where OBS = estimated probability of observing an elephant
Distance = distance to permanent water source.

Studies on daily and seasonal movements of elephants showed that elephants frequently travel up to 10 km to water points. Frequency decreased with increasing distance, up to about 30 km when recordings were very rare (Bax and Sheldrick, 1963). The assumption here is that elephants are already in the area of interest. The model applies to the dry season, when elephants are known to rely heavily on permanent water sources.

The sum is then divided by the total number of pixels in the area of interest to scale the indexes to a number >0 and <1.

The severity of the elephant/human conflicts depend on proximity of human settlements to the natural habitat of elephants, location of permanent sources of water and habitat quality in areas neighbouring human settlements. The conflicts result in elephants being killed by people on one hand and damage to crops and injury to people, some fatal, caused by elephants on the other hand. Evaluating the potential for conflict therefore focussed on the spatial relationships among habitat suitability for elephants, areas of

human settlement and agricultural crops, and distance to permanent sources of water. The land cover map (Chapter 6) was used to prepare a new map showing distances from areas of human settlement and agricultural crops.

9.2.2 Evaluation of Spatial Characteristics

The spatial characteristics of the study area were evaluated using the spatial diversity index. Equation 2, which is an adaption of the one proposed by Mead et al. (1981), was applied as a multivariate inductive model to derive the spatial diversity index for each pixel.

$$SD_A = [(\alpha_A \frac{IS}{8}) + (\sigma_A \frac{JX}{12})] / 2 \quad \text{(Equation 2)}$$

where:

- A = a specific wildlife species or group of species
- IS = interspersion
- JX = juxtaposition
- σ = the relative importance of juxtaposition to interspersion for the wildlife species
- α = the relative importance of interspersion to juxtaposition for the wildlife species

Interspersion (IS) is the intermixing of different habitat types. This is an index derived from a 3 x 3 matrix of pixels summing up all pixels with a land cover type different from the central one. The sum is then divided by the total number of pixels in the matrix (eight) to scale the indices to a number >0 and <1.

Juxtaposition (JX) is the proximity of the habitat requirements of a given wildlife species to a site being analyzed. This is an index derived by first identifying all possible land cover type combinations (edge types) in contact with that of the central pixel in a 3 x 3 matrix. Because the pixels at the horizontal and vertical edges have greater areas of contact with the central pixel than those on the diagonals, (ie, those in the corners of

the matrix), they were each assigned a weighting factor of 2, and because certain land cover edge type combinations are more important to a given wildlife species than others, the total for each possible edge type combination was multiplied by a weighting factor that reflected the relative importance of that combination to a particular wildlife species. The products from the different edge type combinations were summed and divided by 12 to scale them to a figure between 0 and 1. Information from literature and expert knowledge were used to determine the importance of each edge-type combination to the elephant. This formed the basis for assigning the weighting factors in calculating juxtaposition. Some wildlife species prefer uniform habitats. Such animals may be either pure grazers or pure browsers. For such wildlife species, interspersions are more important than juxtaposition. For mixed feeders, a more mixed habitat is preferred. For them, juxtaposition is more important than interspersions. In deriving the spatial index, a weighting factor is used to reflect the habitat preferences of different wildlife species.

Interspersions and juxtaposition maps were created in the GIS for the study area by applying neighbourhood function operations and tables to each pixel in the land cover map, using the ILWIS 'spatial modelling' module. The two maps were then combined by applying equation 2 to produce a spatial diversity map. The procedure for deriving the spatial diversity maps that are then used to assess habitat quality is shown in Figure 9.1.



Fig. 9.1 Scheme for Assessing Habitat Quality for Elephants

9.2.3. Parametric Indices for the Human/Elephant Conflict

The main assumption when evaluating the potential for conflict at a site was that elephant/human conflict depends on three variables (i.e. distance of human activity from the natural habitats of elephants, distance to permanent water sources and habitat suitability). These variables are not independent of each other.

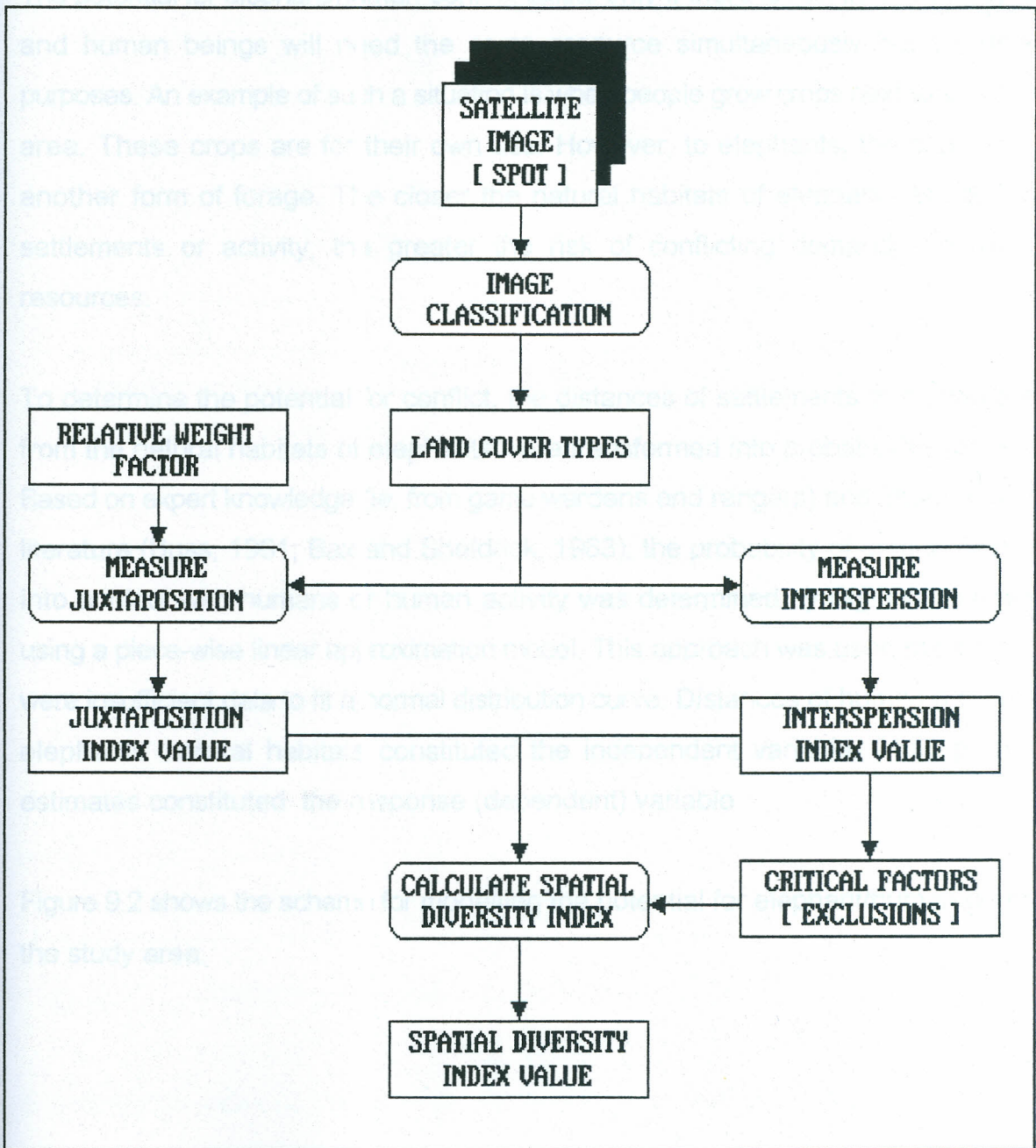


Fig. 9.1 Scheme for Assessing Habitat Quality for Elephants

9.2.3 Parametric Indices for the Human/Elephant Conflict

The main assumption when evaluating the potential for conflict at a site was that elephant/human conflict depends on three variables (i.e. distance of human activity from the natural habitats of elephants, distance to permanent water sources and habitat suitability). These variables are not independent of each other.

The potential for elephant/human conflict exists only if there is risk that both elephants and human beings will need the same resource simultaneously but for different purposes. An example of such a situation is when people grow crops next to a protected area. These crops are for their own use. However, to elephants, the crops are just another form of forage. The closer the natural habitats of elephants are to human settlements or activity, the greater the risk of conflicting demands on available resources.

To determine the potential for conflict, the distances of settlements or human activity from the natural habitats of elephants were transformed into probabilities for conflict. Based on expert knowledge (ie, from game wardens and rangers) and information from literature (Buss, 1961; Bax and Sheldrick, 1963), the probability of elephants coming into contact with humans or human activity was determined by regression analysis, using a piece-wise linear approximation model. This approach was used because there were insufficient data to fit a normal distribution curve. Distances of human activity from elephants' natural habitats constituted the independent variable, while probability estimates constituted the response (dependent) variable.

Figure 9.2 shows the scheme for modelling the potential for elephant/human conflict in the study area.

Fig. 9.2 Modelling Potential Human/Elephant Conflict in a Protected Area

A parametric index of the potential for conflict was derived for each site based on an additive model (Equation 3):

$$P_c = W_1 P_1 + W_2 P_2 + W_3 P_3 + W_4 P_4 \quad \text{(Equation 3)}$$

- P_c = potential for elephant/human conflict
- W_1 = weighting factor for each variable
- P_1 = probability of encountering elephants based on habitat structure
- P_2 = probability of encountering elephants based on distance to permanent water
- P_3 = spatial diversity indices

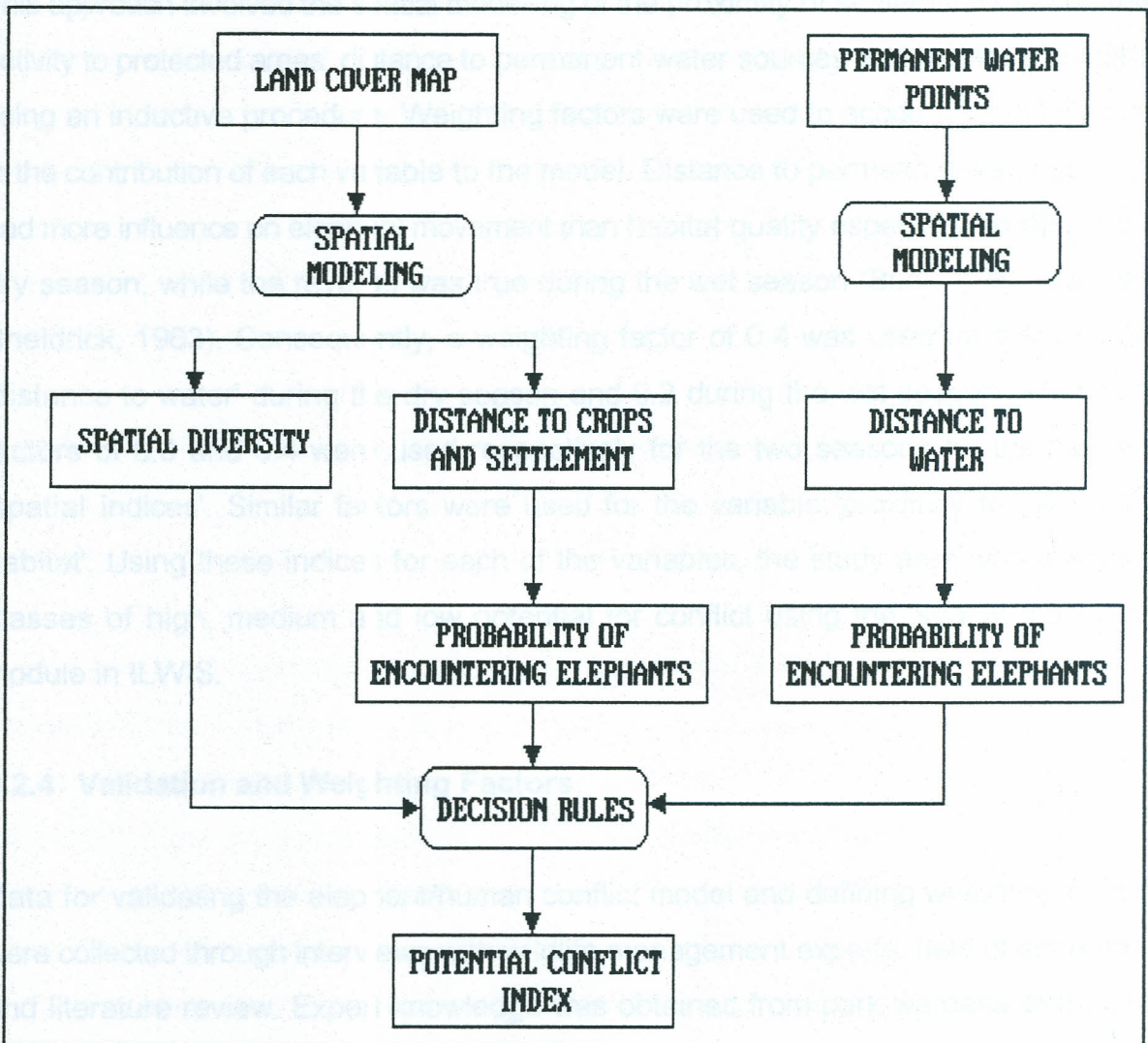


Fig. 9.2 Modelling Potential Human/Elephant Conflict in a Protected Area

A parametric index of the potential for conflict was derived for each pixel using an additive mode (Equation 3).

$$P_c = W_i P_i + W_{dw} P_{dw} + W_{sd} P_{sd} \quad (\text{Equation 3})$$

where

- P_c = potential for elephant/human conflict
- W = weighting factor for each variable
- P_i = probability of encountering elephant based on proximity to elephants' natural habitat
- P_{dw} = probability of encountering elephants based on distance to permanent water
- P_{sd} = spatial diversity indices

This approach involved the spatial modelling of the proximity of settlements and human activity to protected areas, distance to permanent water sources and habitat suitability, using an inductive procedure. Weighting factors were used to account for differences in the contribution of each variable to the model. Distance to permanent water sources had more influence on elephant movement than habitat quality especially so during the dry season, while the reverse was true during the wet season (Buss, 1961; Bax and Sheldrick, 1963). Consequently, a weighting factor of 0.4 was used for the variable 'distance to water' during the dry season and 0.2 during the wet season. Weighting factors of 0.3 and 0.4 were used respectively for the two seasons for the variable 'spatial indices'. Similar factors were used for the variable 'proximity to elephant's habitat'. Using these indices for each of the variables, the study area was assigned classes of high, medium and low potential for conflict using the 'spatial modelling' module in ILWIS.

9.2.4 Validation and Weighting Factors

Data for validating the elephant/human conflict model and defining weighting factors were collected through interviews with wildlife management experts, field observations and literature review. Expert knowledge was obtained from park wardens and game rangers, who were asked to identify the land cover types preferred by elephants. More information was extracted from recorded cases of elephant damage to crops or reported injury to people. These data were used to define the actual spatial pattern of elephant/human conflict over the past 10 years. This was then visually compared with the map of predicted potential for conflict. The approach was adopted because it was not possible to accurately geo-reference the available data. Thus only qualitative validation of models was possible. Information about the habitats was also used to weight factors used in deriving the spatial diversity index.

9.3 Results

Six spatial models were developed for part of the Taita Taveta buffer zone of Tsavo East National Park. The interspersion (IS) and juxtaposition (JX) models describe the spatial characteristics of the study area. These spatial models provide a means for

measuring a habitat's structural connectivity and ascertaining the existence of functional continuity, ie, the ability of a hypothetical species to move freely within a single habitat without ever leaving it (Forman and Gordon, 1986). The models also provide an indication of the different types of forage available for wildlife species.

The combination of the IS and JX models produced the spatial diversity model (Fig. 9.3) for the elephant habitat. This model shows a continuous surface of parametric indices that are indicators of habitat suitability for elephants. Further, two other models were developed, containing information on the probability of encountering elephants based on the proximity of a site to suitable natural habitats, and the distance of the site to permanent water sources.

A model of a continuous surface of parametric indices on the potential for human/elephant conflict was produced by combining the spatial diversity model and the models for predicting the potential for human/wildlife conflict based on distance to permanent water sources and distance of human settlements from the natural habitats of elephants. The indices, which range from 0 to 1 were classified into areas of: (1) low potential (0 to 0.5), (2) medium potential (>0.5 to 0.8) and (3) high potential (>0.8). Figure 9.4 is a product of overlaying data on crop damage and injury to people with the map on the potential for human/elephant conflict. The figure has been classified to show the connectivity between areas with a similar potential for conflict. This is crucial information required by biodiversity resource managers for use in resolving different human/elephant conflicts.

Data on crop damage and injury to people were obtained from interviews with wildlife management experts, daily park records, expert knowledge and field observations. This provided a qualitative means of validating the potential human/elephant conflict model. Most of the damage to crops and injury to people occurred in areas predicted by the model as having medium or high potential for human/elephant conflict.

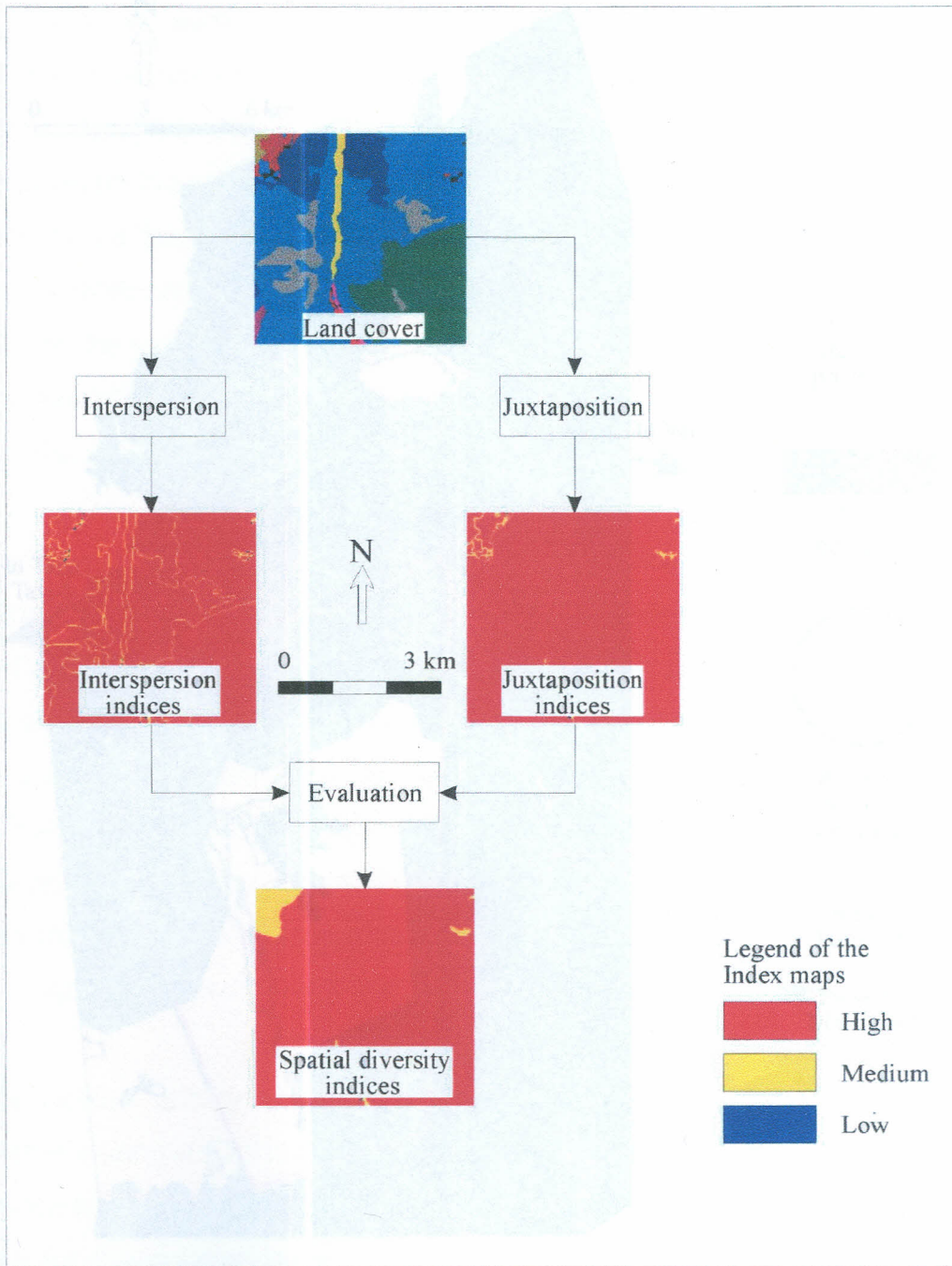


Fig. 9.3 Derivation of a spatial index map

Fig. 9.4

Potential and actual human/elephant conflicts in

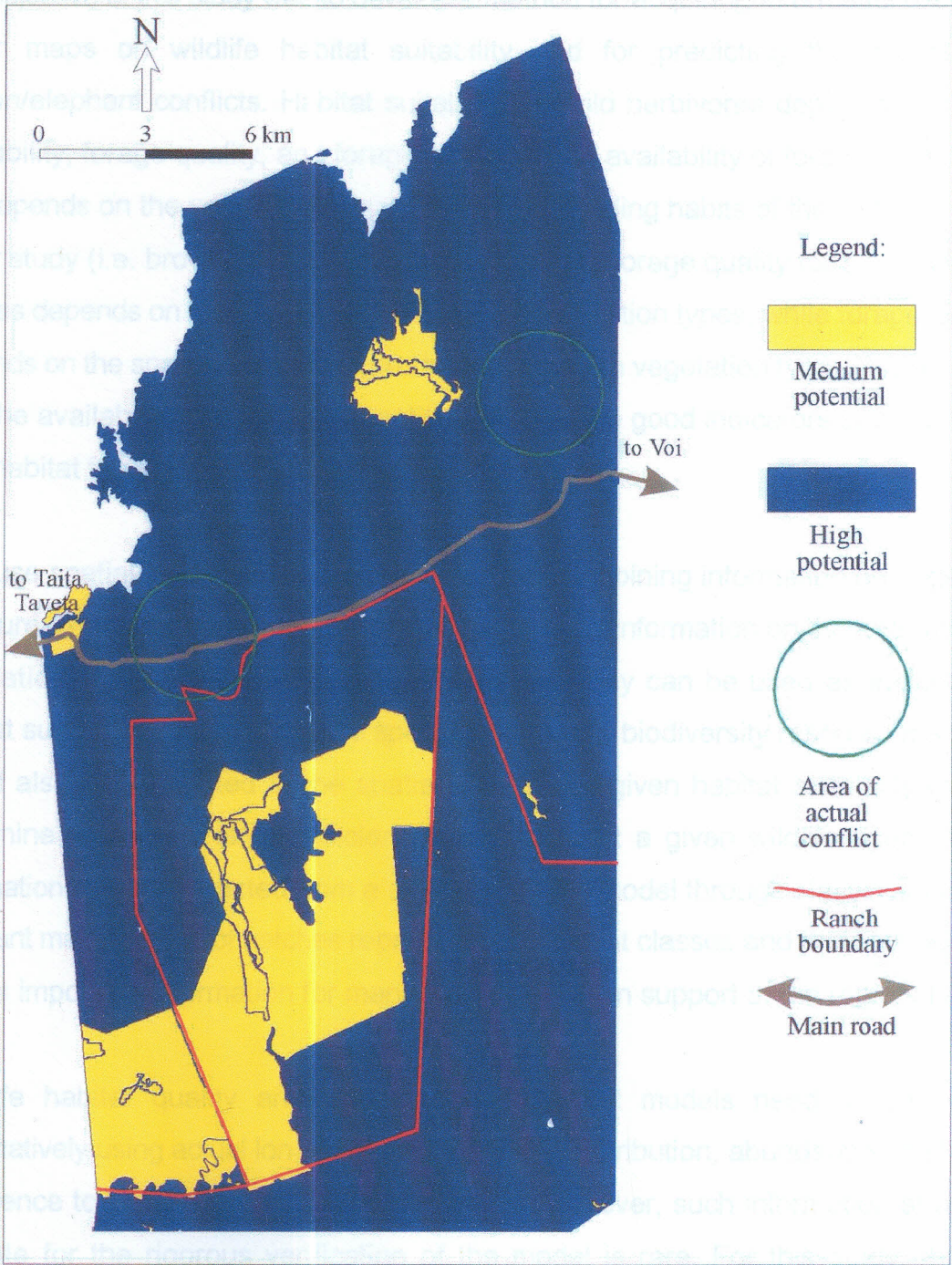


Fig. 9.4 Potential and actual human/elephant conflicts in the study area.

9.4 Discussion

The objective of this study was to develop a method for acquiring information from land cover maps on wildlife habitat suitability and for predicting the potential for human/elephant conflicts. Habitat suitability for wild herbivores depends on: forage availability, forage quality, and forage quantity. The availability of forage at any given site depends on the vegetation structure and the feeding habits of the wildlife species under study (i.e. browsers, grazer or mixed feeder). Forage quality for a given wildlife species depends on the intermixing of different vegetation types, while forage quantity depends on the spatial extent and productivity of each vegetation type. For a specific site, the availability, quality and quantity of forage are good indicators of its suitability as a habitat for a given wildlife species.

Because spatial diversity maps are prepared by combining information on vegetation structure, (i.e. forage availability -interspersion) with information on the intermixing of vegetation types (forage quality - juxtaposition), they can be used as indicators of habitat suitability for given wildlife species. However, biodiversity resource managers would also be interested in the spatial extent of a given habitat suitability class to determine whether it is of sufficient size to support a given wildlife species. This information can be extracted from a spatial diversity model through classification. The resultant map consists of patches representing different classes and their connectivity. This is important information for management decision support at the regional level.

Wildlife habitat quality and wildlife/human conflict models need to be verified quantitatively using actual long term animal data on distribution, abundance and habitat preference to verify their predictive properties. However, such information at a scale suitable for the rigorous verification of the model is rare. For this study, the only information available was on a 5 x 5 km grid that was too general for habitat preference analysis for most wildlife species. The only other data source was interviews with wildlife management experts, daily park reports and field observations. The information included reported cases of crop damage and injury to people but showed only the general locations where they had occurred. These could not be accurately georeferenced for use in statistical analysis. Consequently, only qualitative verification

of the models was possible. However, the areas predicted by the model to have a high potential for conflict generally coincided with those where actual conflicts had been reported.

This study has demonstrated a technique for integrating remote sensing and GIS technology in order to describe and understand the spatial characteristics of biodiversity resources. By using the interspersion and juxtaposition indices, the spatial characteristics of terrain objects can be described quantitatively and consistently and at various scales. Consequently, it is possible to evaluate habitat suitability for different wildlife species and the potential for human/wildlife conflict, and to monitor changes in spatial characteristics and biodiversity of terrain objects through change in their geometric and thematic characteristics.

- (1) to design an information system structure for multi-scale data support in biodiversity resources management and conservation
- (2) to test the decision support system in the Tsavo Ecosystem
- (3) to model biodiversity resources and their current trends at regional levels, and to model trends to these resources at a local scale

In the framework of this study a method for defining a biodiversity resource system plan has been developed (Chapter 5). The basic data types that can provide information for decision support for effective management of these resources have been identified. This was done by analyzing biodiversity resources and their spatial data in a database and for defining a database structure (Chapter 6). A method for acquiring data storage in the database was developed. The evaluation of the prototype biodiversity information system was done in order to obtain results from this study, several conclusions can be made related to the system plan, management of biodiversity resources, data acquisition and quality.

Chapter 10 Conclusions and Recommendations for Future Research

10.1 Information System Plan

For effective and efficient management of biodiversity resources in the country, there is need for appropriate and timely information to support management decisions, made at different hierarchical levels. The general object of this study was:

To develop a mechanism for the provision of information necessary for effective and efficient management of biodiversity resources in Kenya.

The specific objectives were:

- (1) to design an information-abstraction structure for multi-level management decision support in biodiversity resources management and conservation in Kenya.
- (2) to test the decision-support system in the Tsavo Ecosystem (Taita Taveta district) to model biodiversity resources and their current trends at regional and national levels, and to model threats to these resources at a local scale.

In the framework of this study, a method for defining a biodiversity resources information system plan has been developed (Chapter 5). The basic data types that are needed to provide information for decision support for effective management of these resources have been identified. This was done by analyzing biodiversity resources as a natural system. The data types identified formed the basis for defining a data model for representing the data in a database and for defining a database structure (Chapter 6). An example of a method for acquiring data storage in the database was developed (Chapter 7). An evaluation of the prototype biodiversity information system was done (Chapter 8). Based on results from this study, several conclusions can be made related to: information system plan, management of biodiversity resources, data acquisition and quality, and biodiversity

resources information system, as detailed in subsequent sections of this chapter.

10.1 Information System Plan

This study has identified two distinct hierarchies (management decision hierarchy and information hierarchy) that have to be integrated for effective and efficient management of biodiversity resources (Chapter 2 and 5). Linking these two hierarchies, facilitated the development of mechanisms for the identification of appropriate information to support decisions in biodiversity resources management. It also facilitated identification of primary data sets that need to be analyzed to derive desired information to support management decisions. This makes it possible to optimize data collection, eliminate or minimize duplication, and maximize use of available data through data sharing. This should result in the reduction of costs for data acquisition as well as increase efficiency in the use of available human and financial resources. Linking decisions and information hierarchies is an approach which can be used to manage other environmental situations similar to biodiversity resources.

10.2 Management of Biodiversity Resources

Four conclusions can be made from this study with regards to the management of biodiversity resources. These are:

- (1) The study has successfully demonstrated a system for supplying information to support management decision making at various hierarchical levels. Since the method is generic, it could be applied to manage other natural resources in Kenya or any other country.
- (2) Results from this study provide a basis for developing a framework for a more

responsive information system for decision support in the management of biodiversity resources in the entire country. Many current management challenges of biodiversity resources in Kenya are as a result shortcomings in conservation policies of the last 100 years. Many of these policies have not been adjusted over time so as to cope with changing circumstances outside and inside protected areas.

- (3) This study has developed methodology for identifying data types that are relevant to biodiversity management, and for integrating them into a common database for any organization. The current trend in KWS is to convert into digital format any existing data for any area without prior consideration of their relevance with regard to supporting management decisions. This has led to the creation of a large number of unintegrated databases holding large amounts of redundant data.
- (4) Currently, the use of GIS technology, as a management tool, in KWS is limited. Although implementation of this technology is not a prerequisite for effective and efficient management of biodiversity resources, it never the less provides resource managers with a tool to make better and informed decisions. However the technology will not change the way biodiversity resources are being managed unless an organization first changes by adopting a resource management approach that fully utilizes the functions of a GIS and the data stored in it. Secondly, resource managers need to appreciate potential uses and limitations of the technology to ensure that no false exceptions are created.

10.3 Data Acquisition and Data Quality

Results from Chapter 5 indicate that the management of biodiversity resources involved collection, processing, storage and dissemination of large amounts of special data. It also involves monitoring of change within the resource base. The study has demonstrated that GIS technology provides resource managers with a powerful tool for handling and

managing such large amounts of data. However because of inherent and processing errors in GIS, information extracted from these databases should indicate the associated uncertainty that has to be taken into account when using it as a basis for making management decisions.

10.4 Prototype Biodiversity Resource Information System

Uncertainty in digital data held in a GIS has to be explicitly stated unlike in the traditional analog data where it is implicit in the final map product. The uncertainty in these data therefore has to be quantified so as to allow decision makers to :

levels of management of biodiversity resources (see Appendix 10.1)

- set tolerance levels within which uncertainty will be accepted for making different types of decisions.
- understand the basis of their decision. It is expected that knowledge of uncertainty will lead to better decisions in the long run.
- Identify those parts of the analysis that are most uncertain and the uncertainties that are apt to adversely influence decisions; and
- identify information gaps and evaluate the need to acquire more information before decisions are made

The biodiversity resource information system developed operates in a

The study reaffirmed that aerial photographs are a major source of information on biodiversity resources. In Chapter 7, a method has been defined for quantifying and minimizing uncertainty associated with mapping land cover from aerial photographs and ground survey data. Results show that:

decision making

- The percentage cover of high woody plants species can be reliably predicted from aerial photographs.
- The percentage of low woody plant species can not be reliably predicted from aerial photographs.

issues such: information sharing, ownership, standards, data transfer

Further results from Chapter 7 show that by integrating remotely sensed data with ancillary

data in a GIS environment, it is possible to produce information on land cover of acceptable accuracy and precision to support biodiversity resources management decisions.

10.4 Prototype Biodiversity Resources Information System

During this study a prototype biodiversity resources information system has been designed and developed. Its potential to provide information to support decisions at the different levels of management of biodiversity resources has effectively been demonstrated using two case studies from the Tsavo Ecosystem (Chapter 8 and Chapter 9). The results show that the system is able to provide information to support management decisions in two key areas of biodiversity resources i.e. trends in the resource base and human/wildlife conflict. The overall objective and the specific objectives of this study have therefore been achieved.

10.5 Future Research

The biodiversity resource information system developed operates in a GIS environment. Due to the vast potential offered by GIS and models as management tools, more research into ways of linking GIS with ecosystem simulation models and models of ecological processes is needed. Emphasis should be given to incorporating spatial and temporal variability and feedback in the models, and interfacing with expert systems for real time decision making.

There is need to test and implement the prototype biodiversity information system developed in this study on the whole KWS organization. This would require the KWS to develop and implement a clear information and communication policy that would address issues such; information sharing, ownership, standards, data transfer protocol, data quality, data collection frequency, among others. There is therefore need for further

Appendix 1 Process dictionary

Process type	Process description	Input data	Output data
Aerial survey	Animal census using systematic reconnaissance flights	Topographic maps, logistic support data, security data, research methodology and management strategy	Aerial survey data
Ground survey	Collection of ground truth data	Topographic maps, logistic support data, security data, research methodology and management strategy	Ground survey data
Data classification	Preprocessing of ground truth and aerial survey data before storage in the database	KWS objectives, climatic data, ground survey data, aerial survey data, satellite images, soil maps, aerial photographs, protected area management plans and tourist data	Bio-physical and socio economic data (classified ground and aerial survey data)
Environmental impact assessment	The assessment of the impact of various management interventions and human activities on the natural ecosystems of protected areas	Land use conflict data, tourist data, animal data, land unit map and socioeconomic data	Environmental impact assessment data
Analyze remotely sensed data	Analysis of digital remotely sensed data	Remotely sensed data and topographic maps	Preliminary land unit map based on satellite image interpretation
Analyze aerial photographs	Interpretation of aerial photographs	Aerial photographs and topographic maps	Preliminary land unit map based on aerial photo interpretation
Analysis of vegetation field samples	Analysis of vegetation samples to determine plant community structure and floristic composition	Ground survey data	Vegetation structure data Plant community data
Analyze soil samples	Analyzing soil samples to determine their chemical, physical and biological properties	Topographic maps and ground survey data	Soil property data
Compile land unit map	Combine data from various sources (vegetation structure, floristic composition, preliminary land unit map, soil properties) to produce a land unit map	Preliminary land unit map (LUM) based on aerial photo interpretation, preliminary LUM based on satellite image analysis, soil property data, vegetation structure data and plant community data	Land unit map
Define conservation value of spp	Deciding the importance of a plant or animal spp. The less abundant and the narrower its distribution range, the more importance attached to its conservation	Animal data and land unit map	Conservation value and importance of spp
Classification	This is the classification of protected areas into different wildlife and protected area categories	Conservation value and importance of spp and tourist data	Classification of wildlife districts Classification of protected areas
Determine actual and potential land use conflict areas	Analyze land use/ land cover data to determine current and potential land use conflict areas	Land unit data and animal data	Land use conflict data
Define the department problem tree	Determine hierarchy of ecologic problems that require solutions	Land unit data, socio-economic data, KWS problem tree.	Department problem tree
Establishment of goals and objectives of the department	Having identified the problem hierarchy, this process sets out goals and objectives for the department	Goals and objectives of KWS, problem tree of department, list of security data and logistic support data	List of department goals and objectives
Define specific research problems	Defining specific research problems	List of department objectives and goals	Specific research problems
Develop research projects	Develop research projects	List of specific research problems	List of research activities
Implement research projects	Implementation of research projects	Research projects	Research results
Establish a management strategy	The establishment of a strategy to meet the department goals. This defines how research activities are to be administered and the reporting procedure, to ensure that set targets are met	Land conflict data, animal disease data, range condition and trend, classification of wildlife districts and classification of protected areas	Management strategy for protected areas
Analyze animal survey samples	This is the analysis of animal samples as obtained through ground surveys using the results to extrapolate for the entire animal population on factors such as feeding habits, food preferences, habitats, etc.	Ground survey data	Animal data Animal disease data
Estimate primary production	Estimate the primary production for various vegetation communities	Land unit data, climatic data and ground survey data	Primary productivity estimates
Determine stocking rates	This is to determine current stocking rates	Land unit data and animal data	Stocking rates
Determine range carrying capacity	This is to determine the range carrying capacity based on available animal and crop biomass data	Primary productivity data and animal data	Range carrying capacity
Assess range condition and trend	This is to assess the range condition and trend to determine the survival of the different ecosystems in protected areas	Range data	Range condition and trend

Appendix 2 Data types dictionary

DATA NAME	DATA DESCRIPTION	DATA TYPE	DATA VOLUME	DATA QUALITY	PROBLEMS	DATA SOURCE
Climatic data	Data on precipitation, temperature, solar radiation, humidity, & evapotranspiration.	Point data alpha-numeric	Very large as the data are collected daily	good	These data are collected by the meteorological department. There is currently no arrangement for this data to be made available to KWS on a regular basis. These data are currently acquired on a project by project basis.	Meteorological dept.
Topographic maps	Data that describes physical features and infrastructure of a protected area.	Line, Point, & area data graphic	Medium	Fair	Few of the protected areas have these maps in digital form.	Survey dept.
Aerial photographs	Large format or sample photographs taken from an aircraft	Point, line, & area data - analogue	Large	Good / Fair	Most protected areas are not a top priority for aerial photography by the survey dept and for most of them, the photographs available are more than 15 years old.	Survey Dept.
Remotely sensed data	Data on reflectance energy from the earth surface as captured by satellite (satellite imagery).	Digital format, numeric	Large	Good	The potential of remote sensing as a source of land cover data is not being fully utilized due to the lack of trained staff & equipment.	EOSAT LANDSAT NOAA
Preliminary land unit map	Land unit maps based on interpretation of satellite images or aerial photographs. These data are an intermediate product and are only stored for short periods	Point, line & area data- alpha numeric	Large	Variable	Data quality depends on the experience of the interpreters, quality of photographs and remotely sensed data, and scale.	Intermediate product
Goals & objectives of KWS	The goals and objectives of Kenya wildlife Service.	Alpha numeric	Small	Good		Directorate
List of security data	A list detailing security measures in protected areas especially regarding poaching activity & relations between wild animals & human beings	Alpha numeric	Small	Good		Security service
Tourist data	Data regarding tourist activities in various parts of different protected areas	Alpha numeric	Large	Good		Park administration & management.
KWS problem tree	This is a list of important structured problems constraining the proper management of protected areas.	Alpha numeric	Low	Good		Scientific services and planning section
Logistic support data	These are data on the resources available to enable the research department meet its objectives.	Alpha numeric	Medium	Good	Some vital equipments not currently available. These include computer hardware, software, and adequate transport.	Technical department.
Land unit data	These are data on land cover, land use, and landforms	Point, line, area Graphic & alpha numeric	Large	Good	Not all protected areas have been surveyed adequately to provide detailed landscape information.	Research & monitoring
Land use conflict data	These are data actual and potential land use conflict areas. These data are derived from analyzing land cover/ land use maps	Point, line, area graphic & Alpha numeric	Medium	Good		Research & monitoring
Research results	These are the results of studies and projects undertaken by the Research department or in collaboration with external scientists.	-do-	Medium	Good		Research & monitoring
Animal data	These are data on animal distributions, density, age structure, habitat preference, mortality, genetic structure, home range and recruitment rate.	Point, line, and area. Alpha numeric	Large	Fair-good	Data are collected by other departments or by collaborating scientist who sometimes are not very willing to share.	External organizations, research & monitoring
Conservation value and importance of wild animal species	Data on the importance of the different wildlife species in different protected areas based on their numbers, and distribution	Area, point and line	Medium	Good	This has concentrated on the large herbivores and yet one of the objective of KWS is to conserve total biodiversity.	Research & monitoring
Classification of protected areas	These are data that groups protected areas with similar qualities and characteristics together.	Area, graphic Alpha numeric	low	Good		-do-

DATA NAME	DATA DESCRIPTION	DATA TYPE	DATA VOLUME	DATA QUALITY	PROBLEMS	DATA SOURCE
Classification of wildlife districts	These are data that divides the country into different wildlife regions for management purposes	-do-	Low	Good		Research and monitoring
Research management strategy	This is a list of steps, procedures and activities to be undertaken by the department in trying to meet its goals and objectives	Alpha numeric	Low	Good		-do-
Range condition and trend	These are data on the range carrying capacity, condition trend and stocking rates in & around protected areas.	Area, graphic and alpha numeric	High	Good	Not much is currently being done on this topic due to lack of personnel.	-do-
Research department's problem tree	These are identified problems related to the sound management of protected areas that have to be addressed by the department.	Alpha numeric	Low	Good		Research & Monitoring
Department goals, objectives, and activities	These are goals and objectives of the research department and the activities to be undertaken to meet these goals & objectives including reporting procedure.	Alpha numeric	Low	Good		-do-
Aerial survey data	These are data from reconnaissance aerial surveys on large herbivore species and their habitat.	Alpha numeric	Large	Good	Not all protected areas are being surveyed at the moment	-do-
Ground survey data	These are data collected through ground surveys and includes: Social economic, soil, vegetation, Geophysical and animal data.	Point, line, area, and alpha numeric	Large	good	-do-	Research & monitoring
Soil property data	These are data on soil chemical, physical, & biological properties as obtained from ground surveys.	Point, area & alpha numeric	Large	Good	Not much data being collected at the moment	Research & Monitoring
Plant communities data	These are data on floristic composition, dominant species, indicator species, species distribution, density, sociability, vitality, frequency, desirability, nutritional value, and phenological stage, primary productivity, and standing crop biomass.	Point, line, area, alpha numeric & graphic	Large	Good	Not currently being collected in all the protected areas.	Research and monitoring
Animal disease distribution	These are data on the disease status of the different animals in and around protected areas and their control.	Point, area, alpha numeric Graphic	Large	Good	The concentration at the moment is on treating confirmed cases of injury. A survey on the prevalence of animal diseases is not being done regularly	-do-
Vegetation structure	These are data on the structure of different vegetation communities	area, alpha numeric	large	fair-good	Not currently being collected in all the protected areas. Research and monitoring	Research and monitoring
Primary productivity data	These are data on the primary productivity of different vegetation communities	area, alpha numeric	large	poor	Very little data being generated at the moment	-do-
Range stocking rate	These are data on the numbers of wildlife occupying different parts of protected areas at a given time	area, alpha numeric	large	poor	Very little data being generated at the moment	-do-
Range carrying capacity	These are Data on the number of wild animals that can be supported on a sustainable basis in different protected areas	area, numeric	large	poor	Very little data being generated at the moment	-do-
Animal disease distribution	These are data on the disease status of the different animals in and around protected areas and their control.	Point, area, alpha numeric Graphic	Large	Good		Research and monitoring
Specific research problems	These are data on problems in protected areas for which solutions are being sought.	Alpha numeric	small	fair-good	The problems of many protected areas are not very well structured.	-do-
Environmental impact assessment data	These are data on the possible impact on wildlife of various activities in protected areas.	area, point, line, alpha numeric	medium	poor	Not much analysis is being done at the moment.	-do-
Socioeconomic data	These are socioeconomic data collected in protected areas and their buffer zones.	area, alpha numeric	large	medium	Data is not being collected from all the protected areas.	Research and monitoring, other KWS departments.

Appendix 3 A Straight Line Fitted by Least-squares Regression: Parameter Estimates and ANOVA Table of Log-transformed Elephant Counts Outside the Protected Area

3a. A Straight Line Fitted by Least-squares Regression: Parameter Estimates and ANOVA Table of Log-transformed Elephant Counts Outside the Protected Area.

Variable	Coefficient	Standard error	t	P(2 tailed)
Constant	11.161	27.186	0.411	0.696
Year	-0.004	0.014	-0.291	0.781

ANOVA Table

Source	ss	d.f.	m.s.	F-Ratio	P
Regression	0.007	1	0.007	0.085	0.781
Residual	0.506	6	0.084		

$R^2_{adj} = 0.000$

3b. A Straight Line Fitted by Least-squares Regression: Parameter Estimates and ANOVA Table of Log-transformed Elephant Counts in the Whole Ecosystem.

Variable	Coefficient	Standard error	t	P(2 tailed)
Constant	42.367	12.630	3.355	0.015
Year	-0.019	0.006	-3.030	0.023

ANOVA table

Source	ss	d.f.	m.s.	F-Ratio	P
Regression	0.167	1	0.167	9.183	0.023
Residual	0.109	6	0.018		

$R^2_{adj} = 0.539$

3c. A Straight Line Fitted by Least-squares Regression: Parameter Estimates and ANOVA Table of Log-transformed Metabolic Weights for Grazers Outside Ecosystem.

Variable	Coefficient	Standard error	t	P(2 tailed)
Constant	42.411	17.539	2.418	0.052
Year	-0.021	0.009	-2.333	0.058

ANOVA table

Source	ss	d.f.	m.s.	F-Ratio	P
Regression	0.191	1	0.191	5.443	0.058
Residual	0.211	6	0.035		

$R^2_{adj} = 0.388$

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