VEGETATION AND LAND-USE DATA COLLECTION METHODS FOR ENVIRONMENTAL MANAGEMENT PURPOSES, WITH PARTICULAR REFERENCE TO THE RIVERS ENTERING FALSE BAY, CAPE, SOUTH AFRICA

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<u>Contents</u>

Summary

The increasing population and urbanization occurring in South Africa is threatening the survival of many environments, particularly those in close proximity to urban areas. Present legislation does not adequately protect the environment, and methods are needed to collect data to guide the development of conservation-orientated management and developmental policies. These data should provide a general description of the environment, indicating sensitive areas, while taking physical, socio-economic and natural features into account. To be most meaningful, these data should be stored in a survey information system which is accessible to any person or institution involved in management or developmental policy formulation. Chapter 2 describes some of the components of such a system.

Chapter 3 discusses the data collection component of the survey information system. The use of vegetation features to describe the natural environment, and the use of land-use features for the socio-economic environment, are emphasized. Numerous methods are available to collect vegetation and land-use data, but for management purposes the methods should be elementary enough to be used by non-specialilists while still supplying meaningful data.

Aerial photography can be applied to vegetation and land-use studies. However, numerous inaccuracies can occur when using aerial photography as a source of data

and Chapter 3 also discusses some of these limitations.

The study area used to test proposed methods of collecting vegetation and land-use data for a management information system are described in Chapter 4. The study area consists of eleven study sites, each at a river mouth on the False Bay coast.

The first proposal made in this thesis concerns the use of vegetation data to determine units which have similar management implications. Chapter 5 compares a structural method with a simplified floristic method of sampling the vegetation. The structural methods use growth form, height and percentage cover to distinguish vegetation units while the floristic method makes use of the cover-abundance of dominant and prominent species. It was found that the simplified floristic method supplies well-consolidated units which can be compared with more formal floristic studies in the area. The results of the structural method cannot easily be used to guide management policy formulation.

When using aerial photographs for the determination of land-use patterns, it is essential to define land-use types. This is achieved in Chapter 6 which shows that 13 land-use types can be identified from aerial photographs of the study area. In general housing, industry, recreation and alien plants have increased in this study area while open sand and natural vegetation types have decreased. However, without some correction procedure, land-use changes cannot be adequately quantified. The accurate quantification of land-use change could yield an accurate measurement of the rate of change (i.e. the amount of pressure being placed on the environment), and could be used to guide policy formulation.

A methodology for quantifying land-use changes from a temporal series of aerial photographs is described in Chapter 7. This is achieved by selecting the aerial photographs so as to systemize the major photographic inaccuracies throughout the temporal series and correcting measurements by comparison with corrected orthophotos. This methodology results in a corrected measurement of the area of each study site. It is not possible to determine the accuracy of this correction procedure, but the results appear to have an error of less than 10%.

Chapter 8 uses the data obtained in Chapter 7 to accurately determine the area of each land-use type. Each of these types is given an environmental importance factor and these data are manipulated so as to be useful in guiding management policy formulation.

The relative environmental state of each study site was determined throughout the temporal series according to the area of each land-use type. It is shown that, in general, the environmental state of each study site decreased throughout the temporal series.

The coefficient of change of each study site was determined by observing the changes in land-use patterns throughout the temporal series. The sites where the most change has taken place can be determined from these data.

The present status of each site was calculated in terms of its historical state and the amount of change that has taken place. This gives an indication of the environmental value of the site and has been called the 'conservability' of the site.

In conclusion, Chapter 9 indicates that the data obtained using these methods could be used in guide plan and management policy formulation, as well as for a data base in environmental impact assessments. These data can also be used to guide regional development planning and, with legislative support, these methods would lead to the maintenance of much of the natural environment.

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Chapter 1. Introduction

Natural resource management and the utilization of the environment by man, progresses through a number of stages as the population increases and as technological ability improves (Myers and Shelton, 1980). Initially, local resources are exploited without concern for the environment (as in a hunter/gatherer society). Thereafter, extensive areas are managed in a rudimentary manner, utilizing the results of natural processes (e.g. game farming, fisheries or natural harvesting). As the resources become scarce relative to population size, successively smaller units are managed for increased production e.g. intensive agriculture. The environmental value of a resource, particularly a non-economic resource, is often not perceived until exploitation becomes limited by the lack or degraded quality of the resource. At this stage management policies are often forced to become conservation orientated.

Conservation orientated management policies vary in emphasis from preservation where man is excluded (Margalef, 1968), to the maintenance of ecologically viable systems (Macfayden, 1963) where the emphasis is placed on man as a user (Cragg, 1968; Fisher, 1969; Usher, 1973). It is unlikely that any ecosystems exist today that are not affected by man. The utilization pressure placed on these ecosystems by man is increasing with the rapidly increasing human population.

Conservation should, therefore, be concerned with the interaction between man and the natural environment (Usher, 1973) and the major aim of environmental management should be to maintain the quality of the environment, and thus human life.

Management policies often achieve this aim by attempting to change the environmental status quo in a desired direction, or attempting to prevent the status quo from changing in an undesirable direction (Usher, 1973). Large data bases are usually required to formulate such a policy. For example, the conservation of botanical resources is often concerned with the preservation of rare or endangered species. This can only be achieved if the optimum conditions for the species' survival, the reproductive biology of the species and the reasons for the species' scarcity are known. If these factors are not readily available, intensive research and survey programs must be instituted to collect the necessary data.

When one manages more complex systems (e.g. ecosystems or human/environmental interrelationships), the data base required for effective management becomes more complex. However, much of the natural environment could be maintained if conservation orientated management is instituted before the environment has become severely degraded.

1.1 The South African Situation

The total South African population has increased from approximately 5×10^6 (1904) to 16×10^6 (1960) and from 21×10^6 (1970) to 24×10^6 (1980, excluding Venda and Transkei). The percentage urban population has increased from 23,4% (1904) to 46,7% (1960) and from 47,8% (1970) to 53,2% (1980, excluding Venda and Transkei) (Central Statistical Services, 1982). It is not known if these statistics accurately reflect the situation in terms of black homelands, townships and 'non-registered' migrants. However, the total population is increasing and much urbanization is taking place.

At present, large areas of undisturbed vegetation exist in close proximity to urban areas. For example, the Western Cape region is one of the most densly populated areas in the country (Central Statistical Services, 1982). Zietsman (1982), however, has shown that approximately 50% of 3×10^5 km^2 of the south-western Cape consists of natural vegetation. Admittedly, much of this area is mountainous, but unless timely management policies are implemented, increasingly large tracts of natural environment are likely to be destroyed by human demand on natural resources.

South African environmental legislation is contained in a variety of parliamentary acts, provincial ordinances, local by-laws and ministerial regulations (Rabie and Erasmus, 1983). This division of legislation has led to much confusion and inefficiency in the implementation and enforcement of environmental legislation (Malan *et al*., 1983).

The Physical Planning Act 88 of 1967 is the most important single piece of legislation dealing with land-use planning and control in South Africa (Page and Rabie, 1983). In general, this Act allows for the establishment of controlled areas, without these areas being linked to any purpose or subject; commonly called 'zoning'. However, the provisions pertaining to guide plans contained in this Act are potentially the most important from the environmental perspective (Page and Rabie, 1983) and are discussed below.

1.2 Guide Plans

The minister of Constitutional Development and Planning, after consultation with the minister of Agriculture and the Provincial Administrator, may call for a committee to be established whose task it will be to compile a guide plan for a particular area. After this guide plan has been accepted by notice in the Government Gazette, it lays down guidlines for the future spatial development of the area by defining the purpose, or purposes, for which the land may be used. It restricts the amendment or introduction of a town planning scheme which, in the opinion of the Provincial Administrator, is not in accordance with the aims of the guide plan. It also restricts the use of land for any purpose other than that for which it has been zoned in terms of a town-planning scheme. The minister of Constitutional

Development and Planning may, by notice in the Government Gazette, amend or withdraw the guide plan on advice from the Provincial Administrator.

This Act is administered by a department whose objective is regional planning rather than environmental conservation, and thus strong environmental emphasis in a guide plan is not ensured. However, the importance of guide plans can be appreciated if one realizes that there is no single law that specifically protects the environment as a whole. Furthermore, there is no legal requirement that environmental matters be considered in the formulation of development plans and policies (Fuggle, 1983).

A guide plan ultimately determines land-use planning and development. To be environmentally sympathetic, it must take cognizance of local physical, socio-economic and natural environments.

1.2.1 The Physical Environment : the physical environment places numerous restrictions on development. If parameters such as climate, rainfall, topography, land-form, flood levels, etc are not readily available from the published sources or from various government departments, they must be collected and taken into account when developing a guide plan.

1.2.2 The Socio-economic Environment : socio-economic parameters, such as land-use patterns, value of existing developments, income per capita, distribution of population groups, etc are available from maps (e.g. Van der Merwe and Zietsman, 1977; Zietsman and Van der Merwe, 1981; Zietsman, 1982) or from census statistics (e.g. Central Statistical Services, 1982). These data concern the nature of the local population and their needs and should be included in a guide plan. However, the above sources of data are often of a relatively large scale and more detailed information concerning the spatial distribution of socio-economic parameters is required for value judgements concerning the environment.

1.2.3 The Natural Environment : parameters concerning the natural environment are necessary to determine conservation-worthy areas, to give an indication of the environmental consequences of different types of development and to indicate the type of management required to maintain natural resources. The inclusion of these data allows for environmentally judicious policy formulation which would play an important role in maintaining the environment.

The remainder of this thesis is concerned with establishing techniques for collecting natural and socio-economic environmental data. Ideally, these data should be available to all concerned with the establishment of management or developmental policies. However, due to the fragmentary nature of environmental legislation and administration in this country, this ideal can only be achieved by establishing a well-developed survey information system.

Chapter 2. Developing a Survey Information System

The data required for the formulation of guide plans and management policies concern quantities and conditions of various components of the physical, socio-economic and natural environments. If these data form part of a well-developed survey information system, they could also be used as a foundation for conservation policies, monitoring studies and impact assessments (Jenkins, 1978).

A survey information system consists of a number of components, each placing restrictions and requirements on the system (Myers and Shelton, 1980).

2.1 The User Component

An information system should be designed for the user. The system must supply information required by the user in a form that is accessible and intelligible to the user. The user must be aware of the capabilities of the system and the system must be viable to the user in terms of cost.

2.2 Data Storage, Retrieval and Display Components

Methods of data storage are determined by the type and amount of data, and the facilities available to the user. Small amounts of data might be processed and stored using relatively inexpensive and simple devices such as typewriters and calculators. However, large data bases require more sophisticated equipment, i.e. computers.

Data can be in the form of statistical summaries or maps showing the spatial distribution of environmental parameters. Data display is determined by the needs of the user. Tables, graphs and maps are most easily interpretible (Myers and Shelton, 1980) and data should be stored in this format.

2.3 Data Collection Component

This component determines the information content of the data. A fine balance needs to be struck between the quality and quantity of data required, and the cost per unit of information. Poor data are confusing and detrimental to the planning process, while the collection of excessive data might be prohibitively expensive in both time and money.

Data can be obtained from a number of sources. The most economical would be to use existing data banks. Remote sensing is a relatively inexpensive source of spatial data while field observations tend to be most expensive (Myers and Shelton, 1980).

2.4 Other Components

A well designed information system should also allow for updating, maintenance and administration of the system. Socio-economic (Section 1.2.2) and environmental data (Sections 1.2.1 and 1.2.3), especially in close proximity to developed areas, are likely to become rapidly outdated. Also, to be most meaningful, the consequences of management policies should be fed back into the information system.

A need for administration might become established as the data base enlarges, especially if there is a wide variety of users and data collectors. The essential part of the administration component concerns the personnel required to maintain and manipulate the system. This type of administrative body does not exist at present. The execution of the Physical Planning Act 88 of 1969 is vested in a number of government departments (Page and Rabie, 1983) and the information system should be available to all of these departments as well as local government and private developers. If the establishment of this type of information system is to result in conservation orientated management and planning, it is suggested that the system should be administered by the Department of Environment Affairs.

Chapter 3. Details of the Survey Information System

The most important components determining the characteristics of a survey information system are the user and data collection components. These two components are interrelated and, before a methodology for data collection is established, restrictions imposed by the user must be determined.

3.1 The User

The potential user of this type of system includes any person or body involved with management or development policy formulation i.e. private individuals, local government and central government. Each of these users vary in the amount of time, money and facilities available, as well as the purpose for which the data are required. As such, the system needs to supply meaningful data which are useful to a number of disciplines for a variety of purposes.

3.2 Data Collection

The survey information system must supply an elementary classification of the environment so as to facilitate managerial decisions. Numerous classification systems have been developed, particularly in the United States of America and Canada, which might be used for this purpose (Marmelstein, 1977; Ellis et al., 1977). These classification systems are usually based on human needs (e.g. Bauman, 1977) or on different aspects of the environment (Radford, 1977) i.e. the socio-economic environment or the natural/physical environment. Both the socio-economic and the natural/physical environments are highly complex and, for management purposes, these classification systems are often unwieldy and impractical. For this reason, many user-orientated classification systems are based on one or a few environmental characteristics (e.g. soil, vegetation, land-use, habitat, etc). Although many characteristics of an environment are interrelated (e.g. edaphic factors would affect water retention characteristics of the soil and thus run-off), these relationships are often not well-understood and such a classification system is often too specialized for a management information system.

Furthermore, the majority of these classification systems are aimed at establishing an inventory of habitat types. These data are most easily portrayed as directories or maps (Radford, 1977; Hodgkins and Cannon, 1977; Demarchi and Chamberlain, 1977). Very few of these systems supply values which can be used for comparative purposes. Although cost-benefit analyses might be used to obtain such values (Sassone and Schaffer, 1978), these analyses are often complex and not suited to all applications (Batie and Shabman, 1982).

Many of these classification systems also require specialist knowledge to make value judgements concerning aspects of the environment. For example, Clark (1977) suggests a classification system of coastal environments which uses terms such as 'hazard areas', 'valuable resources', 'areas of concern' and 'vital areas'. The use of these characteristics necessitate subjective decisions concerning the environment and valued judgements can only be made after much deliberation by ecological specialists.

Although data might be collected by a specialized survey team, it is more feasible and efficient for the data to be collected by the prospective users, especially private institutions and local authorities (Emanual and Page, 1969). Data collection techniques must, therefore, be elementary enough to be used by non-specialized persons and must be applicable to a wide variety of habitats. These techniques should classify the environment, indicate sensitive and conservation-worthy areas and give some indication of management procedures. To achive this, attention is focussed on vegetation and land-use charactoristics to classify the natural and socio-economic environments respectively.

3.2.1 Vegetation Characteristics : vegetation characteristics should play an important role in the classification of environments or habitats (Ellis et al., 1977).

Fosberg (1967) maintains that information for vegetation sampling might be selected from the following sources :

Physiognomy	:	external appearance of the vegetation.
Structure	:	spatial arrangement of the vegetation.
Function	:	adaptations of the vegetation to the environment.
Composition	:	floristic composition.
Dynamics	:	successional status.
Habitat	:	environmental relationships.
History	:	changes which have taken place.

Earlier attempts at vegetation classification (Tansley, 1920; Braun-Blanquet, 1928; Clements, 1928) used only one of the above information sources, thus producing classification systems which might not be ecologically sound.

Many classification systems have been developed using the first three information sources mentioned above (Fosberg, 1967; Ellenberg and Mueller-Dombois, 1973; Beard, 1978; Barkman, 1979; Edwards, 1982). A physiognomic/structural/functional classification system is particularly useful for managerial purposes as the vegetation can be classified rapidly and detailed knowledge of the species composition is not necessary. However, a major drawback of any _a priori_ classification system is that it is subjective (Johnstone, 1968), often not applicable to a variety of study areas (Fuggle, 1983) and might not contain all possible classes (Robinove, 1981) of vegetation. It is also artificial and prone to a high degree of misclassification (Linder and Campbell, 1979).

This is well illustrated by Goldsmith (1974) who assessed two classification systems, based on vegetation structure, which have been recommended by the International Biological Programme (IBP) and the United Nations Educational, Scientific and Cultural Organization (UNESCO) (Peterken, 1967 and Ellenberg and Mueller-Dombois, 1967 respectively).

The UNESCO system was designed to classify vegetation at the scale of 1 : 1 000 000 and makes use of habitat criteria. This might be theoretically disadvantageous as these types of data are not directly concerned with the vegetation, but include factors such as rainfall and temperature. The IBP system provides a classification to the smallest units distinguishable using structural data. However, Goldsmith found that some of the definitions encountered in this system were somewhat vague and necessitated subjective decisions being made concerning the vegetation. Furthermore, some of the vegetation types found in his study area could not be defined by this system. For these reasons, Goldsmith (1974) concluded that neither of these systems are ideally suited to the classification of vegetation for conservation purposes.

Many physiognomic/structural/functional classification systems have been proposed in an attempt to circumvent some of these disadvantages (Beard, 1955; Boughey, 1957;

Baur, 1968; Webb, 1968; Specht, 1979; Campbell *et al*., 1981). Unfortunately, these systems are usually established for specific vegetation types and, therefore, frequently cannot be used in vegetation types for which they were not defined. For example, Morant (1981) reviewed 21 wetland classification systems developed between 1953 and 1981. Of these, Cowardin *et al*. (1979) was an attempt to produce a hierarchical classification of wetland habitat types which was to be used to classify wetlands throughout the United States of America for any purpose. Not only is this system complicated, but some adaptation of the system is necessary to suit South African conditions (Morant, 1981).

A rapid survey technique which will supply comparable data from a wide variety of habitats is necessary to serve as a basis for a management information system. It is evident that an *a priori* classification system would not be appropriate for this application. Although an *a posteriori* approach would be superior, it requires much data and computer-based techniques (Linder and Campbell, 1979), especially if the vegetation is to be classified according to structure (Campbell, 1985). Chapter 5 describes a floristic classification technique suitable for this application.

3.2.2 Land-use Characteristics : land-use data can be easily used to guide management policy formulation and implementation (Coppock, 1970). Furthermore, identifying and monitoring land-use changes is basic to resource management (Henderson, 1980) and changes can be used to determine socio-economic pressures (Rind and Hudson, 1980).

The determination of land-use characteristics is most easily accomplished from aerial photographs (McConnell and Archey, 1969; Nunnally, 1974; Stone, 1974; Baker, et al. 1979) and these data are most easily portrayed by means of maps (Fuggle, 1983).

Land-use areas can be measured in a variety of ways which fall into two broad categories : firstly, by using a grid system; secondly, by measuring directly from the map or aerial photograph.

The first of these involves placing a grid system over the defined study area on the land-use map or aerial photograph. The number of grids are determined for each land-use unit, thus calculating the area of each unit.

Although the use of a grid system to determine areas is objective (Ward and Storm, 1983), this method has disadvantages. The optimum grid size often depends on the terrain under study (Henderson, 1980) and, as a managerial information system would contain data from a number of terrain types, difficulties could arise in the selection of an optimum grid size. Possibly, this could be circumvented by defining the grid size for each terrain type. However, this leads to further problems: compromises which depend on the scale of the land-use map or aerial photograph and the size and placement of the grid have to be made. If a variety of grid sizes are used, a non-systematic error would be introduced into the data. If the terrain under study consists of a number of small land-use units, these errors could detract from the accuracy of measurement.

A number of methods can be used to measure areas directly from land-use maps or aerial photographs. Weighing the mapped area to be measured and comparing it with the unit weight of the mapping material produces the least variable results. A sensitive chemical balance can measure mass in milligrams or smaller units, thus producing relatively accurate results. However, this method is not feasible if numerous, small, intricately bound land-use units are to be measured. An easier, though less accurate method, is to use a computerized digitizer of which many makes and models are available.

For this study, a Kontron MOP AM 02 digitizer in the enclosed area mode was used. Twenty replicate measurements of a quadrangular figure with an area of 2550,7 mm^2 yielded a mean area of 2530,5 mm^2 with a range of 76,3 mm^2 ($\pm$ 1,5%). When this process was repeated for an irregular figure of 625,0 mm^2, an average of 625,07 mm^2 and a range of 25,9 mm^2 was obtained ($\pm$ 2%). It would seem that this digitizer measures regular figures more accurately than irregular figures. However, when a t-test for a specified value of the mean (Chakravarti et al.,1967) was applied, the difference between the mean and the known value was found to be significant at the 99% level for the regular figure. The same test for the irregular figure yielded a t = 0,0545 which is not significant, even at the 20% level (for a 2-tailed test, see Pearson and Hartley, 1970). The design of this digitizer is such that it measures irregular figures more accurately than regular figures and it would seem that measurements of irregular areas are reasonably accurate.

Accurate land-use data can be manipulated in a number of ways depending on the user's needs. Chapter 7 describes a method for collecting these data while Chapter 8 shows some manipulations which might be useful for the formulation of conservation-orientated management policies.

3.2.3 The Use of Aerial Photographs : aerial photography is a convenient form of remote sensing which is applicable to land-use and vegetation studies in a number of ways (McConnell and Archey, 1969; Edwards, 1972; Nunnally, 1974; Stone, 1974; Lintz and Simonett, 1976; Jarman et al., 1983;). Numerous photographic types (e.g. black and white, infra-red, false colour) and scales are available (Jarman et al., 1981). The prime aim of using aerial photographs is to simplify the environmental components into manageable categories and to indicate environmental relationships, thus allowing extrapolation and prediction. For this, the semi-detailed to detailed scale of photography (1:500 to 1:50 000) is most useful

(Jarman *et al.*, 1983). Furthermore, orthophotographic maps are available in the scale of 1:10 000. These maps have been corrected and can thus be used as a reference against which other maps and aerial photographs can be calibrated. This, together with the availability in South Africa of aerial photographic material, makes the use of the 1:10 000 scale most convenient for local and regional use.

The use of aerial photographs has a number of advantages over field methods of data collection (Rind and Hudson, 1980). Firstly, by using similar techniques, methods of data collection are consistent and comparable. Secondly, these data are available for most areas and remote sensing is a rapid survey method for large areas. Thirdly, a small number of skilled workers are required during the data collection phase and a high degree of expertise is not necessary for interpretation.

Data obtained from aerial photographs may, however, contain numerous inaccuracies. These fall into three broad categories :

Scale errors
Intrinsic interpretive errors
Extrinsic interpretive errors.

3.2.3.1 Scale Errors : although the recognition of land-use and vegetation units is facilitated by using larger scale photographs, the accuracy of interpretation becomes more critical as the working scale increases. At the scale of 1:10 000, an interpretive error of 1 cm would mean an error of 100 m in real terms. Much of this error could be corrected by using complicated and/or expensive means to verify interpretation. However, managerial interpreters seldom have the expertise or financial resources to carry out these verifications.

Furthermore, information is scale dependent (Lintz and Simonett, 1976) - the smaller the scale, the less detail is discernible. Consistency in interpretation is also inversly related to the measured size of the unit (Lintz and Simonett, 1976).

3.2.3.2 Intrinsic Interpretive Errors

These errors are inherent primarily in the equipment used for recording data. The inaccuracies could be as a result of :

Height Distortion : since aerial photographs are two-dimensional depictions of three-dimensional objects, variations in the third dimension (i.e. height) will result in distortion. This distortion is proportional to the distance of the image from the centre of the photograph and to the ratio of the height of the object to the flying height. Hart (1940) applied the following formula to determine the height distortion on aerial photographs :

$$D = \frac{Ch}{H}$$

(D = horizontal displacement due to height distortion (cm); C = distance from the centre of the photograph (cm); h = height of the object (cm); H = flying height (cm)).

For example, on an aerial photograph taken from a flying height of 300 m, an object 90 m high will be displaced by 3,0 cm away from the centre, at 10 cm from the centre of the photograph.

It might be possible to correct measurements taken from aerial photographs by using a formula of this kind. However, this would be a complex task if the study was being carried out in areas with a variable topography using different scales of photography and a less complex method to correct these distortions is required.

Tilt Distortion : these inaccuracies occur when the aircraft does not fly 'straight and level' i.e. parallel to the ground. The following formula can be used to determine the tilt displacement on an aerial photograph (Wong, 1980) :

$$td = \frac{(y)^2}{(f/\sin t) - y}$$

(td = displacement due to aircraft tilt (cm); f = focal length of the camera lens (cm) t = angle of aircraft tilt; y = distance of image from the isocentre of the photograph (cm)).

For example, on an aerial photograph taken from a flying height of 300 m using a lens with a focal length of 127 mm (5 inches), an object 90 m high will be displaced by 1,58 cm away from the centre of the photograph, at 10 cm from the isocentre and a tilt of 10^{o}. However, an experienced pilot is able to reduce the tilt to 2^{o} (0,28 cm displacement at 10 cm from the isocentre) and the use of an autopilot can reduce the tilt to less than $0,2^{o}$ (0,03 cm displacement at 10 cm from the isocentre).

Distortions by the Camera Lens : distortions due to the camera lens are most often either barrel- or pin-cushion-shaped, i.e. the image at the edge of the photograph is either compacted or spread out. Modern lenses, however, reduce this type of distortion to the scale of micrometres (Baker, 1980), thus having a minor effect on the performance of photogrammetric systems.

Distortions During the Recording and/or Printing of the Image on Film : these distortions may be due to a number of factors, such as the use of different emulsion types, changes in temperature and/or humidity during photography, changes occurring during processing, non-uniform shrinkage with age, etc. McKinney (1980) lists a number of these these factors and shows that, for a number of films commonly used for photogrammetry, distortions due to these factors range from 0,002% to 0,12% and Welch (1975) maintains that these factors are more likely to affect the quality of photography than is lens distortion. Although the effect of many of these factors is reduced by modern photogrammetric systems, these factors may affect temporal photographic studies.

3.2.3.3 Extrinsic Interpretive Errors : these errors are not directly concerned with the photographic procedure but could affect the results of photographic interpretation.

Inadequate Interpreter Experience : the interpreter must be familiar with the units, or at least the recorded relative spectral qualities of each unit. However, the ability to recognize these relative spectral qualities might vary between interpreters. Kelch and Hendriks (1982), used different interpreters to analyse 16 different wetland vegetation types from a temporal series of photographs and showed an 83% to 96% similarity in interpretation. This includes differences in photo-interpretive opinion, and Kelch and Hendriks

(1982) found that discrepancies of this order were acceptable.

Inadequate Ground-truthing : the purpose of aerial photographic interpretation is to describe surface phenomena. Any photographic interpretation must be verified to ascertain the degree of correspondence between the interpretation and the actual state. Many authors have approached the problem of testing the accuracy of photographic interpretation for land-use mapping (Hord and Broomer, 1976; Van Genderen and Lock, 1976; Zeimetz et al., 1976; Ginevan, 1979; Frazier and Shovic, 1980). The methods used to validate map accuracy usually involve relatively complex statistical theory and require costly equipment and/or time. Many of these methods are usually not available to, or feasible for, environmental managers.

Inadequate Interpreter Accuracy : the accuracy of the interpreter in the designation of land-use units and the measurement of their areas will influence the accuracy of the final result.

Many errors can occur when using aerial photographs to determine environmental data. Amongst these, the largest error are the result of height and tilt distortion. Ideally, the methodology for collecting data for an information system would take these errors into account. However, the extrinsic interpretive errors are a function of the accuracy of the data collector and the users should be informed of these limitations.

Chapter 4. Study Area

False Bay (Cape, South Africa) is a large square-shaped bay with open access to the sea (Figure 4.1). The eastern and western sides of the bay are bound by the Hottentots Holland and Peninsula mountain ranges respectively and the northern shore is formed by the low sandy Cape Flats. The coastline, from Cape Point to Cape Hangklip, is approximately 121,5 km long.

The prevailing winds are southerly in the summer and north-westerly in the winter (Keen, 1980, Figure 4.1). Rainfall occurs in winter and is mainly cyclonic i.e. due to north-westerly cold fronts, but marked orographic variation occurs (Heydorn and Tinley, 1980). The variation is from 500 mm on the Cape Flats (Ninham Shand, 1979) to over 900 mm in the mountainous areas adjacent to the coast (Heinecken et al., 1982).

The natural vegetation consists of mountain fynbos communities on sandstone-derived soils, particularly on the western and eastern sides of the bay. The Cape Flats consist predominantly of calcareous sand which supports strandveld vegetation (Taylor, 1980).

Many factors affect the bay, some of which were discussed at a seminar entitled 'The Future Management of False Bay' (Gasson, 1980). Pressures are being placed on the False Bay environment in the form of utilization by an ever increasing local population for recreation, residence and industry; and by encroaching

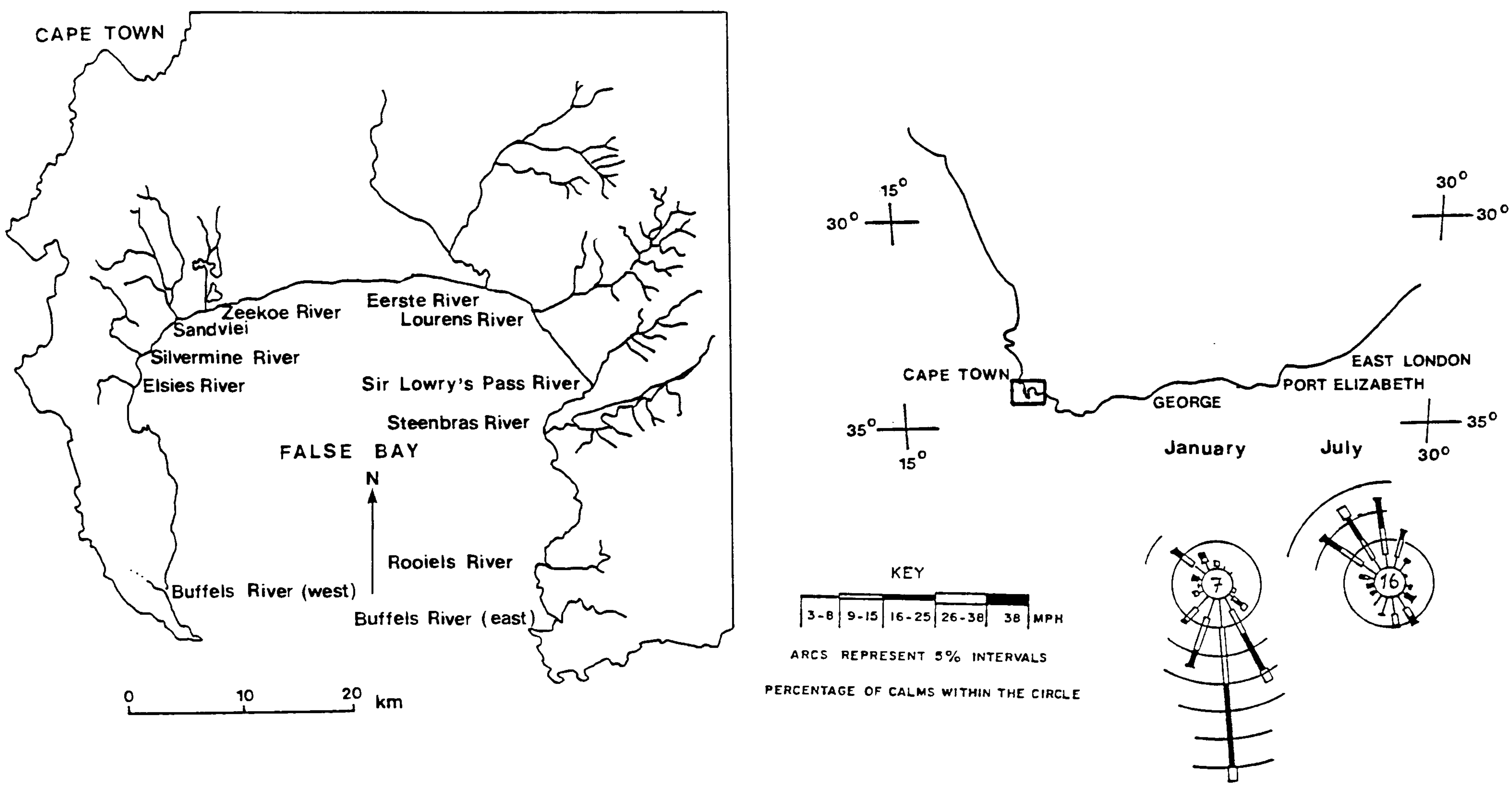


FIG. 4.1 The location of the rivers entering False Bay and wind roses for Cape Town (from Schulze, 1965).

alien plants, especially Australian acacias. As such, there is need for well-planned management policies. However, available data are not sufficient for a complete understanding of the diversity and functioning of the False Bay environment. The formulation of well-planned management policies for this bay is limited by the absence of adequate environmental data (Gasson, 1980).

The 1:50 000 topographic maps (3418 AB, AD, BA, BB and BD; Appendix 4.1) of the area show eleven rivers entering False Bay. These are, from west to east (see Figure 4.1) :

1. Buffels (west)
2. Elsies
3. Silvermine
4. Sandvlei
5. Zeekoe
6. Eerste
7. Lourens
8. Sir Lowry's Pass
9. Steenbras
10. Rooiels
11. Buffels (east)

Although a number of these rivers do not form true estuaries (Pritchard, 1967), the lower parts of all of these rivers are subject to pressures commonly placed on estuaries, particularly residential, recreational and industrial development (Wiley, 1978; Kennedy, 1980).

Much information concerning these rivers has been summarized by the Estuarine and Coastal Research Unit of the National Research Institute for Oceanology (CSIR) (Bickerton, 1982; Cliff and Grindley, 1982; Grindley, 1982; Heinecken, 1982a; 1982b; Heinecken et al., 1982; Morant and Grindley, 1982). However, very little comparative scientific work has been carried out and the data required to classify these estuaries are not available.

For example, Begg (1984) used relatively elementary methods to collect data for 62 of the smaller estuaries on the Natal south coast. These estuaries were classified according to the presence or absence of animal species, particularly marine and fresh water fish, prawns and crabs. Ordination of these data classified the estuaries along gradients related to the condition of the mouth (permanently open to permanently closed) and salinity (fresh to stenohaline) (Begg, 1984).

This classification system may be invaluable for estuarine management as the biota of the estuary could be maintained by manipulating the condition of the mouth and thereby the salinity of the water, depending on fresh water input into the estuary. However, even if the relevant data were available for the False Bay estuaries, the ordination technique would not be suitable for the classification of estuaries in a management survey information system. Not only are computer techniques required, but the socio-economic environment is not considered in this classification method. Developments in the immediate coastal environs as well as in the catchment affect estuarine functioning (McLusky, 1981). It is unlikely that any of the rivers entering False Bay still function in a manner that has not been altered by human developments. Although such developments might affect the biota of the estuary, the effects are complex and concern factors such as chemical pollution, organic pollution, increased run-off, denudation of surrounding vegetation, the effects of alien plants, specific disturbances of the environment caused by residential, industrial and recreational developments, etc. The effects of many of these factors are not fully understood and the correlation of socio-economic gradients to the ordination of faunal data would be impossible.

The coastal environs adjacent to, and including each river mouth were selected as study sites. Each river mouth thus comprised a study site and each site is referred to by the name of the river as listed above. For vegetation studies (Chapter 5) and the determination of land-use types (Chapter 6), the area of the individual sites varied to include various vegetation and land-use types. However, for the determination of areas (Chapters 6, 7 and 8), the width of each study site was approximately 500 m (250 m on either side of the middle of the river mouth) and extended one kilometre inland from the shore.

Chapter 5. Sampling the Vegetation

5.1 Introduction

Structural and physiognomic classification systems have been used in Australia for a number of years (Webb, 1959; 1968). They have been used for classifying wildlife habitats (Webb *et al.*, 1973) and for determining site potentials (Webb *et al.*, 1980). Most of this work has been carried out in woodland and forest vegetation types which are particularly suited to structural classification (Shimwell, 1971).

However, Webb *et al.* (1984), are of the opinion that floristic classification does have advantages over structural classification in some cases. The method proposed by Webb *et al.* (1984) only supplies a presence/absence list of species for each study site and this system would require an *a priori* knowledge of the vegetation ecology if it was to be used for management policy formulation.

For the establishment of an information system, a method of surveying the vegetation is required which is both rapid and easy to apply, while remaining ecologically meaningful. The methodology must be applicable to various habitat types and should not require subjective decisions concerning the data. It must indicate well-defined vegetation (or managerial) units at the local, regional, provincial or national level and must be aimed at the establishment of units peculiar to each study area.

An *a priori* approach is rigid and may not cover all possible variations in any particular study area. A structural system (Section 3.2.1) is suited to classification at larger scales (Fosberg, 1967) and might not indicate units at all the required levels of study. Therefore, to satisfy all the requirements of a managerial information system, the methodology must be of an *a posteriori* type and must concern the floristic composition of the study area.

Several methods for the floristic sampling of vegetation are available (Mueller-Dombois and Ellenberg, 1974). However, the phytosociological methodology has become increasingly popular and refined, particularly by the European school. This methodology has influenced vegetation classification throughout the world and is, at present, practically the only methodology being used for vegetation classification by government institutions in South Africa.

One of the major advantages of this methodology is that it is highly adaptable and can be applied to most vegetation types. It involves the placement of plots (relevês) of a statistically viable size and number in each vegetation type. A species list, together with a cover-abundance value for each species, is prepared for each relevé. These lists are processed using synthesis tables where the species common to a number of relevés are identified and emphasized. Floristic units are thus recognized by diagnostic and dominant species.

The ideal information system should contain a complete floristic list of the areas studied. However, this is not feasible if the data are to be collected and used by non-specialized persons. This system, therefore, needs to be adapted and simplified for use by environmental managers.

5.2 Methods

Physiographic/physiognomic units were demarcated from colour aerial photographs of 1979 (Job 326/79, Appendix 5.1) for ech of the eleven study sites (Chapter 4). The area of the study sites varied to include aquatic, littoral and terrestrial units (see Chapter 4).

The vegetation was sampled during 1980 and 1981. Relevês were not used to sample the vegetation and each unit was regarded as an open-ended plot i.e. a plot which is not artificially bound but consists of the entire physiographic/physiognomic unit. The dominant and prominent species were recorded for each unit, together with a Braun-Blanquet cover-abundance value (Braun-Blanquet, 1965) for each recorded species. Where necessary, physiographic/physiognomic units were combined or further divided to attain some degree of uniformity in the vegetation of each open-ended plot or vegetation unit.

These vegetation units were classified structurally using a combination of the systems proposed by Campbell *et al*. (1981) and Edwards (1982), with some adaptation (see Table 5.1).

The floristic data were sorted by tabulation into communities using the TABSORT suite of computer programs (Boucher, 1977). However, the use of a computer is not essential as these data could be sorted manually (Mueller-Dombois and Ellenberg, 1974).

5.3 Results and Discussion

Figures 5.1 to 5.11 show the spatial distribution of vegetation units identified at each of the study sites. Note that these figures, prepared by the author, were originally included in the botanical section of the various publications by the Estuarine and Coastal Research Unit (NRIO, CSIR). The name of each vegetation unit was selected for the sake of convenience only, usually according to the two most dominant species in the unit. Table 5.2 shows the structural demarcation of each vegetation unit. Appendix 5.2 is a complete list of species grouped according to their similarity in distribution amongst the vegetation units. Appendix 5.3 is an abbreviated version of Appendix 5.2 and also shows some habitat criteria for each vegetation unit.

5.3.1 Structural Classification

As shown by Appendix 5.2, alien shrubs and grasses were found throughout most of the emergent wetland and

Table 5.1. Structural classification system (adapted from Campbell *et al.* 1981 and Edwards, 1983). Cyperoid, gramminoid and herbaceous varieties of these classes may be distinguished on the basis of floristics

Growth Form	Height Class	Cover Class 100% - 75%	75% - 50%	50% - 25%	25% - 0%
Shrubs >2,00 m	tall shrubland	closed tall shrubland	mid-dense tall shrubland	open tall shrubland	sparse tall shrubland
1,00 - 2,00 m	mid-high shrubland	closed mid-high shrubland	mid-dense mid-high shrubland	open mid-high shrubland	sparse mid-high shrubland
0,25 - 1,00 m	low shrubland	closed low shrubland	mid-dense low shrubland	open low shrubland	sparse low shrubland
0 - 0,25 m	dwarf shrubland	closed dwarf shrubland	mid-dense dwarf shrubland	open dwarf shrubland	sparse dwarf shrubland
Herbs >0,50m	tall herbland	closed tall herbland	mid-dense tall herbland	open tall herbland	sparse tall herbland
0,25 - 0,50m	mid-high herbland	closed mid-high herbland	mid-dense mid-high herbland	open mid-high herbland	sparse mid-high herbland
0 - 0,25m	low herbland	closed low herbland	mid-dense low herbland	open low herbland	sparse low herbland
Grasses >1,00m	tall grassland	closed tall grassland	mid-dense tall grassland	open tall grassland	sparse tall grassland
<1,00m	low grassland	closed low grassland	mid-dense low grassland	open low grassland	sparse low grassland
Sedges >0,75m	tall sedgeland	closed tall sedgeland	mid-dense tall sedgeland	open tall sedgeland	sparse tall sedgeland
<0,75m	low sedgeland	closed low sedgeland	mid-dense low sedgeland	open low sedgeland	sparse low sedgeland

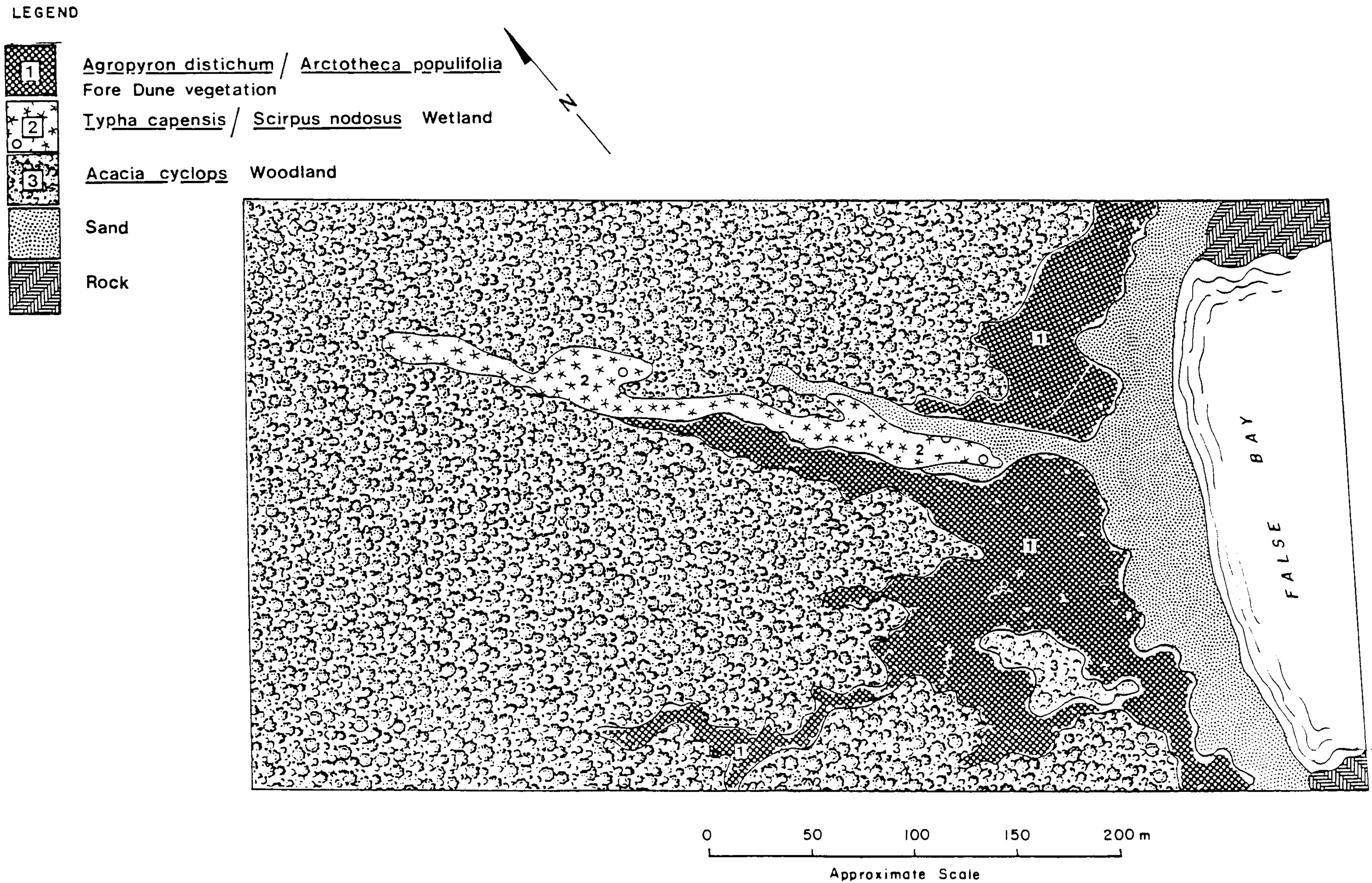


FIG. 5.1 Spatial distribution of the vegetation units identified at the **Buffels (west) River** (After Heinecken *et al*. 1982).

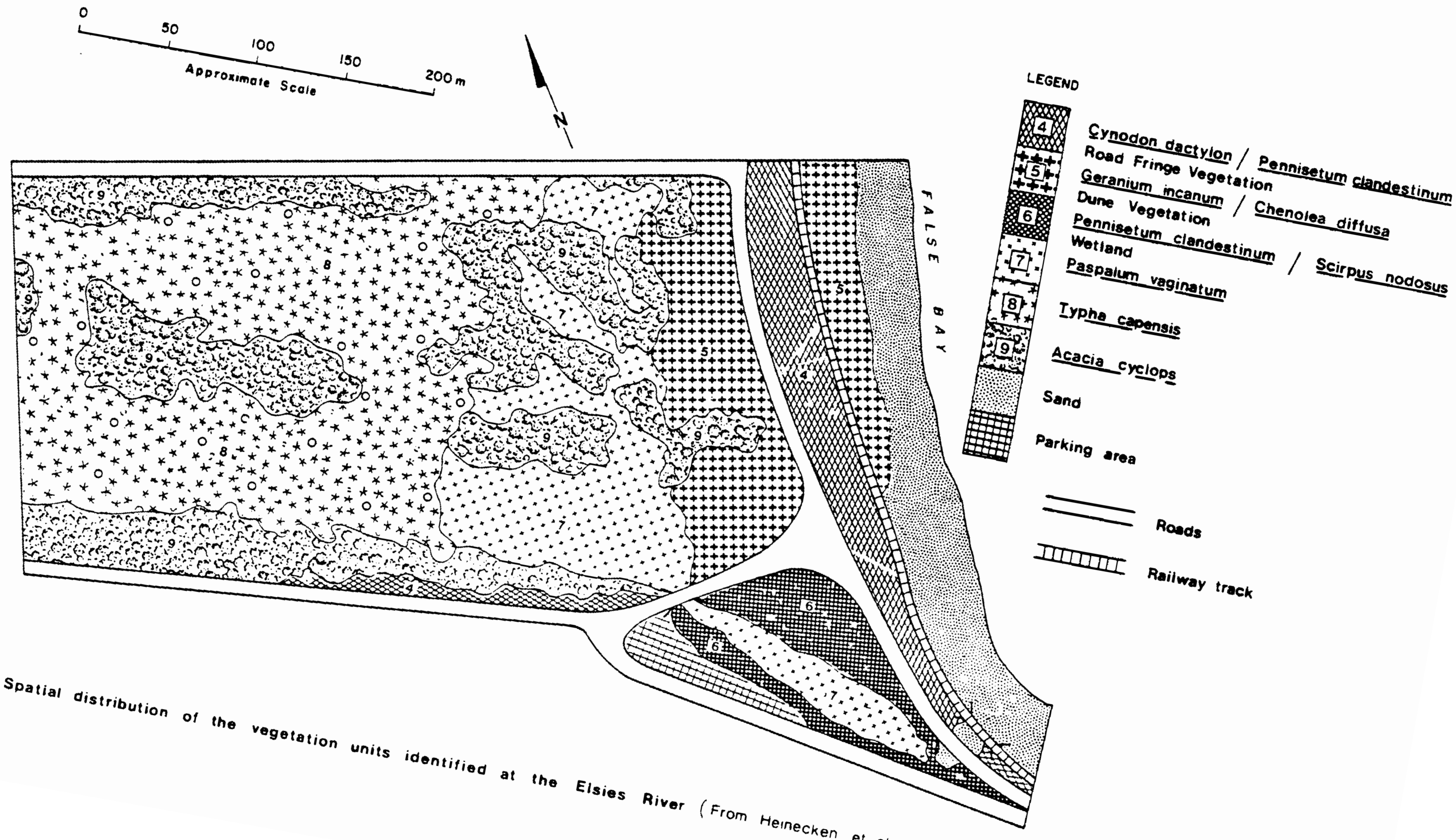


FIG. 5.2 Spatial distribution of the vegetation units identified at the Elsies River (From Heinecken et al., 1982)

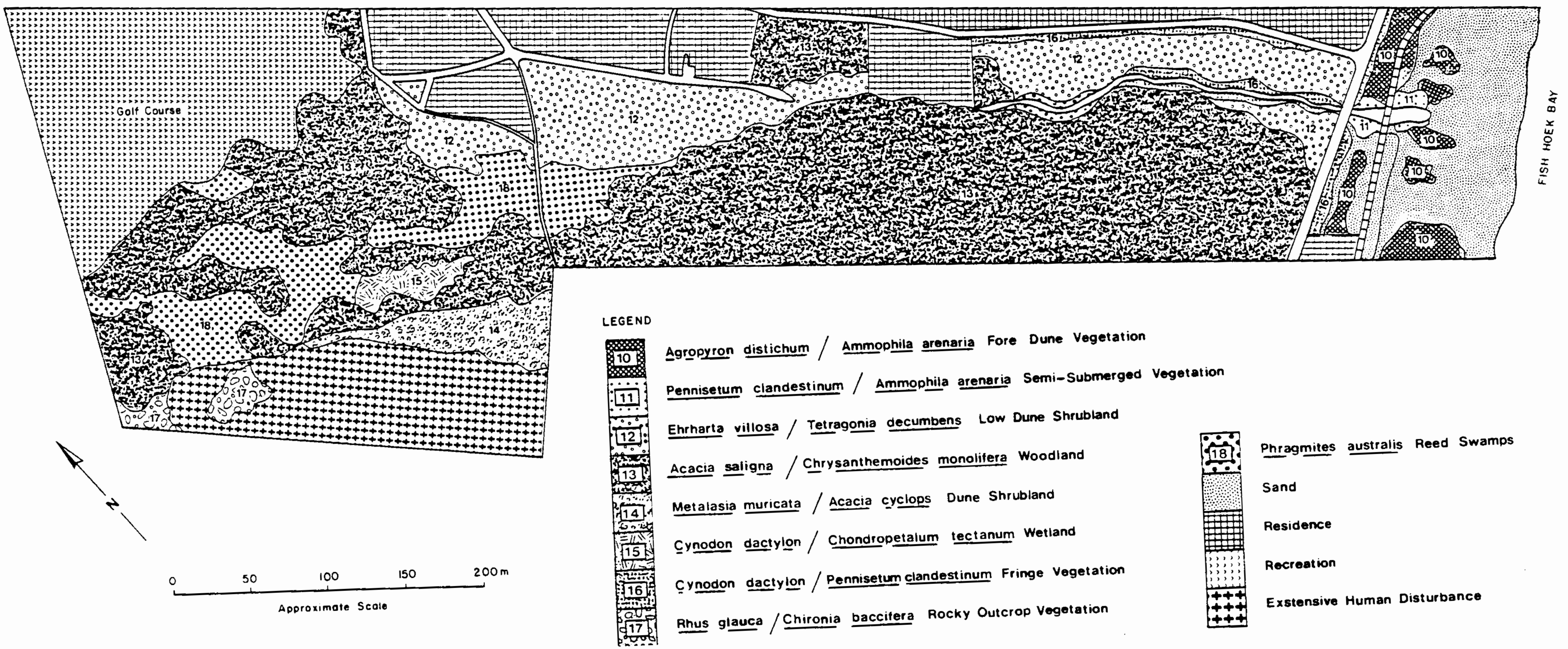


FIG. 5.3 Spatial distribution of the vegetation units identified at the Silvermine River (After Heinecken, 1982a).

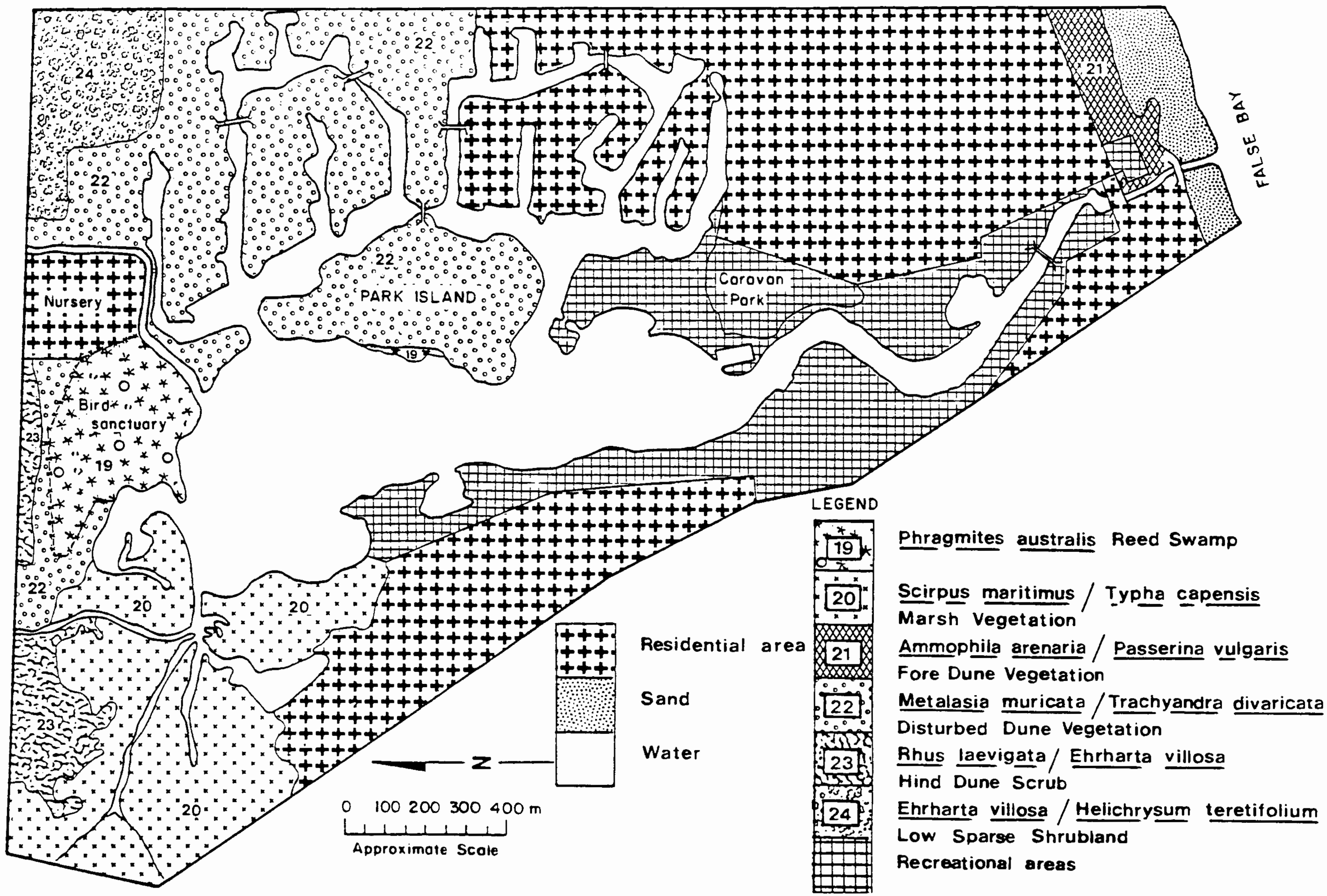


FIG. 5.4 Spatial distribution of the vegetation units identified at Sandvlei (After Morant and Grindley, 1982)

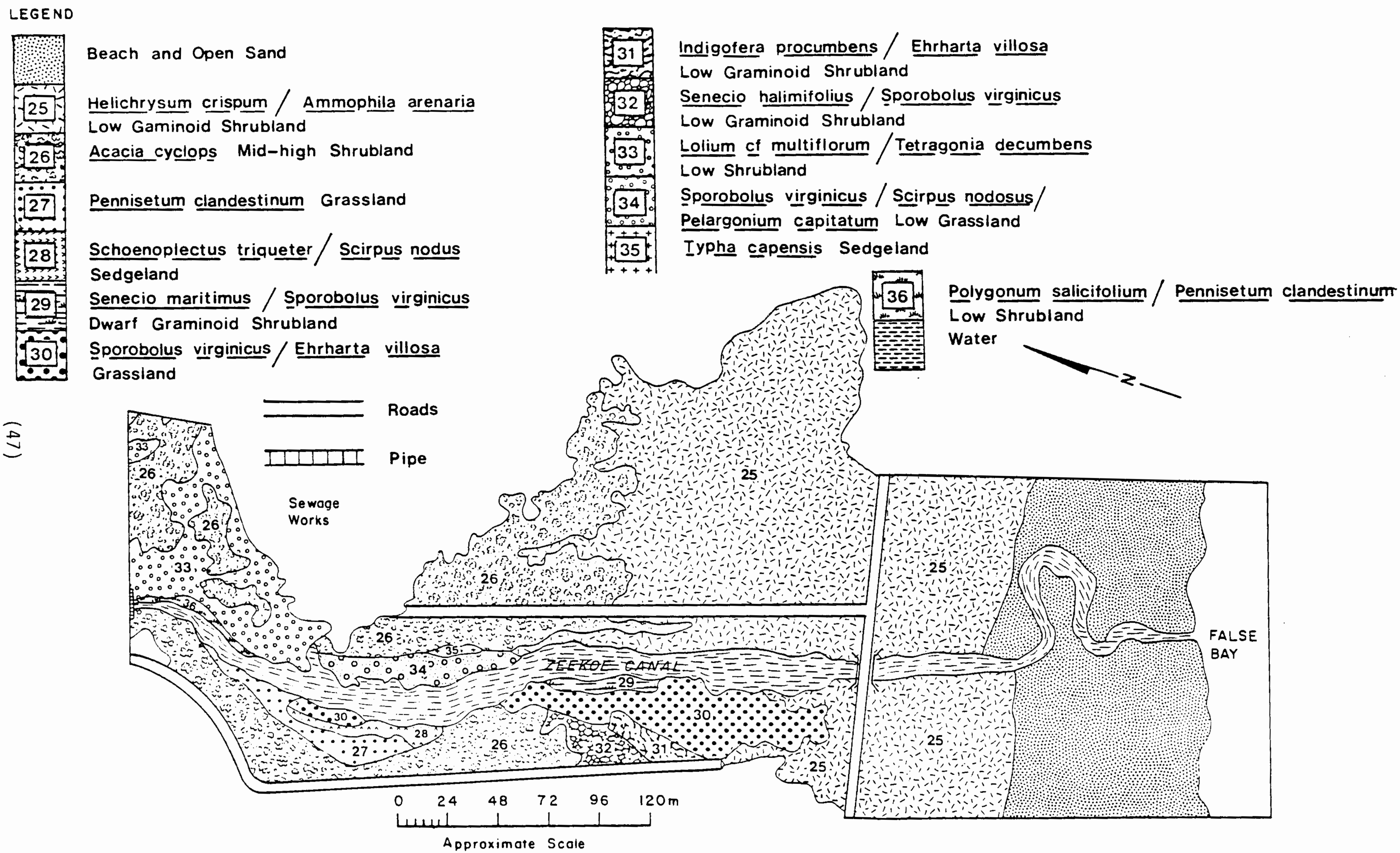


FIG. 5.5 Spatial distribution of the vegetation units identified at the Zeekoe River (After Bickerton, 1982).

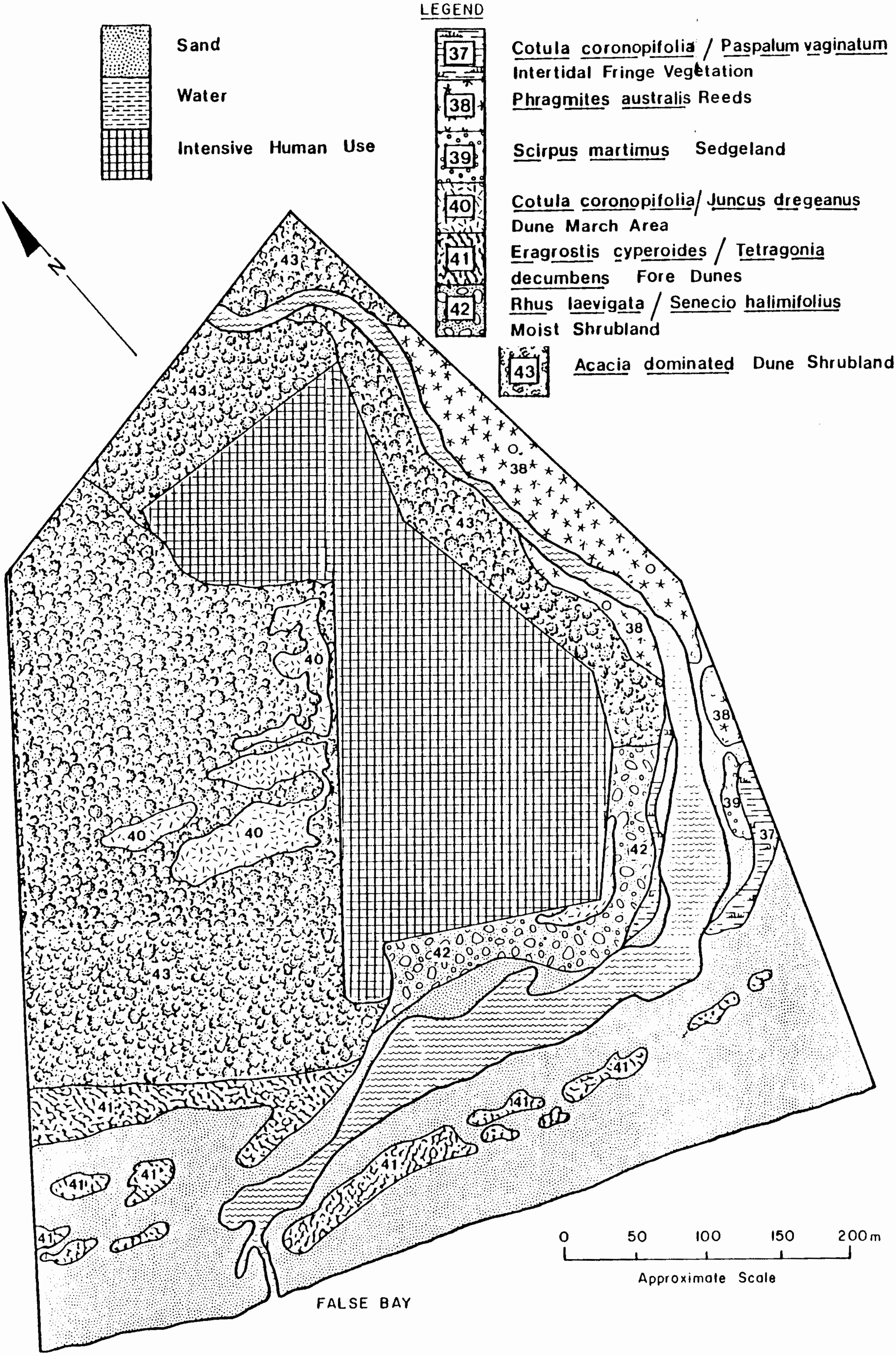


FIG. 5.6 Spatial distribution of the vegetation units identified at the Eerste River (After Grindley, 1982).

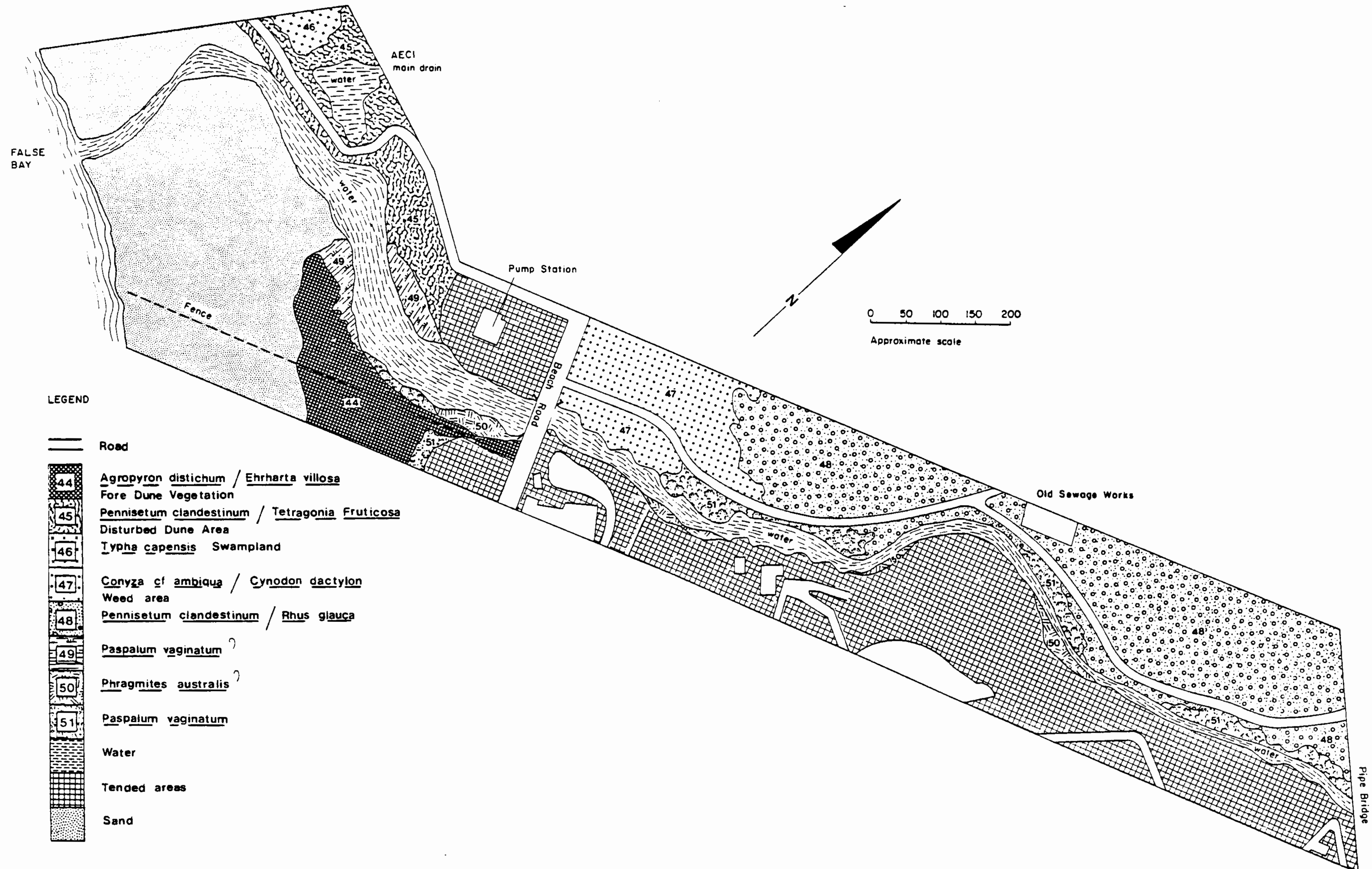


FIG. 5.7 Spatial distribution of the vegetation units identified at the Lourens River (After Cliff and Grindley, 1982).

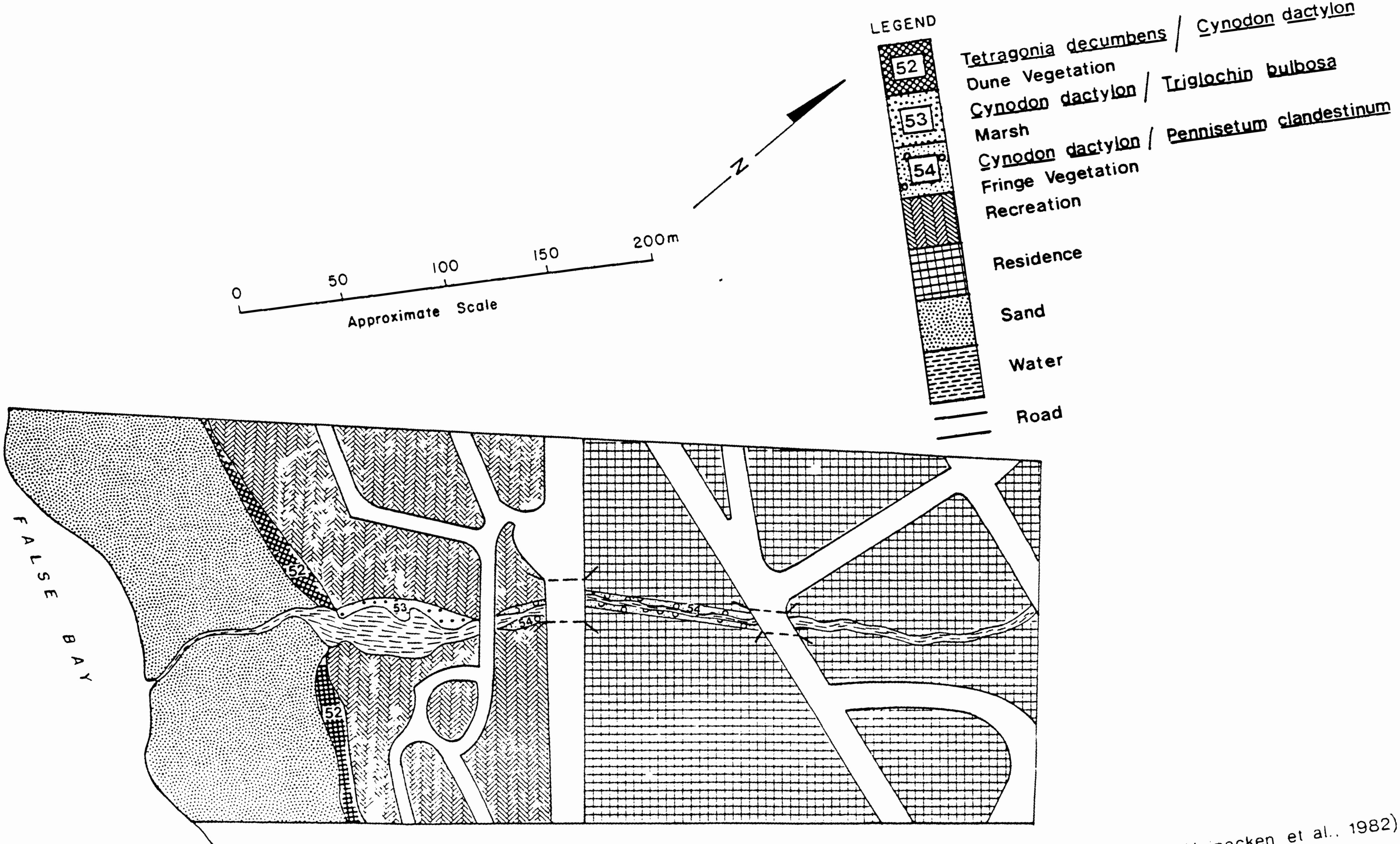


FIG 5.8 Spatial distribution of the vegetation units identified at the Sir Lowry's Pass River (After Heinecken et al., 1982).

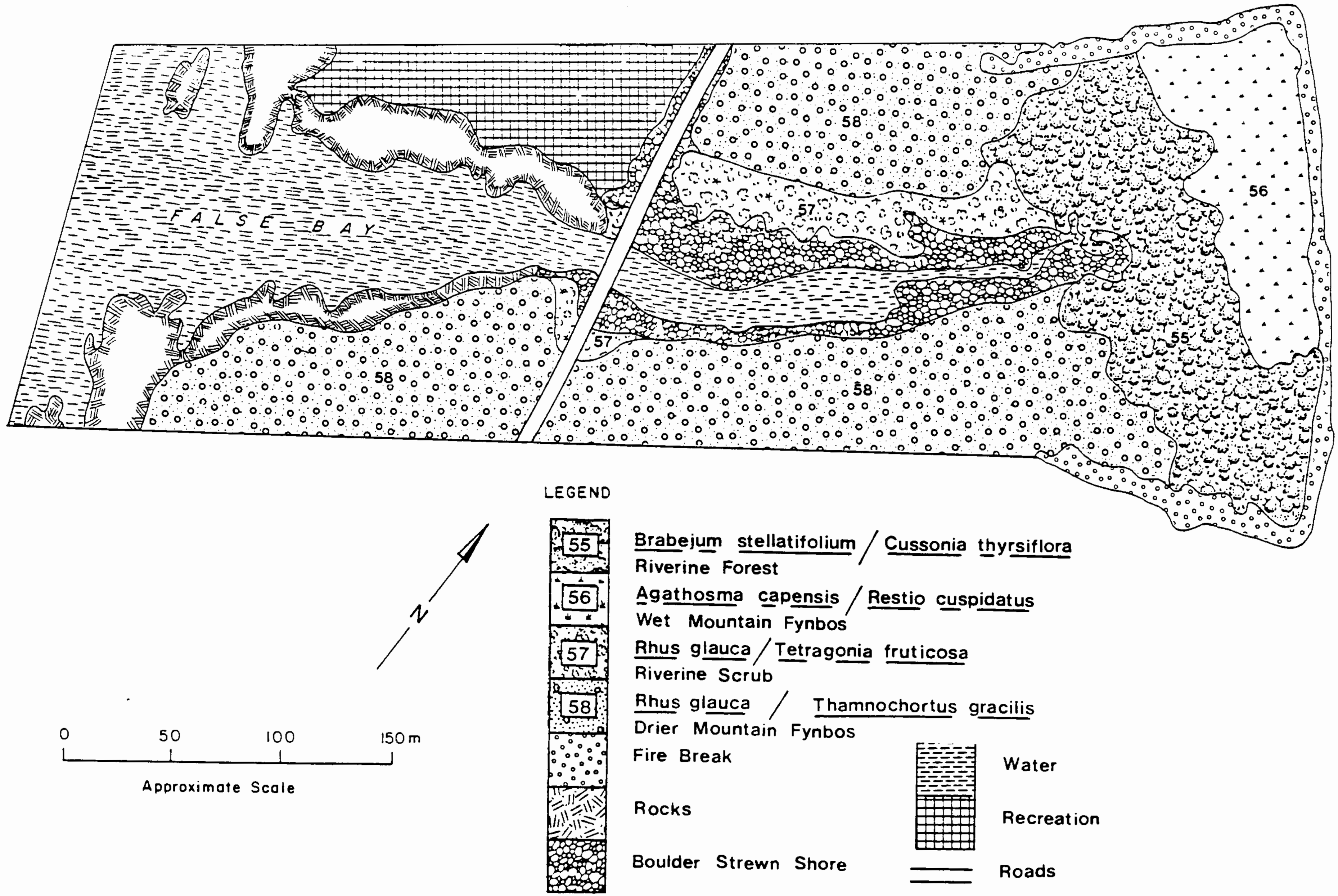


FIG. 5.9 Spatial distribution of the vegetation units identified at the Steenbras River (After Heinecken *et al.* 1982).

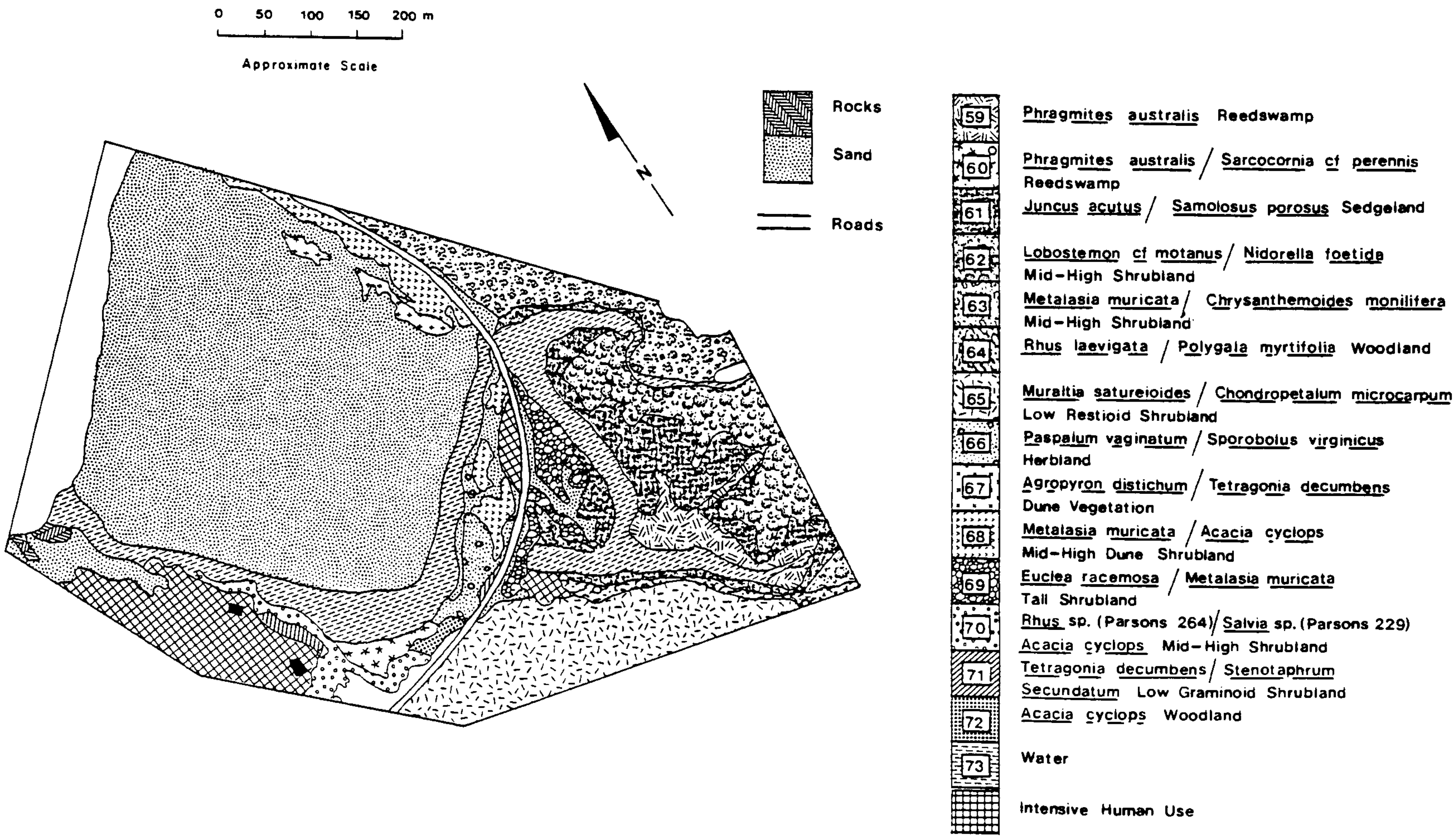


FIG. 5.10 Spatial distribution of the vegetation units identified at the Rooiels River (After Heinecken, 1982b).

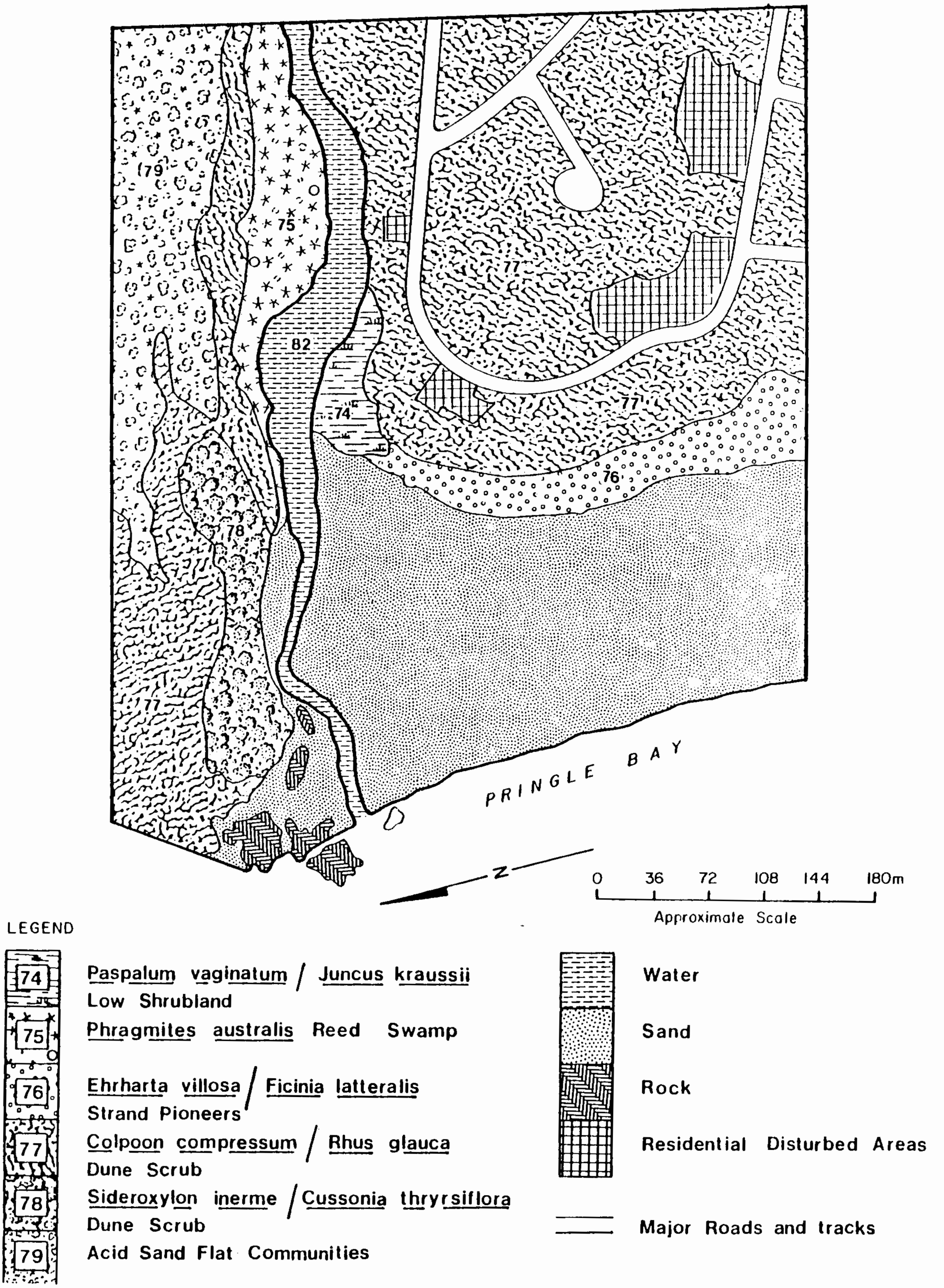


FIG. 5.11 Spatial distribution of the vegetation units identified at the Buffels (east) River (After Heinecken et al., 1982).

Table 5.2. Structural description of each vegetation unit.

Unit No.	Description
1.	sparse low herbland
2.	cyperoid closed tall herbland
3.	closed mid-high shrubland
4.	graminoid closed low herbland
5.	mid-dense mid-high herblasnd
6.	herbaceous closed low sedgeland
7.	closed low grassland
8.	closed tall herbland
9.	closed mid-high shrubland
10.	open mid-high herbland
11.	graminoid mid-dense low herbland
12.	graminoid mid-dense dwarf shrubland
13.	graminoid mid-dense tall shrubland
14.	graminoid open low shrubland
15.	cyperoid closed low grassland
16.	closed low grassland
17.	closed mid-high shrubland
18.	closed tall grassland
19.	cyperoid open mid-high herbland
20.	tall closed grassland
21.	graminoid sparse low herbland
22.	closed mid-high shrubland
23.	closed mid-high shrubland
24.	sparse low shrubland
25.	graminoid open low shrubland
26.	sparse low shrubland
27.	closed low grassland
28.	cyperoid open tall herbland
29.	graminoid mid-dense mid-high herbland
30.	graminoid closed tall herbland
31.	graminoid closed low shrubland
32.	cyperoid closed mid-high shrubland
33.	closed low shrubland
34.	cyperoid closed mid-high herbland
35.	cyperoid mid-dense tall herbland
36.	closed low shrubland
37.	closed mid-high herbland
38.	closed tall grassland
39.	closed tall sedgeland
40.	cyperoid open tall herbland
41.	graminoid sparse mid-high herbland
42.	closed mid-high shrubland
43.	mid-dense tall shrubland
44.	sparse mid-high herbland
45.	graminoid closed mid-high herbland
46.	closed tall herbland
47.	graminoid sparse tall herbland
48.	closed low shrubland
49.	closed low grassland
50.	closed tall grassland
51.	mid-dense mid-high shrubland
52.	graminoid sparse tall herbland
53.	cyperoid closed low grassland
54.	open mid-high shrubland
55.	closed tall shrubland
56.	closed mid-high shrubland
57.	open mid-high shrubland
58.	open mid-high shrubland
59.	mid-dense tall grassland
60.	mid-dense tall grassland
61.	mid-dense tall sedgeland
62.	closed mid-high shrubland
63.	mid-dense mid-high shrubland
64.	mid-dense tall shrubland
65.	open low shrubland
66.	graminoid mid-dense mid-high herbland
67.	graminoid open mid-high herbland
68.	open mid-high shrubland
69.	mid-dense mid-high shrubland
70.	mid-dense mid-high shrubland
71.	graminoid mid-dense dwarf shrubland
72.	closed tall shrubland
73.	closed submerged aquatic
74	cyperiod closed low grassland
75.	closed tall grassland
76.	herbaceous sparse low grassland
77.	closed mid-high shrubland
78.	closed tall shrubland
79.	closed low shrubland
80.	sparse submerged aquatic
81.	closed submerged aquatic
82.	sparse submerged aquatic

terrestrial vegetation units. *Acacia cyclops* is particularly common in the strandveld vegetation types (Moll *et al*., 1984), while *Pennisetum clandestinum* is found in the wetland and strandveld types. Because these widespread species tend to standardize the structure of a number of vegetation units, they must be ignored for the structural classification. The aim of this classification process is to identify units for managerial purposes, and the presence of alien plants indicate specific management treatments i.e. they must be eradicated. The necessity to ignore these species is thus a distinct disadvantage of the system.

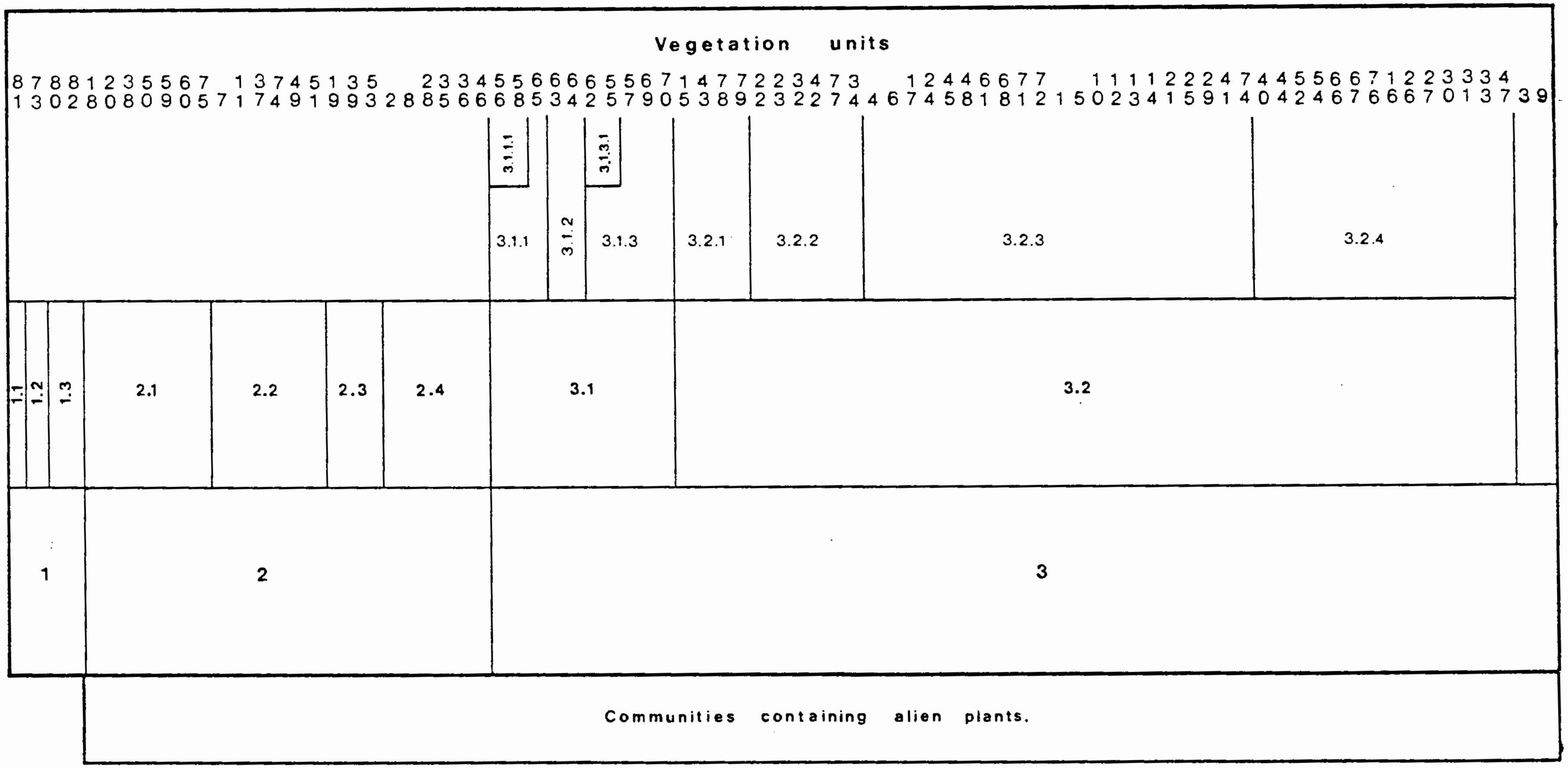
For convenience, the structural classification was subdivided on the basis of growth form and successively by height class, cover class and finally by variety (Table 5.1). These data are presented in a hierarchical form in Table 5.3 where each subdivision is numbered to aid reference thereto.

5.3.1.1 Description of Structural Units : five growth forms were recognized in this study area :

1. Submerged Aquatic Plants : height classes were not recorded for these vegetation types, but they form two cover classes : sparse and closed. The former (1.0.1) is restricted to *Ruppia maritima* while the latter (1.0.2) contains *Potamogeton pectinatus* and *Ruppia cirrhosa*. The latter two species have different salinity tolerances (Obermeyer,

Table 5.3. Hierarchical classification according to structure where :

1. Submerged aquatic plants
1.0.1. Sparse submerged aquatic plants
1.0.2. Closed submerged aquatic plants
2. Sedgelands
2.1. Low sedgeland
2.1.1. Closed low sedgeland
2.1.1.1. Herbaceous closed low sedgeland
2.2. Tall sedgeland
2.2.1. Closed tall sedgeland
2.2.2. Mid-dense tall sedgeland
3. Grasslands
3.1. Low grassland
3.1.1. Closed low grassland typicum
3.1.1.1. Cyperoid closed low grassland
3.1.2. Sparse low grassland
3.1.2.1. Herbaceous sparse low grassland
3.2. Tall grassland
3.2.1. Closed tall grassland
3.2.2. Mid-dense tall grassland
4. Herblands
4.1. Low herbland
4.1.1. Closed low herbland
4.1.1.1. Graminoid closed low herbland
4.1.2. Mid-dense low herbland
4.1.2.1. Graminoid mid-dense low herbland
4.1.3. Sparse low herbland typicum
4.1.3.1. Graminoid sparse low herbland
4.2. Mid-high herbland
4.2.1. Closed mid-high herbland typicum
4.2.1.1. Cyperoid closed mid-high herbland
4.2.1.2. Graminoid closed mid-high herbland
4.2.2. Mid-dense mid-high herbland typicum
4.2.2.1. Graminoid mid-dense mid-high herbland
4.2.3. Open mid-high herbland typicum
4.2.3.1. Cyperoid open mid-high herbland
4.2.3.2. Graminoid open mid-high herbland
4.2.4. Sparse mid-high herbland typicum
4.2.4.1. Graminoid sparse mid-high herbland
4.3. Tall herbland
4.3.1. Closed tall herbland typicum
4.3.1.1. Cyperoid closed tall herbland
4.3.1.2. Graminoid closed tall herbland
4.3.2. Mid-dense tall herbland
4.3.2.1. Cyperoid mid-dense tall herbland
4.3.3. Open tall herbland
4.3.3.1. Graminoid open tall herbland
4.3.4 Sparse tall herbland
4.3.4.1. Graminoid sparse tall herbland
5. Shrublands
5.1. Dwarf shrubland
5.1.1. Mid-dense dwarf shrubland
5.1.1.1. Graminoid mid-dense dwarf shrubland
5.2. Low shrubland
5.2.1. Closed low shrubland typicum
5.2.1.1. Graminoid closed low shrubland
5.2.2. Open low shrubland typicum
5.2.2.1. Graminoid open low shrubland
5.2.3. Sparse low shrubland
5.3. Mid-high shrubland
5.3.1. Closed mid-high shrubland typicum
5.3.1.1. Cyperoid closed mid-high shrubland
5.3.2. Mid-dense mid-high shrubland
5.3.3. Open mid-high shrubland
5.4. Tall shrubland
5.4.1. Closed tall shrubland
5.4.2. Mid-dense tall shrubland typicum
5.4.2.1. Graminoid mid-dense tall shrubland


Vegetation units
8 7 8 8 1 2 3 5 5 6 7 1 3 7 4 5 1 3 5 2 3 3 4 5 5 6 6 6 6 5 5 6 7 1 4 7 7 2 2 3 4 7 3 1 2 4 4 6 6 7 7 1 1 1 1 2 2 2 4 7 4 4 5 5 6 6 7 1 2 2 3 3 3 4
1 3 0 2 8 0 8 0 9 0 5 7 1 7 4 9 1 9 9 3 2 8 8 5 6 6 6 8 5 3 4 2 5 7 9 0 5 3 8 9 2 3 2 2 7 4 4 6 7 4 5 8 1 8 1 2 1 5 0 2 3 4 1 5 9 1 4 0 4 2 4 6 7 6 6 6 7 0 1 3 7 3 9
3.1.1.1
3.1.3.1
3.1.1
3.1.2
3.1.3
3.2.1
3.2.2
3.2.3
3.2.4
1.1
1.2
1.3
2.1
2.2
2.3
2.4
3.1
3.2
1
2
3
Communities containing alien plants.

1966a; 1966b) and, therefore, have different management requirements. The inclusion of these two species into a single unit does not seem realistic and is a disadvantage of this system.

2. Sedgelands : these are made up of two height classes, namely, low and tall.

2.1. Low Sedgeland : this unit consists of a single closed cover class (2.1.1) which is of a herbaceous variety (2.1.1.1). It has been severely invaded by aliens plants which dominate the unit (Pennisetum clandestinum and Acacia cyclops) and only a small portion of the original sedgeland community (mainly Scirpus nodosus) remains.

2.2. Tall Sedgeland : this is further subdivided into a closed and a mid-dense cover class.

2.2.1. Closed Tall Sedgeland : this vegetation type is dominated by Scirpus maritimus which is usually emergent and found on a range of soil types, from sand to typical marsh substrates.

2.2.2. Mid-dense Tall Sedgelands : although these sedgelands might be emergent during parts of the year, they are not inundated as often as the above (2.2.1) community and are generally found on sandier substrates.

The distinction between these two communities (2.2.1 and 2.2.2) by cover class seems to be coincidental since, under different water regimes, the density of the latter community (Scirpus nodosus and Juncus acutis) can increase and even be denser than the former community (pers. obs.).

3. Grasslands : these are divided into two height classes, each with two cover classes, varieties are also present.

3.1. Low Grassland :

3.1.1. Closed Low Grassland : this community forms a relatively good unit. Two of the samples (No. 53 and 27) are dominated by Pennisetum clandestinum and a high water table is indicated for this community. There is a cyperoid variety of closed low grassland which is distinguished by the presence of Juncus spp. and Scirpus nodosus.

3.1.2. Sparse Low Grassland : this dune community is of a herbaceous variety (3.1.2.1) and is well distinguished from community 3.1.1. All the other grassland communities are related to a high water table.

3.2. Tall Grassland : this forms a well-defined unit dominated by *Phragmites australis*, often monospecifically. Factors affecting the cover of this species are not known and the distinction of the closed (3.2.1) and mid-dense (3.2.2) cover classes might be significant.

4. Herblands : the herblands are subdivided into three height classes : low herblands (4.1), mid-high herblands (4.2) and tall herblands (4.3). Each of these is further divided into a number of cover classes with varieties. However, the units seem to be somewhat fragmented. For example, the sparse low herbland (4.1.3) consists of fore-dune vegetation while other fore-dune vegetation is included in the sparse mid-high herbland (4.2.4), the open mid-high herbland (4.2.3) and the closed tall herbland (4.3.1). Furthermore, fore-dune communities are found in other growth form classes, e.g. the sparse low grassland (3.1.2)

5. Shrublands : these are divided into four height classes : dwarf shrublands (5.1), low shrublands (5.2), mid-high shrublands (5.3) and tall shrublands (5.4). The comments made for the herblands also hold true for the shrubland growth form class. For example, the

typicum of the open low shrubland (5.2.2) is a fynbos community including *Leucodendron salignum*, *Restio cuspidatus*, *Tetraria cuspidata*, *Protea repens*, *Erica imbricata*. The majority of this community consists of a graminoid variety (5.2.2.1) which is a strandveld vegetation type including *Tetragonia decumbens*, *Carpobrotus acinaciformis*, *Metalasia muricata*, *Ehrharta villosa*. Fynbos communities are also found in the closed mid-high shrubland (5.3.2), the open mid-high shrubland (5.3.3) and the closed tall shrubland (5.4.1). Except for a cyperoid variety of the closed mid-high shrubland (5.3.1.1), there are no further subdivisions of these latter communities which also contain strandveld and/or other vegetation types.

5.3.2 Floristic Classification

A number of theoretical considerations must be taken into account when using this methodology for floristic classification.

a) When using the Braun-Blanquet methodology, the optimum size of each relevè is predetermined (see below). As such, the cover-abundance values are absolute in so far as they relate to a reference area which is fixed by the size of the relevé (Mueller-Dombois and Ellenberg, 1974). In this study, the sampling unit size was not fixed and the cover-abundance values are relative. Although this did not appear to affect the data, cases may arise where this consideration should be taken into account (e.g. when the vegetation consists of a number of co-dominant species or strata).

b) When using the Braun-Blanquet methodology, the optimum size of the relevè is usually determined from species-area curves (see Mueller-Dombois and Ellenberg, 1974) and a number of relevès are placed in each community type. In this study, the optimum size of the sampling unit was not determined and the entire vegetation unit was regarded as an open-ended plot. As such, each vegetation unit was sampled with a single sampling unit which varied according to the size of the vegetation unit. The cover-abundance values of different sized plots can be compared, but the enumeration of species in the entire vegetation unit would usually result in gross oversampling. However, this has been compensated for by (c) below.

Furthermore, as each vegetation unit only contains one sampling unit, the less common vegetation types (e.g. riverine scrub) are undersampled. In Appendix 5.2, more than 60% of the species have a single occurrence. However, these singly occurring species can be grouped and the more species in such a group, the more likely these species form a community. For example, _Restio eleocharis_ and _Olea exasperata_ are likely to form a community with

Nemesia psammophila, Salvia aurea and others (Boucher, pers. comm.). However, in this study area, this community is rare and these species only have a single occurrence in Appendix 5.2.

c) The Braun-Blanquet methodology requires that all the species in a relevè be recorded. In this study, the majority of vegetation units are floristically relatively simple and contain few species (see Appendix 5.2). In the more complex vegetation types (e.g. fynbos and strandveld), the enumeration of all the species in a sampling unit would be a major task as the sampling unit is equivalent to the vegetation unit.

However, the dominant floristic composition of each vegetation unit played an important role in the recognition of physiographic/physiognomic units from the aerial photographs. It is, therefore, reasonable to assume that only the dominant and prominent species need to be considered to distinguish between vegetation units. This assumption could be erroneous if units are demarcated from photographs taken at different times of the year, different times of the day, or if different vegetation units have similar physiographic/physiognomic characteristics. It is, therefore, necessary to critically evaluate the physiographi/physiognomic units in the field.

The average number of species recorded for each sampling unit were :

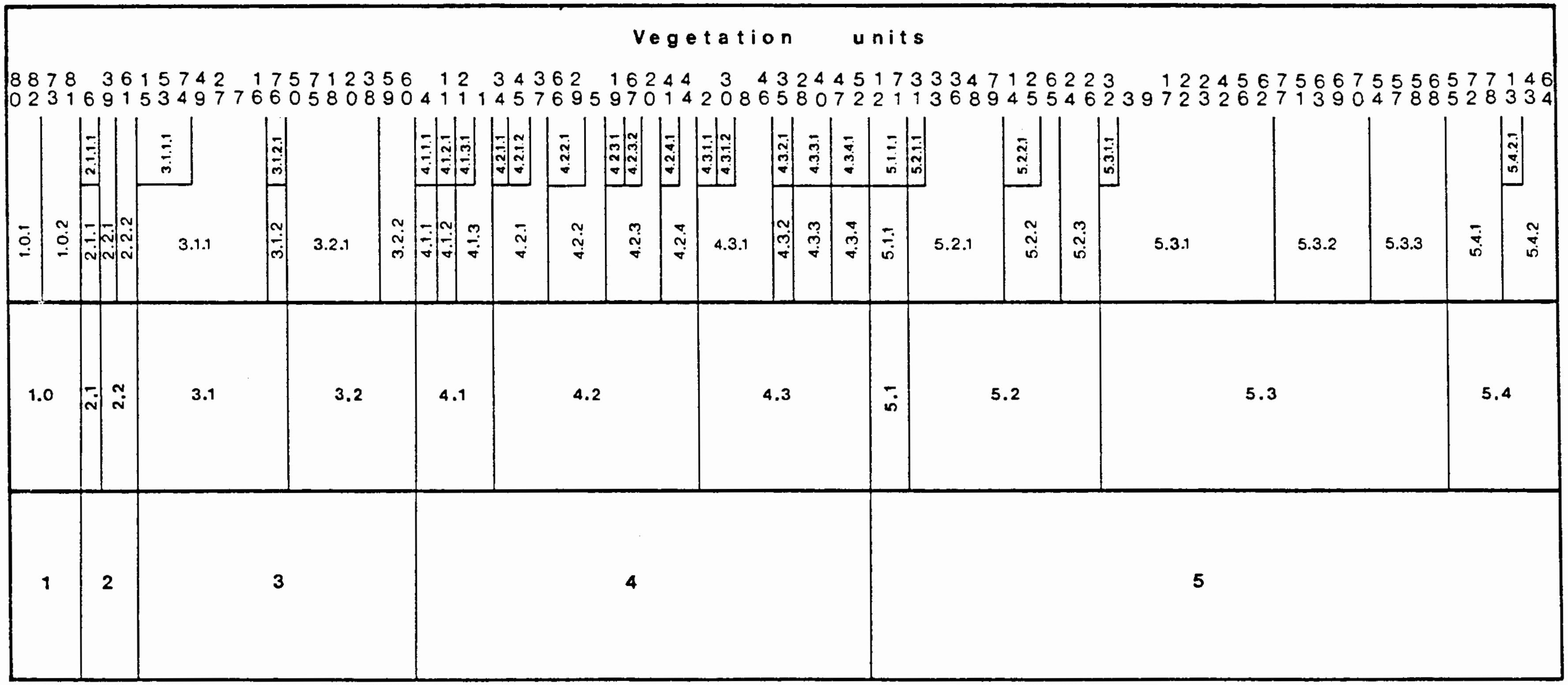
Submerged aquatic communities	: 1
Emergent and Wetland communities	: 5,2
Cassine barbara communities	: 20,2
Non-littoral _Tetragonia decumbens_ communities	: 14,8
Littoral _Tetragonia decumbens_ communities	: 6,5

The number of species recorded for the less complex vegetation types (submerged aquatic, wetland and littoral communities) might represent a high proportion of the total number of species in these vegetation types. However, Boucher (in prep.) found an average of 32 and 31 permanently recognizable species per 5m x 10m plot for Sand Plain Fynbos and West Coast Strandveld respectively. The number of species recorded for the more complex vegetation types is likely to be less representative of the total number of species present.

To facilitate identification of vegetation types, the floristic units were ranked into a hierarchy after Boucher (in prep.; see Table 5.4). No final hierarchical status is implied and communities are referred to by their dominant distinguishing species. Each subdivision in this hierarchy has been numbered to aid reference thereto.

Table 5.4. Hierarchical classification according to floristics where :

1.	Submerged aquatic communities
1.1.	*Potamogeton pectinatus* submerged community
1.2.	*Ruppia cirrhosa* submerged community
1.3.	*Ruppia maritima* submerged community
2.	Emergent and Wetland communities
2.1.	*Phragmites australis* emergent community
2.2.	*Paspalum vaginatum* wetland community
2.3.	*Scirpus maritimus* mixed community
2.4.	*Typha capensis* emergent community
3.	Terrestrial communities
3.1.	*Cassine barbara* fynbos community
3.1.1.	*C. barbara*/*Leucodendron salignum* dry mountain community typicum
3.1.1.1.	*L. salignum*/*Thamnochortus gracilis* mountain community
3.1.2.	*C. barbara*/*Polygala myrtiflora* coastal community
3.1.3.	*C. barbara*/*Rhus lucida* riparian community typicum
3.1.3.1.	*R. lucida*/*Pelargonium angulosum* riparian community
3.2.	*Tetragonia decumbens* strandveld community
3.2.1.	*T. decumbens*/*Sideroxylon inerme* mature hind-dune community
3.2.2.	*T. decumbens*/*Senecio halimifolius* moist dune community
3.2.3.	*T. decumbens*/*Chrysanthemoides monilifera* dune community
3.2.4.	*T. decumbens*/*Agropyron distichum* fore-dune community
3.3.	*Acacia cyclops* monospecific community


Vegetation units
8878 3615742 175712356 12 34362 16244 3 4324451733347126223 1224567566755565771 46
0231691534977660580890411145769597014208658072211368945546239723262713904788528334
2.1.1.1
3.1.1.1
3.1.2.1
4.1.1.1
4.1.2.1
4.1.3.1
4.2.1.1
4.2.1.2
4.2.2.1
4.2.3.1
4.2.3.2
4.2.4.1
4.3.1.1
4.3.1.2
4.3.2.1
4.3.3.1
4.3.4.1
5.1.1.1
5.2.1.1
5.2.2.1
5.3.1.1
5.4.2.1
1.0.1
1.0.2
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3.2
4.1
4.2
4.3
5.1
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5.3
5.4
1
2
3
4
5

5.3.2.1 Description of Floristic Units : for the sake of clarity, the first level of the hierarchy is divided on the basis of general habitat type (namely : submerged communities, emergent communities and terrestrial communities). Using the attributes of the natural vegetation, each of these habitat types are distinct enough to be regarded as a different system. If aliens plants were included in the classification presented in Table 5.4, the emergent and terrestrial habitat types would be combined at the lowest level of the hierarchy, resulting in a group which might be termed 'Alien Dominated Communities'. However, the distinction of communities at higher levels of the hierarchy would not be affected.

1. Submerged Aquatic communities : three aquatic species were recorded in this study area : Potamogeton pectinatus, Ruppia cirrhosa and R. maritima. Each of these species form monospecific stands and should be regarded as distinct communities at the lowest levels of the hierarchy. Many of the environmental characteristics which control the distribution of these species (e.g. salinity, water depth, light penetration, etc) are not comparable with those controlling the distribution of emergent and/or terrestrial communities. The hierarchical status of these aquatic communities relative to the emergent and terrestrial communities is not easily

determined. Nevertheless, the lowest level of the hierarchy presented in Table 5.4 has been delimited on the basis of major habitat type (namely submerged, emergent and terrestrial vegetation types) and the distinction between the aquatic communities has been made at the second level.

1.1. *Potamogeton pectinatus* Submerged Community : this community was found only at Sandvlei where it is confined mainly to the middle reaches of the vlei. It thrives in this brackish to fresh, nutrient-rich water to form dense meadows which are 'managed' by weed cutting.

1.2. *Ruppia cirrhosa* Submerged Community : this species is restricted to the shallow areas above the road bridge at the Rooiels River and can withstand relatively high salinities.

1.3. *Ruppia maritima* Submerged Community : these communities are found at Sandvlei and the Buffels (east) River. They are generally found in less saline conditions than *R. cirrhosa* and do not grow to the same depths as *P. pectinatus*. Also, *R. maritima* does not form the dense meadows which characterize the *P. pectinatus* communities.

2. Emergent and Wetland Communities : these are generally azonal and contain one or a few species. Although aliens plants (particularly Acacia cyclops, A. saligna, A. mearnsii and Pennisetum clandestinum) may be found in these communities, they are generally not found throughout the range of the community. For example, the Phragmites australis emergent community (2.1) is found at the Silvermine, Sandvlei, Eerste, Lourens, Rooiels and Buffels (east) Rivers. A. cyclops is only found within this community at Sandvlei where it grows on ridges constructed for the aborted Westlake component of the Marina da Gama development. It might be argued that A. cyclops constitutes a separate community as this species is found on higher ground and is often limited by surface water (pers. obs.). However, the presence of aliens imply that the area has been disturbed and management plans should be formulated to remove them.

The factors controlling the distribution of wetland species are not clearly understood and the optimum conditions for South African wetland and emergent species has not been researched. These controlling factors become more complex when these communities form a graded interface between different habitat types and might constitute a complex combination of environmental characteristics (Long and Mason, 1983). As such, the relative hierarchical status of these communities has been determined for the sake of convenience rather than ecological relevance.

2.1. <u>Phragmites australis</u> Emergent Community : this species often forms monospecific stands up to 2,5 m tall, usually on substrates where silt deposition is occurring. This species grows optimally in water with a salinity of less than 15 o/oo, although it can withstand higher salinities (Banfield, 1984).

2.2. <u>Paspalum vaginatum</u> Wetland Community : this predominantly monospecific community is found on coarse saline sands and can withstand periods of inundation. This community was found at the Elsies, Silvermine, Eerste and Lourens Rivers.

2.3. <u>Scirpus maritimus</u> Mixed Community : these plants are generally found on non-saline sandy soils which contain some organic matter. Many of them survive inundation in an emergent form. This community was found at Sandvlei, and at the Eerste and Sir Lowry's Pass Rivers.

2.4. <u>Typha capensis</u> Emergent Communities : found on typical marsh soils, i.e. with a high silt and organic content, this community is emergent in slow-running, fresh water as at the Buffels (west), Elsies and Zeekoe Rivers. At the Lourens River, this species was found in a wetland area which is not part of the river.

3. Terrestrial Communities : the delimitation of the terrestrial communities at the second level of the hierarchy seems to correlate with soil types (see Appendix 5.3). The delimitation of communities at higher levels, to some extent, follows habitat forms. However, it would seem that environmental instability is a stronger controlling factor determining the distribution of many of the species. For example, Plantago carnosa is found in seaonally flooded areas as well as on the hummock dunes (see Appendix 5.2 and 5.3). Both of these habitat forms can be regarded as environmentally unstable.

3.1. Cassine barbara Fynbos Community : fynbos was found at the Steenbras and Rooiels Rivers, predominantly on shallow sandstone soils. Boucher (1978) recorded C. barbara on littoral dunes, on limestone and in riverine scrub in the Hangklip area. It would seem that this species is tolerant of a number of habitat factors and its value as a diagnostic species is, therefore, suspect. Nevertheless, Taylor (1969) found this species in a sub-association of upland fynbos. Other species common to this community (Leucospermum conocarpodendron, *Widdringtonia nodiflora*) help to establish this fynbos community.

3.1.1. *C. barbara*/*Leucodendron salignum* Dry Mountain Community : this community is indicative of dry fynbos in this area (see Boucher's, 1978 community 3.2.2.1). The *L. salignum*/*Thamnochortus gracilis* variety (3.1.1.1) was found at the Steenbras River and seems to be a form characteristic of slightly moister conditions.

3.1.2. *C. barbara*/*Polygala myrtiflora* Coastal Community : this vegetation type was found only at the Rooiels River and does not compare well with any of Boucher's (1978) communities. It contains *Protea compacta*, *Phylica ericoides*, *Chondropetalum microcarpum* and *Myrica quercifolia*. A better sampling technique might indicate a combination of Acid Sand Fynbos and South Coast Strandveld. However, C.Boucher (pers. comm.) suggests that, in this region, *P. compacta* does not occur naturally west of the Palmiet River Mouth and this community might be a dune/limestone community (see community 3.1).

3.1.3. *C. barbara*/*Rhus lucida* Riparian Community : this is found in the narrow valleys of the Steenbras and Rooiels Rivers with *Psoralea* pinnata, Podalyria calyptrata and others. The R. lucida/Pelargonium angulosum variety (3.1.3.1) is usually found at the coastal or riverine edge of the typicum.

3.2. Tetragonia decumbens Strandveld Communities : these are found on deep calcareous sands. Boucher and Le Roux (in press) includes T. decumbens in an undifferentiated Tetragonia spp. complex which is common to a number of littoral dune communities.

3.2.1. T. decumbens/Sideroxylon inerme Mature Hind-dune Community : this is found in protected hind-dune areas and compares well with Boucher (1978), Taylor (1969) and Taylor (1980). T. decumbens is seldom found in this community and, from Appendix 5.3, Ehrharta villosa might have been a better diagnostic species for these (3.2) communities.

3.2.2. T. decumbens/Senecio halimifolius Moist Dune Community : found predominantly in dune slacks and poorly drained dune areas, this community compares well with Taylor (1980).

3.2.3. T. decumbens/Chrysanthemoides monilifera Dune Community : this community is typical of deep coastal sands where the above conditions do not prevail. Although this community could be further sub-divided (see Boucher, in prep.), it is unlikely that the establishment of these units would further facilitate management planning.

3.2.4. *T. decumbens/Agropyron distichum* Fore-dune Community : this community consists of psammophilous pioneer vegetation which is commonly found on the fore-dunes. It compares well with Boucher's (1978) '*Ehrharta* - *Ficinia* Strand Pioneers' and Taylor's (1969) 'Pioneer Mixed Dune Fynbos' to which Taylor gives the status of sub-association.

3.3. *Acacia cyclops* Monospecific Community : although *A. cyclops* and other alien plants are found throughout the terrestrial and emergent vegetation types, the natural vegetation can usually be recognized from surviving remnants. However, at the Buffels (west) and Elsies Rivers, *A. cyclops* has, in places, ousted the natural vegetation to form monospecific stands.

5.4 Conclusions

Although the structural system (Table 5.3) might give some indication of management units (e.g. the open low shrubland typicum (5.2.2) could be managed with fire while disturbance of the graminoid variety (5.2.2.1) should be avoided to prevent erosion), this system is confusing and does not result in well-consolidated units. For example, in the closed mid-high shrubland (5.3.1), two of the samples are monospecifically dominated by acacias (No. 3 and 9), two of the samples indicate fynbos communities (No. 56 and 62), three of the samples were found in moist dune areas with Senecio halimifolius (No. 22, 23 and 42), and one sample is strandveld (No. 17). Furthermore, there is a cyperoid variety (5.3.1.1) which is found in moist dune areas with Senecio halimifolius.

Management units established by this system are often fragmented. For example, parts of the low open shrubland (5.2.2), the closed mid-high shrubland (5.3.2) and the closed tall shrubland (5.4.1) contain fynbos species and might be managed with fire. Many of these units are also established erratically through various levels of the hierarchy. For example, the tall grassland (3.2) should be managed as a wetland, as should the graminoid mid-dense herbland (4.1.2.1). Both of these can withstand inundation by saline water, but the distinction of these vegetation types is made at the second and fourth levels of the hierarchy respectively.

Habitat types are also fragmented (e.g. deep coastal sand communities are found in the sparse low shrubland (5.2.3) and the closed tall shrubland (5.4.1)) while some habitat types are combined (e.g. the open mid-high shrubland (5.3.3) contains shallow, acid sand communities as well as deep calcareous sand communities).

By comparison, the floristic classification (Table 5.4) results in well-consolidated units (e.g. community 3.1 indicates fynbos vegetation while community 3.2 indicates strandveld). Management units are not fragmented (e.g. all the Cassine barbara communities (3.1) might be managed with fire while disturbance of the Tetragonia decumbens communities (3.2) should be avoided), and management policies can be aimed at any level of the hierarchy (e.g. the Cassine barbara community (3.1) might be managed with fire and further subdivisions might indicate different fire regimes).

Habitat types are also well-consolidated. For example, the Cassine barbara communities (3.1) are found on acid sands while the Tetragonia decumbens communities (3.2) occur on deep, calcereous sands.

Although habitat characteristics were used to clarify the lowest level of the floristic classification, they were not used to establish communities in either of the above methods of classification. However, habitat data are necessary for the establishment of environmental management policies.

The results of any classification of the vegetation should ultimately result in units which have some ecological or environmental significance. However, the Braun-Blanquet methodology demarcates vegetation units using only floristic attributes. The ecological significance of the units should be confirmed by comparing with habitat data (Werger, 1974).

The floristic units established by the above methodology correlate with some of the habitat characteristics presented in Appendix 5.3, particularly soil types. These units also compare well with those of more formal classifications undertaken in the area (e.g. Taylor, 1969; Boucher, 1978) However, for the establishment of a managerial information system, management units should be established and the vegetation units should be correlated with habitat characteristics which are managerially more meaningful (see Section 1.2.1).

A major disadvantage of the floristic system is the need to identify species. However, many of the dominant species could be identified from floristic guides (e.g. Kidd, 1983) and, although some cost might be involved, species might be taken to herbaria for identification (e.g. National Botanic Gardens; Botanical Reaerch Institute).

It is clear that, although the structural system might indicate some management units and might be used as an elementary classificatory tool, especially for the wetland vegetation types, the floristic system is superior for classifying vegetation for a managerial information system.

Chapter 6. Land-use Mapping Units

6.1 Introduction

Identifying and monitoring land-use change is basic to resource management and planning (Henderson, 1980). Notwithstanding the comments made in Section 3.2.1, a classification system is essential when using aerial photographs to determine the distribution of, and changes in, land-use patterns.

A classification system must establish units which have sufficient homogeneity to be recognized as separate entities (Brink *et al*., 1970). The units must allow easy recognition and definition which is essential for mapping purposes (Webb, 1954).

Consistency in photographic interpretation is inversly related to environmental complexity (Lintz and Simonett, 1979). A classification system is an attempt to reduce environmental complexity by categorization. Furthermore, environmental data must be simplified according to the needs of the proposed user. Although a classification system should consider all possible units and cover all cases (Robinove, 1981), the inclusion of more detail than is required could lead to unnecessary complexity and hence confusion. For example, a detailed floristic classification of fynbos results in the the distinction of various fynbos communities. Although the variety of communities is of scientific interest, the ecological significance of these communities might be doubtful (Campbell, 1985) and many of these communities would have similar management implications. Management units could, therefore, be classified according to a less complex system.

The choice of an *a priori* classification is subjective (Johnstone, 1968). As such, a classification system is a source of error and numerous attempts have been made to produce standard classification systems (Laut and Paine, 1982).

Unfortunately, indices of environmental quality vary temporally, between habitats and between individuals (Ashman and Bowden, 1972). No single classification technique can be developed to serve all users all the time, especially with the great variety of imagery types, scales, etc. which are available (Nunnally, 1974). For this reason, Nunnally's (1974) suggestion that specific units and classification systems be defined for each particular use, is realistic.

6.2 Methods

Photographic material for this study spanned forty years (see Appendix 6.1) from the earliest photographs available (1938 or 1944) to the most recent set of colour pictures (1979). The area of each study site varied so as to indicate the major changes in land-use and vegetation at each river mouth.

The data presented in Chapter 5 were analysed to indicate the various vegetation units present in this study area. Furthermore, non-vegetated and developed areas were also analysed to define the different land-use categories.

The ability to distinguish these vegetation and land-use units was checked for all the aerial photographs and, if necessary, units were combined to form mapping units which were recognizable from all the aerial photographs of a temporal series.

A Bausch and Lomb Zoom Transfer Scope (Model 53-05-04-23) was used to draw the outlines of each mapping unit from colour aerial photographs of 1979 (Job 326/79), thus producing a land-use map for 1979. A copy was made of this map and the next preceding aerial photograph of the temporal series was superimposed thereon. The land-use map was adapted by redrawing the land-use units so as to correspond with the earlier aerial photograph. This process was repeated until land-use maps had been drawn for all study sites and all aerial photographs of a temporal series.

In an attempt to quantify temporal changes, an area of approximately 250 m on either side of the river mouth by 1 km inland was selected. The area of each mapping unit within this selected area was measured with a digitizer (Kontron MOP AM 02) set on the enclosed area mode.

6.3 Results and Discussion

The identified mapping units could be classified into three basic types. The first type could be described as 'geological units'. Although these units did not necessarily exclude the presence of vegetation, the vegetation did not play an important role in their photographic signature. Included here were units such as rocks, water and sand.

The second type of mapping unit consisted of vegetation. Although different colours played an important role in the recognition of vegetation units from colour photographs, unit recognition using monochromatic photographs was largely dependent on differing structural forms. As such, some vegetation units, although recognizable from colour aerial photographs, could not be identified from monochromatic aerial photographs. Some vegetation units were, therefore, combined so as to be recognizable throughout the temporal series. For example, the presence of Sideroxylon inerme in some South Coast Strandveld communities was easily discernible from colour aerial photographs. However, on monochromatic photographs, this species could only be recognized in sheltered areas where its structure is that of a small tree or tall shrub (e.g. at the Buffels (east) River). In exposed areas, this species is usually wind-cropped and is not structurally different from the surrounding vegetation, making recognition impossible.

The third type of mapping unit relates to human development of the land. These developments are of various kinds and can commonly be referred to as 'land-use' units.

Thirteen mapping units are thus recognizable in this study area. The spatial distribution of these units throughout each temporal series is shown in Figures 6.1 to 6.11. The units are defined as follows :

1. Water : this unit does not necessarily exclude the presence of aquatic plants and does not include water within other units e.g. sewage works.

2. Rock : consists of rocky shores.

3. Sand and Pioneer Vegetation : this unit includes bare sand on the beaches and along the river courses as well as the sparse dune pioneer vegetation. This consists mainly of herbs (*Arctotheca populifolia*, *Tetragonia decumbens*) and grasses (*Ehrharta villosa*).

4. Dune Scrub : this includes the various strandveld communities (Moll *et al*., 1984; Taylor, 1980) occurring on calcareous sands in the area. It consists primarily of a broad-leaved scrub, up to 3 m tall, formed by an overstorey of *Chrysanthemoides monilifera*,

LEGEND (for Figures 6.1 to 6.11)

1 Water

2 Rocks

3 Sand and Pioneer vegetation

4 Dune Scrub

5 Wetlands

6 Riverine Scrub

7 Fynbos

8 Alien Scrub

9 Agricultural areas

10 Residential areas

11 Recreational areas

12 Industrial areas

═ Roads and Rail

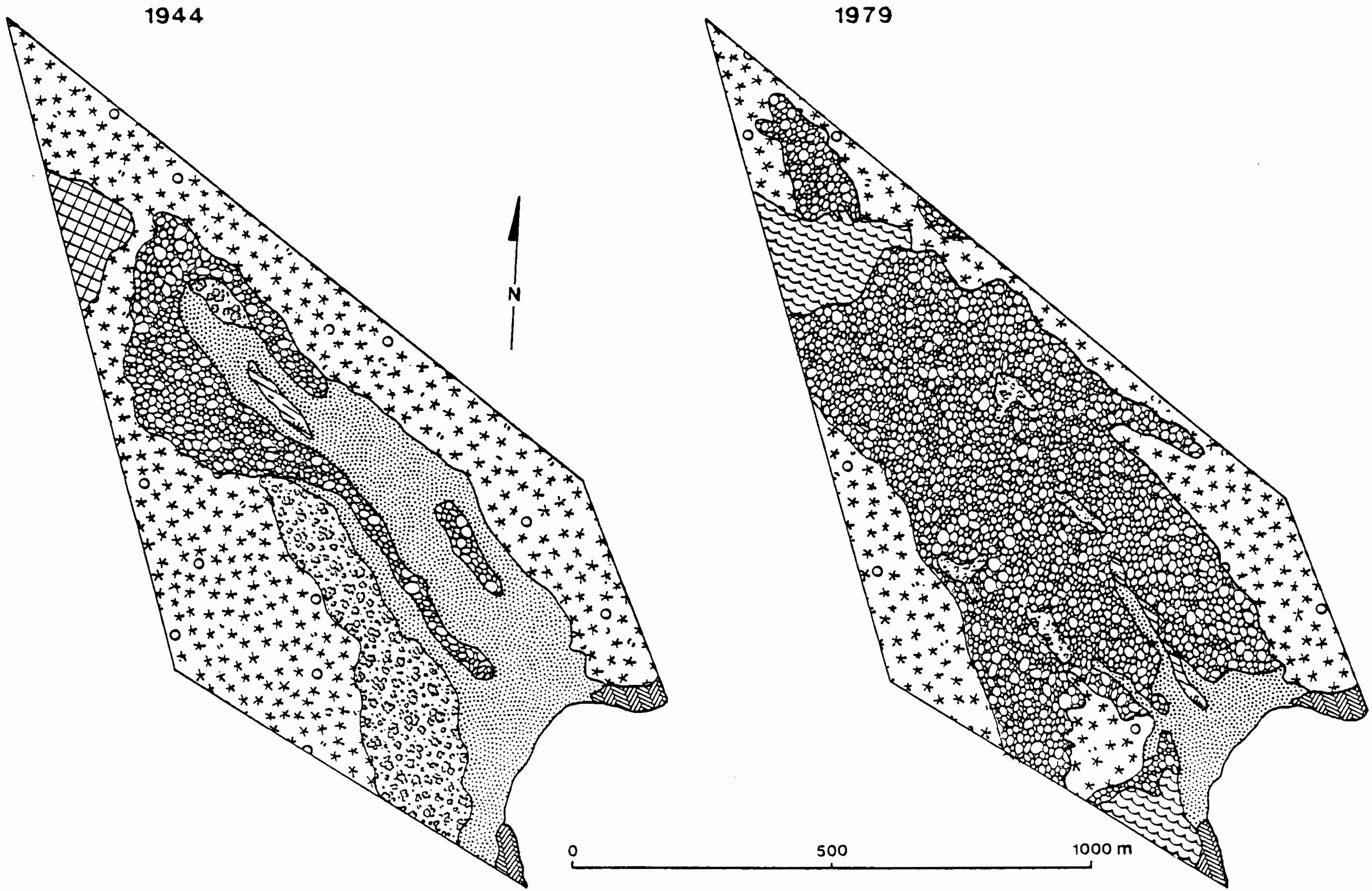

FIG. 6.1 Schematic representation of the mapping units identified at the Buffels(west) River.

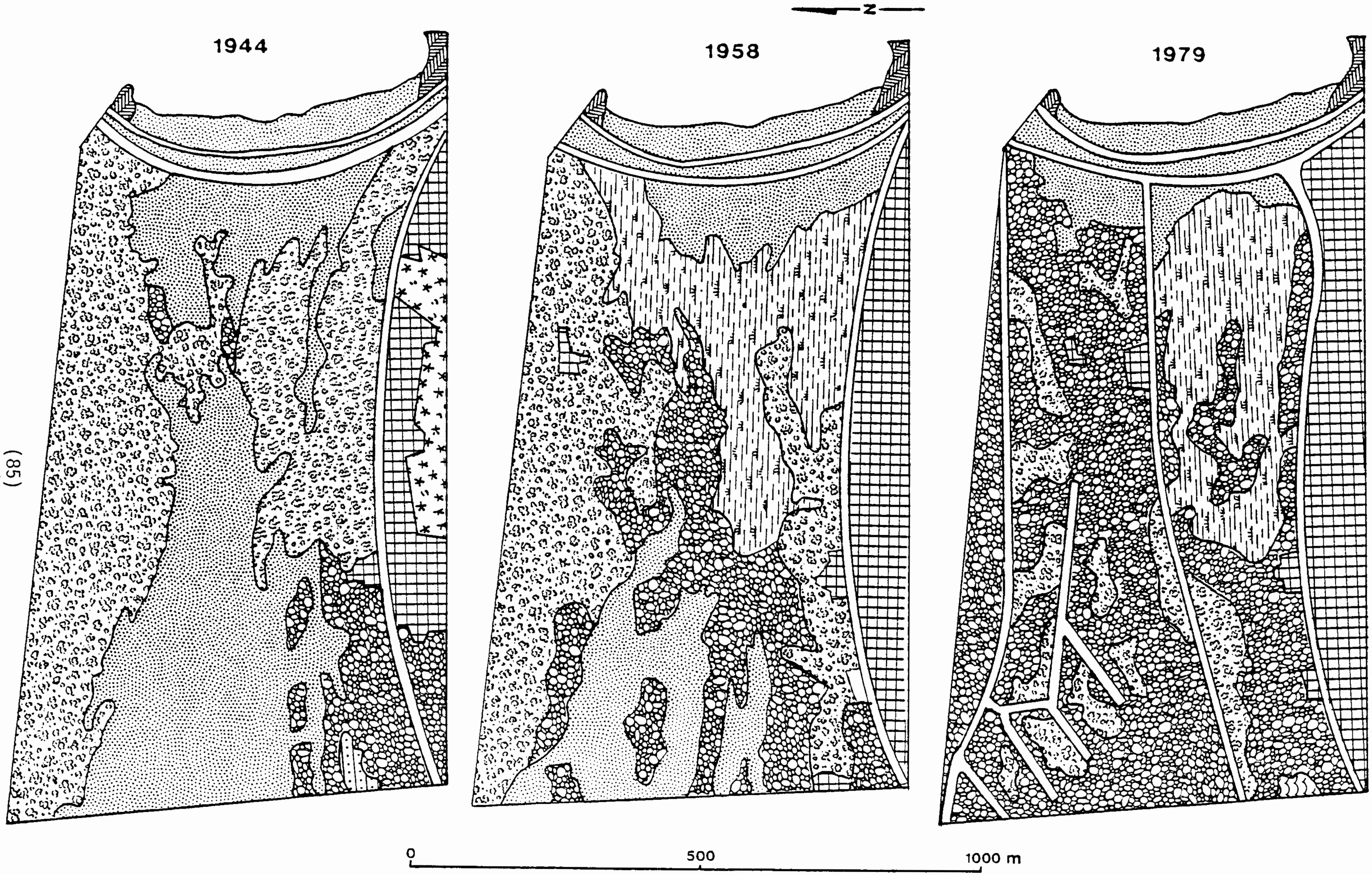

FIG. 6.2 Schematic representation of the mapping units identified at the Elsies River.

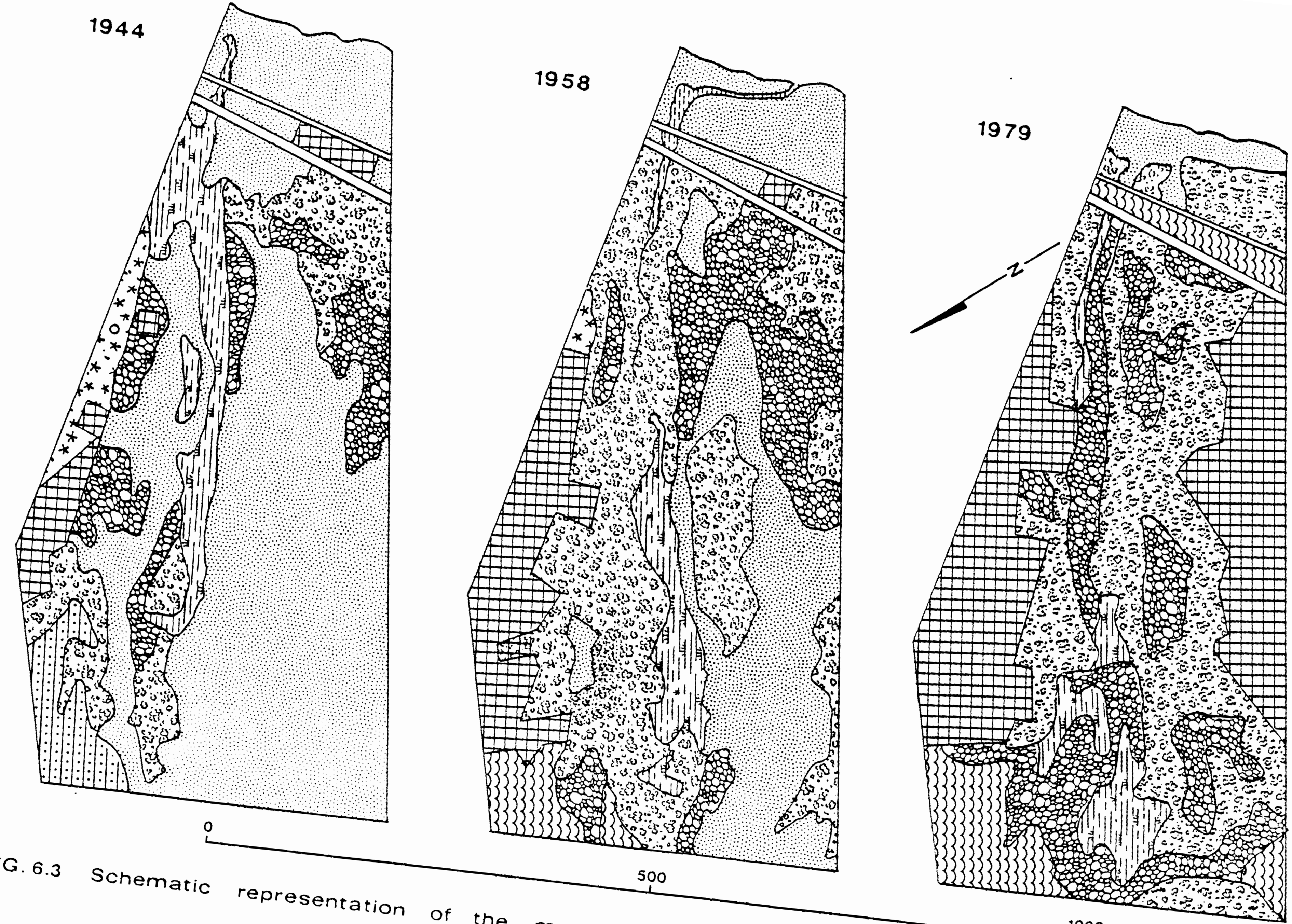

FIG. 6.3 Schematic representation of the mapping units identified at the Silvermine River.

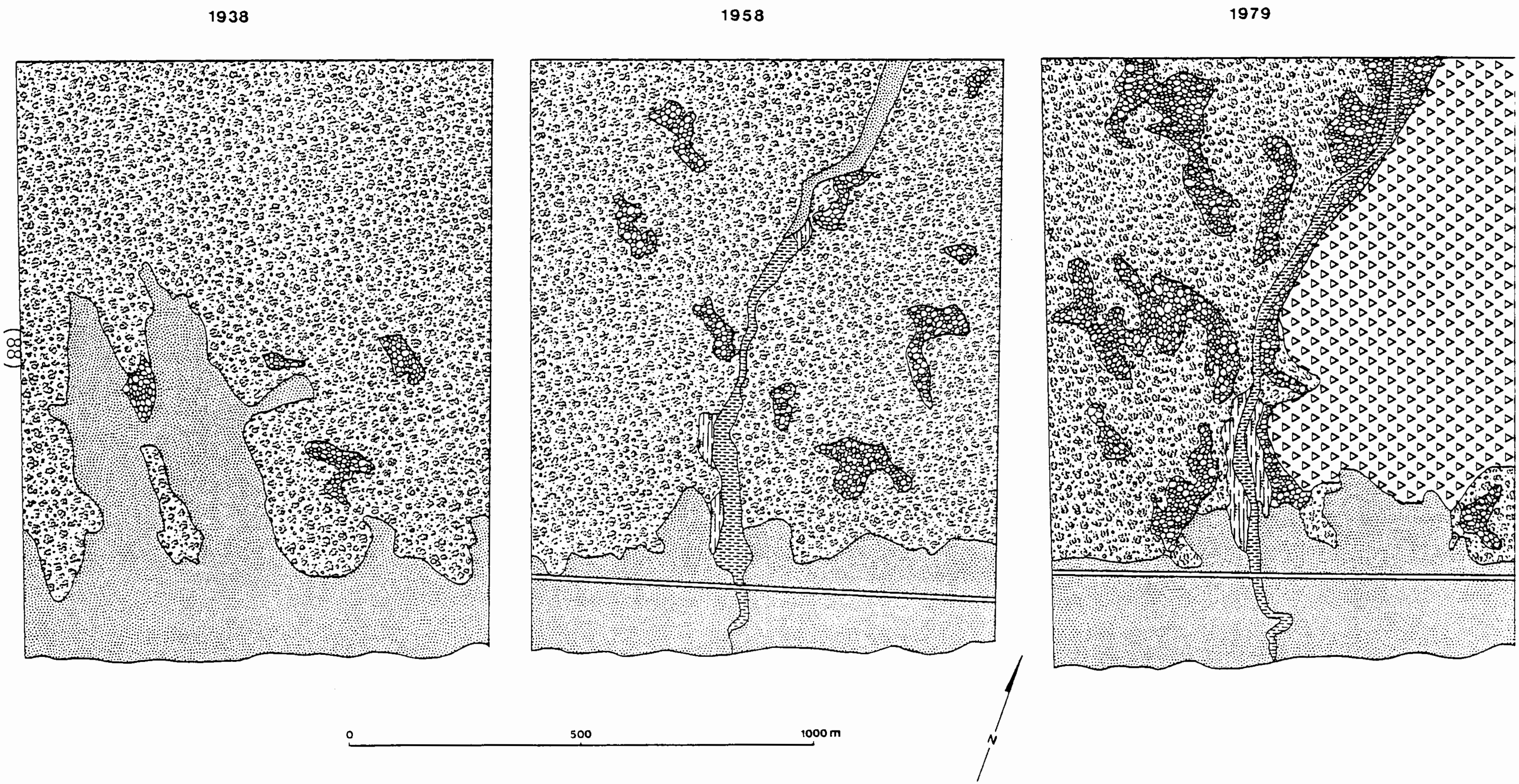

FIG. 6.5 Schematic representation of the mapping units identified at the Zeekoe River.

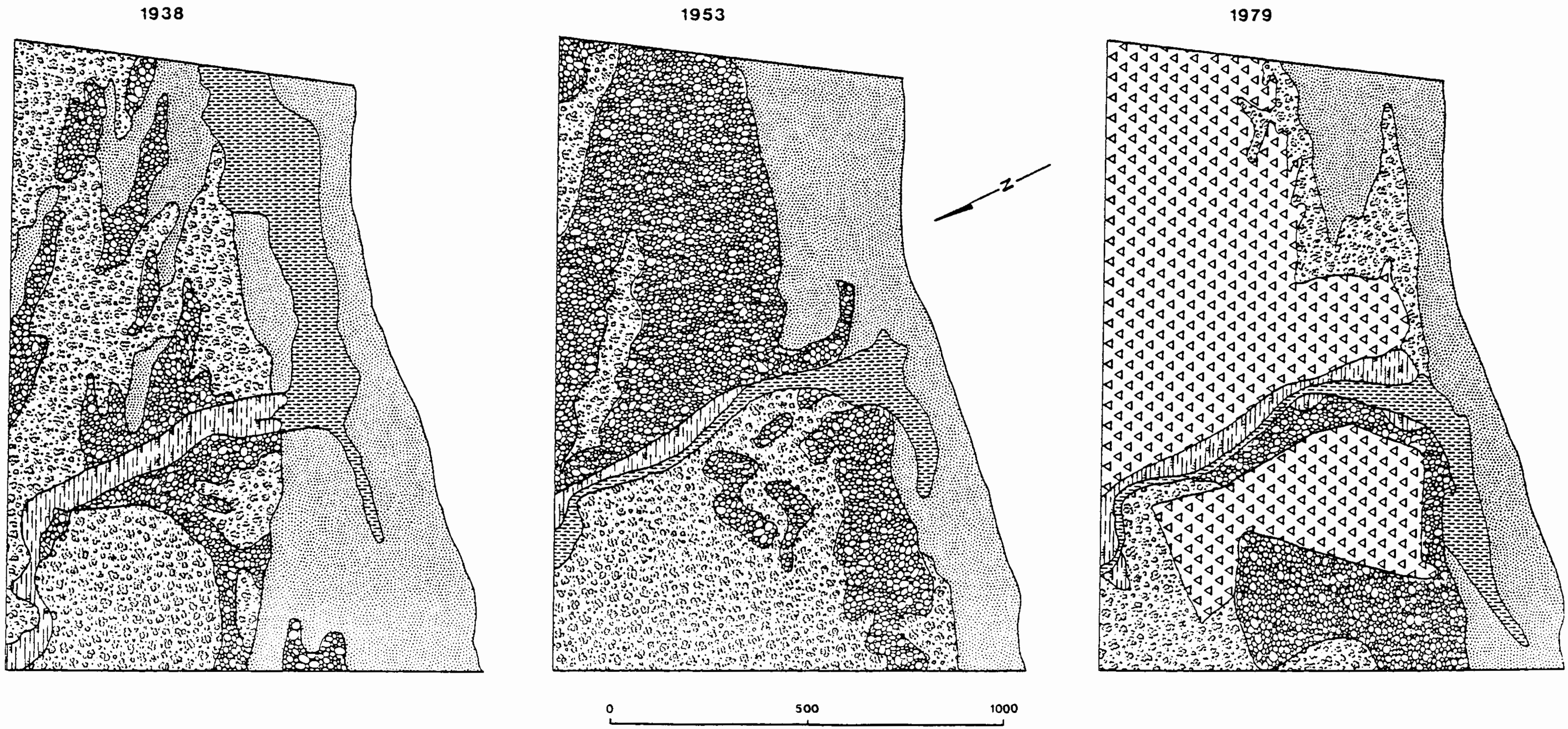

FIG. 6.6 Schematic representation of the mapping units identified at the Eerste River.

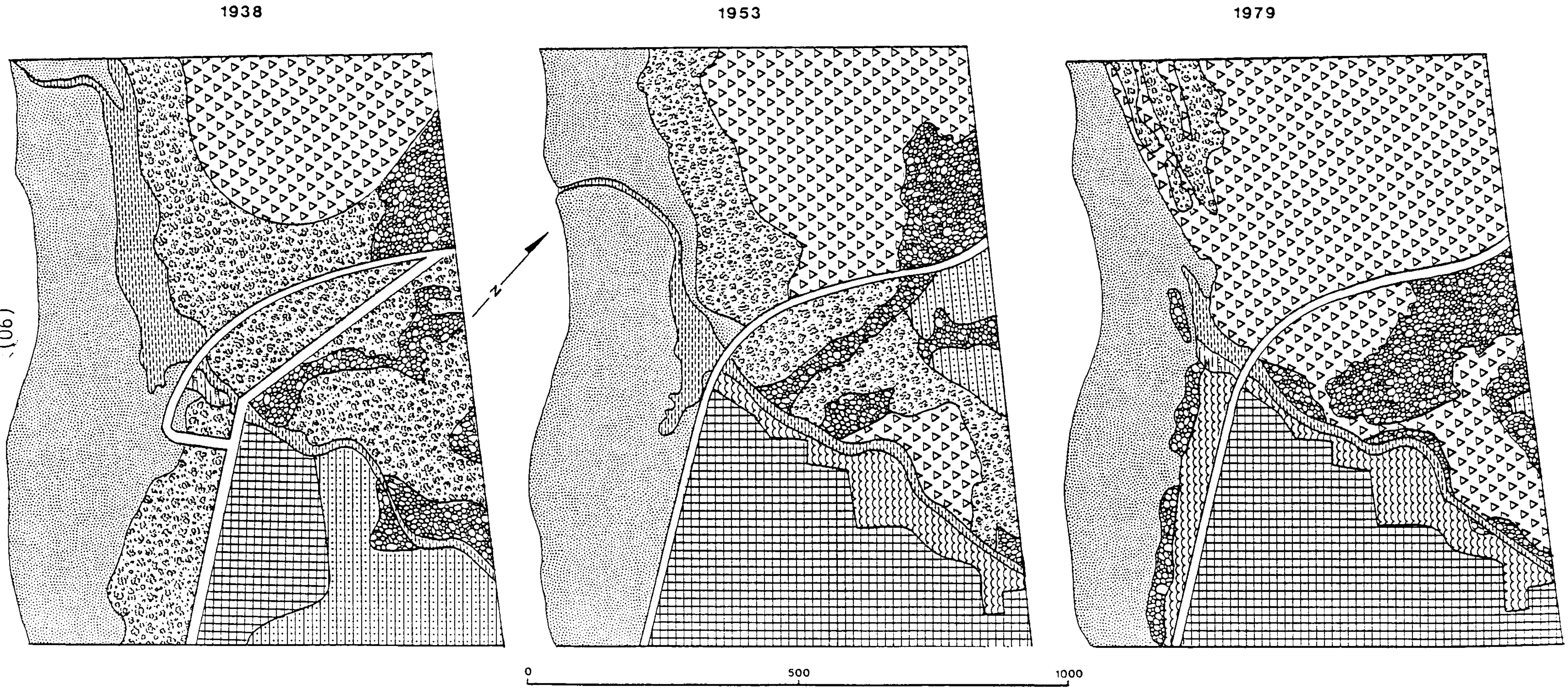

FIG. 6.7 Schematic representation of the mapping units identified at the Lourens River.

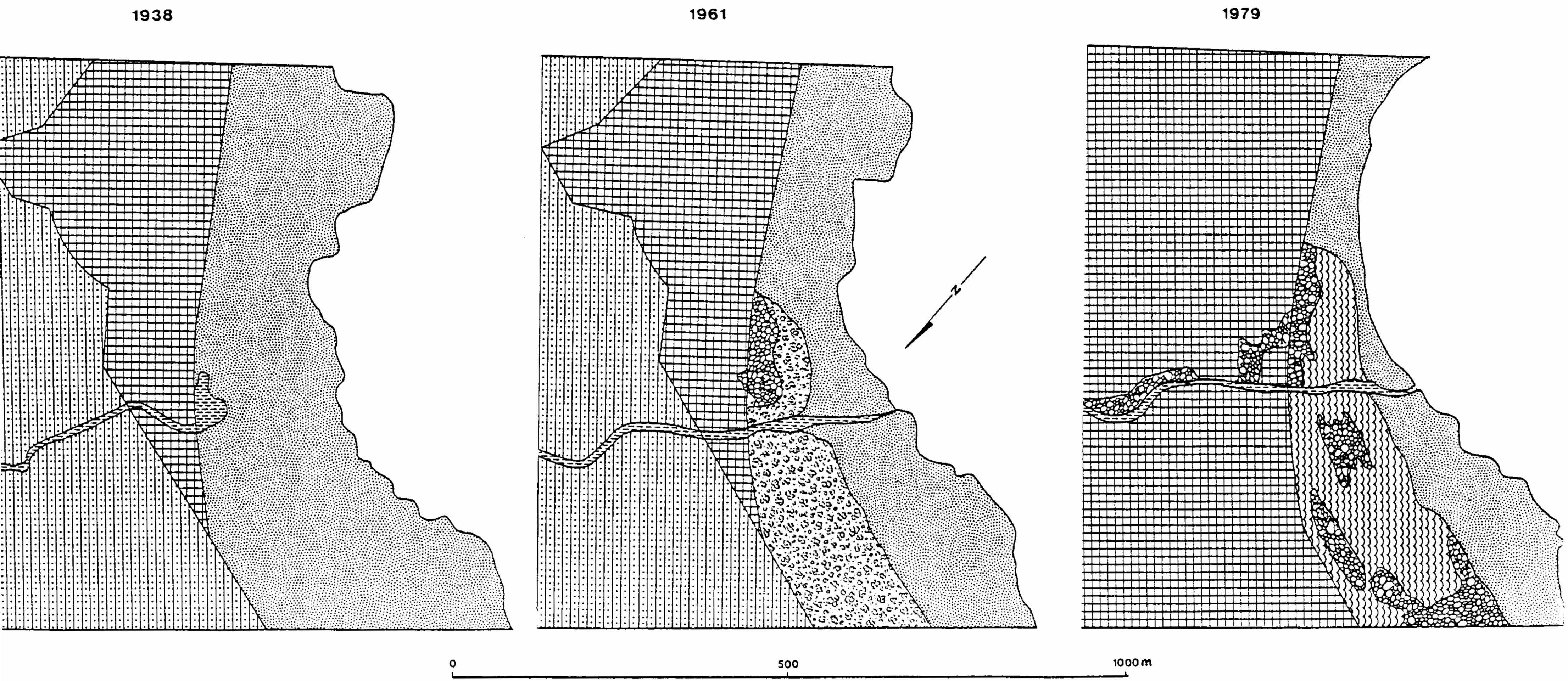

FIG. 6.8 Schematic representation of the mapping units identified at the Sir Lowry's Pass River.

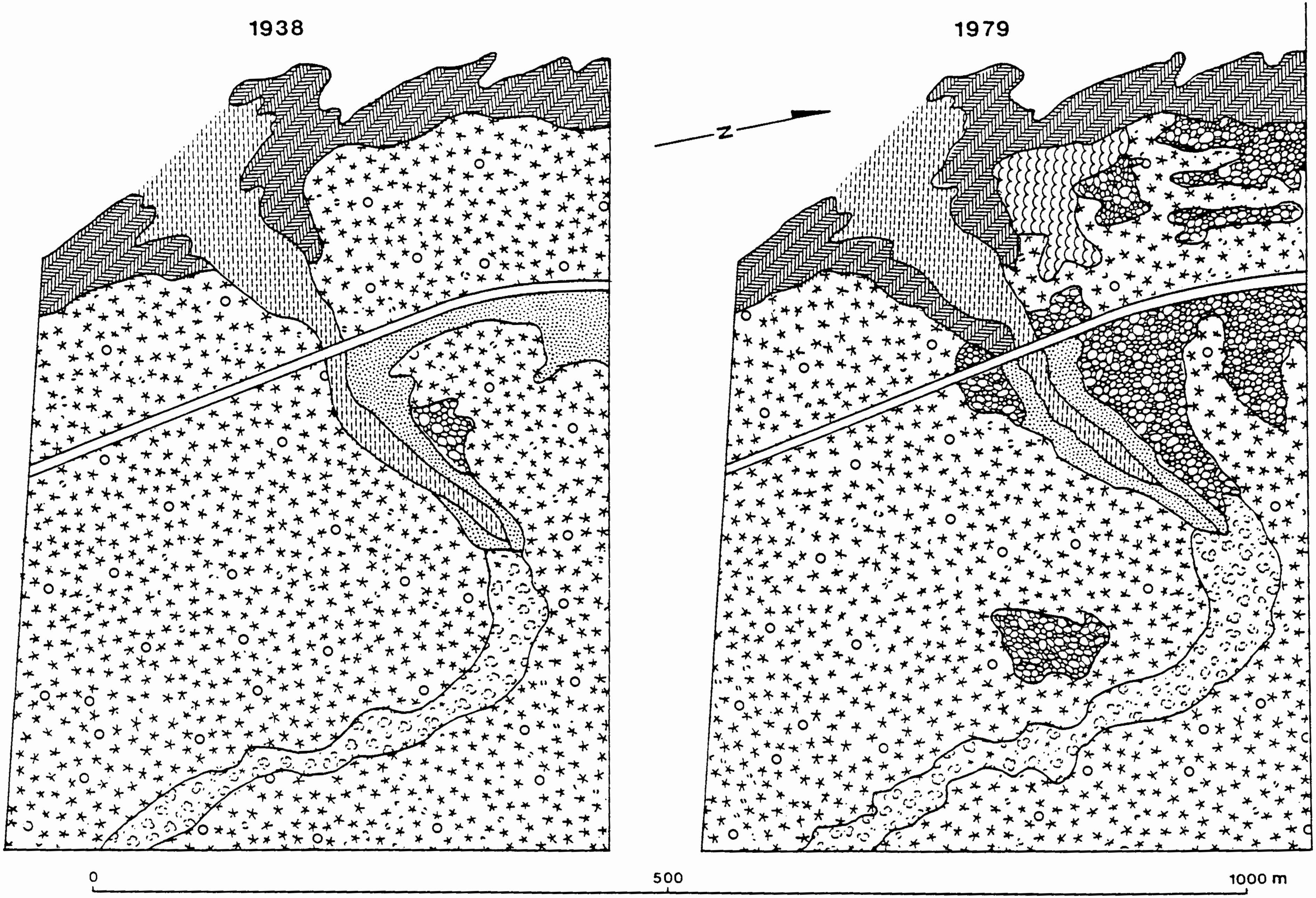

FIG. 6.9 Schematic representation of the mapping units identified at the Steenbras River.

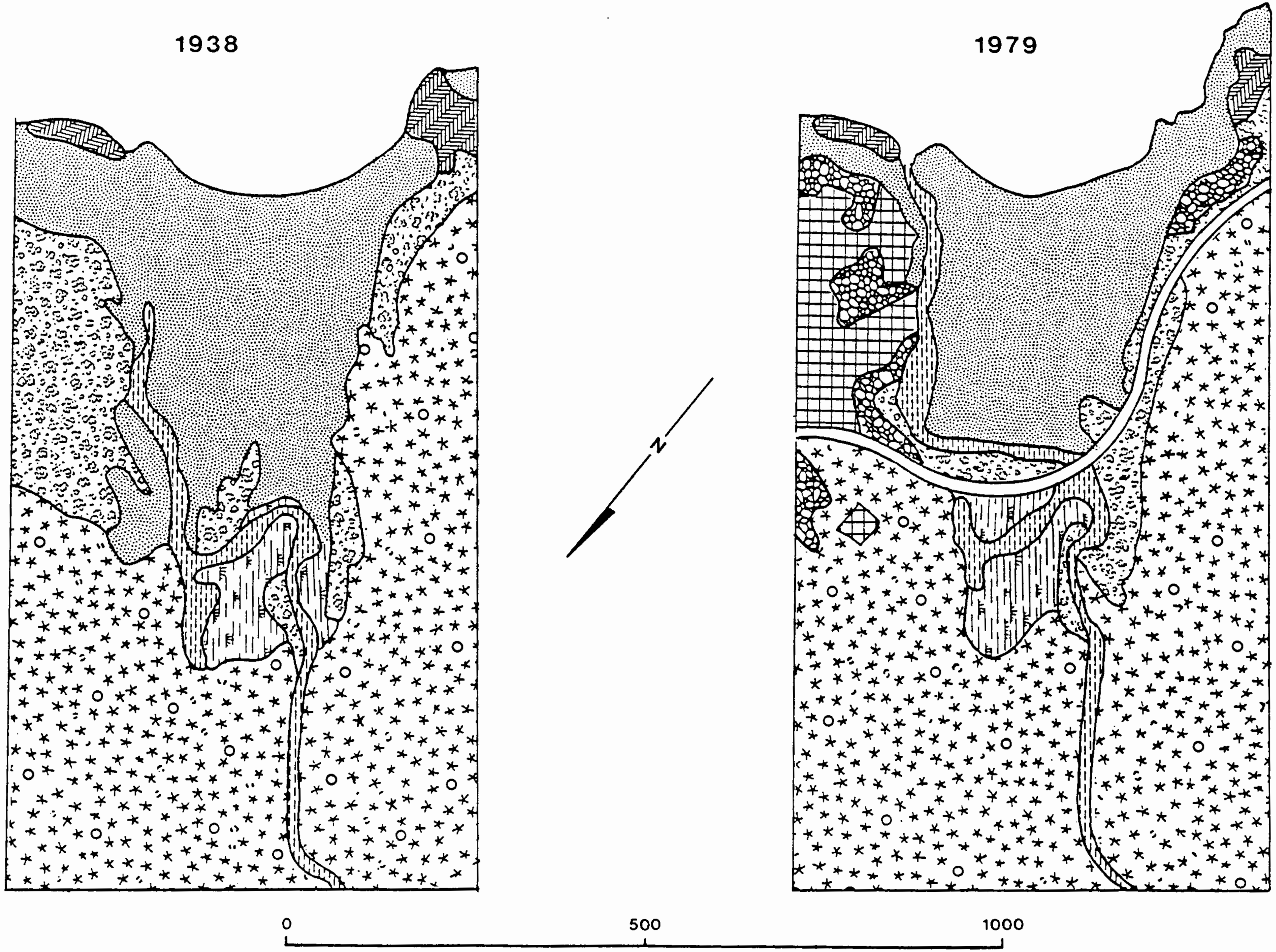

FIG. 6.10 Schematic representation of the mapping units identified at the Rooiels River

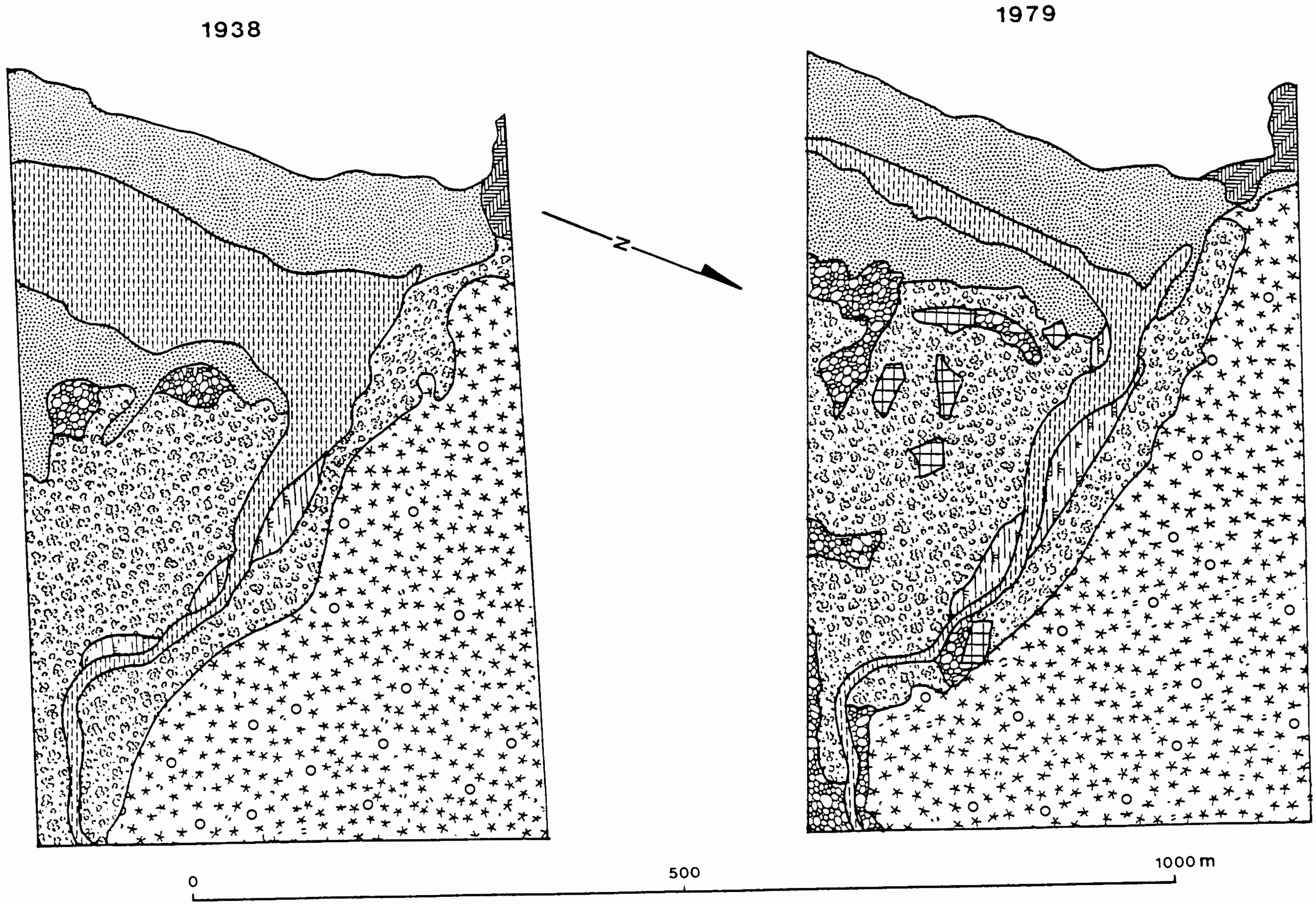

FIG. 6.11 Schematic representation of the mapping units identified at the Buffels (east) River.

Colpoon compressum, *Euclea racemosa* and sometimes *Sideroxylon inerme*. It often contains a lower stratum of *Metalsia muricata*, *Olea exasperata* and *Rhus* spp. with an understorey of *Restio eleocharis*, *Carpobrotus* spp. and *Stenotaphrum secundatum*.

5. Wetlands : this includes areas dominated by reeds, rushes and sedges such as *Phragmites australis*, *Typha capensis*, *Scirpus nodosus* and *Juncus kraussii*. Also included are wetlands containing herbs and grasses, such as, *Cotula coronopifolia*, *Paspalum vaginatum* and *Sarcocornia* spp.

6. Riverine Scrub : this vegetation was recognizable only at the Steenbras River. It consists of tall shrubs : *Brabeium stellatifolium*, *Heeria argenteum*, *Metrosideros angustifolia* and *Rhus lucida*, together with smaller plants, especially nearer the water : *Pelargonium angulosum*, *Pycreus polystachys* and *Restio subverticilata*.

7. Fynbos : the various fynbos communities (Moll *et al*., 1984; Taylor, 1980; Boucher, 1978; Taylor, 1969) are described by this unit. These are found on shallow sandstone soils and contain numerous species belonging mainly to the Restionaceae, Ericaceae, Proteaceae,

Asteraceae and Rubiaceae.

8. Alien Vegetation : dominated by alien plant species (see Stirton, 1978), usually acacias, pines or eucalypts.

9. Agricultural Areas : areas used for crops or grazing.

10. Residential Areas : areas used for housing.

11. Recreational Areas : includes caravan parks, car parks and tended public areas.

12. Industrial Areas : sites used for, or disturbed by industrial and/or commercial activities, including sewage works. Other units might have been included in these areas (e.g. 'Alien Vegetation' or 'Water'), but these were not distinguished.

13. Roads and Rail : includes well established roads and rail lines as well as road and rail embankments. Roads within other developed units (e.g. 'Residential Areas' or 'Industrial Areas') were not distinguished.

As each land-use map was used as a base for the preceding aerial photograph of a temporal series, the total areas of each land-use map of a temporal series should be the same, except for changes along the shore.

However, if the total area of each land-use map is calculated by summing the areas of each mapping unit, discrepancies are evident (Table 6.1). For example, at the Elsies River, there is a difference of 0,01 ha (0,02%) between the total areas studied for 1958 and 1979, while at the Buffels (east) River, there is a decrease of 9,61 ha (18,34%) in total area studied.

These discrepancies could be due to actual changes in the environment. However, error sources, some of which are mentioned in Section 3.2, could affect these data. For example, the recognition of the unit 'Alien Vegetation' varies if aliens do not have 100% cover in the observed unit. Small areas devoid of aliens plants were often included in this unit. Similarly, single alien plants were often included in other vegetation types. Furthermore, the borders of most units are curvilinear and errors might occur when measuring the area of small intricately bound units. As the land-use maps differ in scale, these errors would be random throughout the data.

When the areas measured for each mapping unit (Table 6.1) are reduced to a percentage of the total area used for areal measurements (Figure 6.12), trends are clearly discernible. Within this study area, from 1938/44 to 1979, Water (mapping unit (MU) 1) has shown an increase at Sandvlei, and at the Rooiels and Eerste Rivers, while it has decreased at the Lourens and Steenbras Rivers. There was a slight increase in the percentage area of sand (MU3) at Sandvlei and decreases of this unit at all

Table 6.1. The areas (ha) of each land-use unit for each of the aerial photographs studied

Study Site	Year	Land-use unit 1	2	3	4	5	6	7	8	9	10	11	12	13	Total
Buffels (west)	1944		0,73	12,19	5,48	0,48		11,53	5,52						36,73
	1979		0,68	3,03	0,87	0,31		5,45	25,34			0,38		0,56	36,62
Elsies	1944		0,64	16,87	13,15			5,58	4,26		2,63			2,66	45,79
	1958		0,71	8,10	15,17			2,37	12,21		4,98			2,70	46,24
	1979		0,66	4,57	4,26	7,85		1,41	14,31		8,41			4,76	46,23
Silvermine	1944		0,37	29,14	5,15	3,57		7,14	4,82		3,21			3,72	57,12
	1958	0,30	0,47	13,05	19,28	0,78		0,45	13,85		4,66			3,63	56,47
	1979	0,23	0,39	8,67	22,09	0,22			12,02		7,96	0,48		3,91	55,94
Sandvlei	1944	2,31		6,77	1,99	17,01		0,94			13,70	3,08		2,72	48,52
	1958	7,25		6,94	3,82	9,40		0,93			14,15	2,90		3,00	48,39
	1979	6,84		7,01	0,63						16,46	13,81		3,19	47,94
Zeekoe	1938			12,24	32,27				0,56						48,07
	1958	2,40		11,85	28,24	0,79			5,55						48,83
	1979	1,64		11,07	17,84	0,52			10,10				7,30		48,47
Eerste	1938	1,16		27,95	34,25	3,56			6,67						73,59
	1953	6,29		14,53	22,63	0,92			30,51						74,88
	1979	8,56		11,87	9,88	2,31			8,30				33,32		74,24
Lourens	1938	5,30		11,74	17,06				6,46	3,29	2,06		0,26	2,02	48,19
	1953	4,20		12,27	13,51	0,13			5,70	6,13	2,94		2,03	1,34	48,25
	1979	1,81		9,39	1,24	0,17			6,24	2,32	7,21	4,46	13,72	1,02	47,58
Sir Lowry's Pass	1938	0,51	2,39	11,00						26,74	2,63			1,61	44,88
	1961	1,53	1,47	4,89	5,15				0,67	26,07	3,83			1,04	44,65
	1979	0,33	2,34	4,57	0,19				1,03		30,45	4,94		0,66	44,51
Steenbras	1938	0,28	1,57	0,87			3,70	33,55	0,19					0,78	40,96
	1979	0,28	1,52	0,51			3,88	31,90	1,52			0,51		0,78	40,90
Rooiels	1938	1,83	1,54	13,02	6,84	1,60		7,61							32,44
	1979	4,93	0,91	7,96	3,78	2,19		8,07	0,79		2,82			1,11	32,56
Buffels (east)	1938	8,38	1,98	9,00	12,16	1,14		19,42						0,32	52,40
	1979	3,18	2,37	6,44	10,11	1,51		18,19	1,40		0,80			2,16	43,79

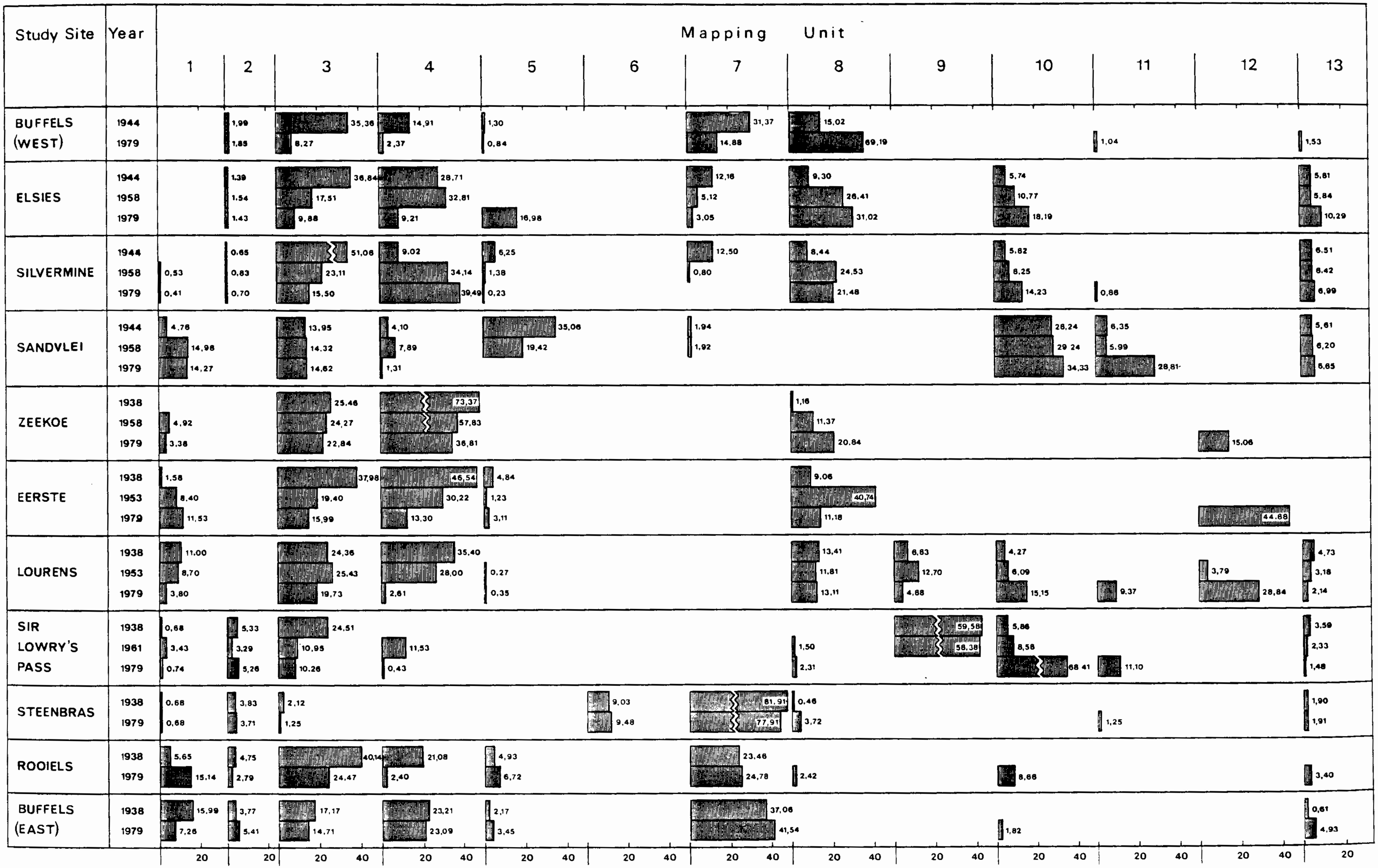

Fig. 6.12 The relative area (%) of each mapping unit for each aerial photograph studied.

the other rivers. Dune scrub (MU4) was never present at the Steenbras River. There was a decrease of this unit at all the other rivers except Silvermine, which showed a large increase from 1944 to 1958. Wetlands (MU5) increased only at the Elsies and Buffels (east) Rivers. The sharpest decrease of this unit was at Sandvlei : from 35,06% (1944) to 19,42% (1958) to 0% (1979). Fynbos (MU7) was at no stage found at the Zeekoe, Eerste, Lourens or Sir Lowry's Pass Rivers. There was a slight increase of this unit at the two most easterly rivers and a decrease at all the others. At all the rivers where alien vegetation (MU8) was found, this unit showed an increase. However, at the Eerste River, much of the area covered by this unit was incorporated into industrial areas (MU12) between 1953 and 1979. By 1979, agricultural areas (MU9) were to be found only at the Lourens River. At the rivers where residential (MU10), recreational (MU11) and industrial areas (MU12) were present, these units all increased during the study period. Although some rivers showed a decrease in roads and rail (MU13), these decreases were usually due to incorporation into other mapping units. In general, housing, recreation, industry and aliens have increased while open sand and natural vegetation units have decreased. Some of the factors which caused these changes are discussed in Section 8.3.1.

These trends, however, can also be inferred by observing the land-use maps. For example, the increase in alien vegetation at the Silvermine River (Figure 6.3) can be clearly seen. Furthermore, this map indicates that aliens plants spread from the southeast of the study area.

6.4 Conclusions

For management, general trends in temporal land-use patterns are useful to indicate the type and probable location of change. For this purpose, temporal land-use maps are a practical medium for portraying the data. For example, Figure 6.10 shows that a bridge was built across the Rooiels River between 1938 and 1979. Changes that might have occurred in the water flow patterns and distribution of wetlands in the vicinity of this bridge were probably brought about by this development (Heinecken, 1982b).

However, the accurate quantification of change will not only yield an accurate measurement of the rate of change, but sensitive areas, or areas where the most change has occurred, would be indicated with some confidence. These data, together with land-use maps, could be used to deduce the implications of management policies and should be included in a management information system.

Note

As some of the methods presented in the following chapters involve the use three-dimensional data matrices, the following convention was used to name variables :

1) The first upper case letter denotes the type of variable :

T = total area of a study site

M = area of a mapping unit

P or Q = area of different parts of a study site

L = a linear measurement of length

W = a linear measurement of width

A = a defined factor (co-efficient of change or alteration)

C = a defined variable (conservability)

D = a defined factor (central displacement factor)

E = a defined factor (environmental state)

I = a defined factor (environmental importance)

2) The second upper case letter, if present, denotes the method by which an area is measured :

*A = method 7.2.1

*B = method 7.2.2

*C = method 7.2.3

*D = method 7.2.4

The absence of a second upper case letter in a measurement of area indicates that the area has been corrected (see chapters 7 and 8).

3) Lower case letters in a variable name denote the source of the measurement or the dimension concerned :

a = an average

e = the distance from the centre of the aerial photograph to where the river enters the study site

l = the distance from the centre of the aerial photograph to where the river leaves the study site

m indicates that the measurement is concerned with a mapping unit, of which there may be a total of 13. However, the number of mapping units at a particular site might vary

o indicates that the measurement is taken from an orthophotographic map

p indicates that the measurement is taken from an aerial photograph

r indicates that the measurement concerns a study site or river, of which there are eleven

y indicates that the measurement concerns either of the two or three aerial photographs of a temporal series (i.e. photographs of different years).

For example :

Try = the total corrected area (see chapter 7) for each study site, for each aerial photograph of a temporal series.

Mrym = the corrected area (see chapter 7) of each mapping unit for each study site for, each aerial photograph of a temporal series.

4) In mathematical formulae, i and j are used as subscripts to refer to a particular aerial photograph of a temporal series and to a particular mapping unit at a study site respectively.

i = 1 to N where N = the number of photographs in a temporal series

j = 1 to U where U = the number of mapping units distinguished at a particular study site for a particular year.

Chapter 7. Quantifying Land-use Change

7.1 Introduction

Many errors can occur when using aerial photographs for mapping and a number of methods are available to correct these.

'Ground-truthing' techniques involve the establishment of a statistically valid sampling programme which is used to collect data from the field. These data are then compared with the maps and the degree of correspondence can be determined (Hord and Broomer, 1976; Van Genderen and Lock, 1976; Zeimetz *et al.*, 1976; Ginevan, 1979; Frazier and Shovic, 1980). These methods are often time-consuming and complex, and cannot be used to verify maps produced from old photographs, especially if many changes have taken place since the photographs were taken.

Another method for correcting maps is outlined by Baker *et al.* (1979). This involves producing an overlay map from the photograph, the verification of the identified mapping units in the field, and the subsequent projection of these units onto a corrected base map. Using this method, interpretive, scale and distortion errors are minimized. This method is feasible if residential areas are being studied and a high degree of correspondence exists between the photographs in a temporal series (e.g. Lo and Wu, 1984), or if numerous corresponding points are available between the land-use maps and the base maps. Difficulties will, however, be experienced when projecting the overlay onto the base map if the study area is of a dynamic nature.

The above methods rely on the *a posteriori* rectification of the maps. However, *a priori* rectification of the photographs will also diminish errors. This usually involves the use of costly photogrammetric and surveying techniques and/or equipment. However, when studying land-use change, it is not necessary to rectify all possible errors, but they must be systemized throughout the temporal series. For example, as height distortion is radial from the centre of the photograph, (Hart, 1940), the selection of those photographs with a similar distance between the centre of the photograph and the study site will systemize height distortion. Furthermore, although it might not be possible to accurately compare or overlay photographs of different scales and years, two or more corresponding points can usually be found between the different photographs of a temporal series. Further corresponding points can be determined by triangulation.

Paine (1981) discusses radial-line triangulation as a method of transfering points between photographs and between photographs and base maps. However, geometric triangulation, although less accurate, is an easier method for transferring points. This involves measuring the distance from at least two control points to the point which is to be transferred; compensating for differences in scale and transferring these distances to the next photograph or base map. By maximizing the distance between the control points while keeping the distances between the control points and the transferred point to a minimum, fairly accurate results can be obtained.

7.2 Methods

To minimize the intrinsic errors between the photographs of a temporal series, the relative distance between the study site and the centre of the photograph was determined for each of the available photographs (Appendix 8.1). This measurement, the central displacement factor (Dp), was calculated by using the following formula:

$$Dp = 100 \left(\frac{Lep + Llp}{2} \right) / Wp$$

(Dp = central displacement factor (%); Wp = width of the photograph (cm); Lep = distance from the centre point of the photograph to the middle of the river where the river enters the study site (cm); Llp = distance from the centre point of the photograph to the middle of the river mouth or to the middle of the river where the river leaves the study site (cm)).

A temporal series of photographs was selected as having the most similar Dp (Appendix 7.1).

After an indication of the approximate scale of each aerial photograph had been determined by comparison with orthophotos, the aerial photographs were photographically enlarged to an approximate scale of 1:10 000.

The study sites were selected as being approximately 250 m on either side of each river mouth, by 1 km inland from the shore. With the use of a Bausch and Lomb Zoom Transfer Scope (Model 53-05-04-21), an area of 5 cm x 5 cm in the centre of the study site was compared with the orthophotos to determine the scale of each enlarged aerial photograph (Appendix 7.1).

Quantitative measurements of the distortions caused by the lenses of the Bausch and Lomb Zoom Transfer Scope (Model 53-05-04-21) are not available. However, these distortions can be observed visually and are, therefore, large enough to affect measurements. When using this instrument, it was ensured that the centre of the area under study was in the centre of the Transfer Scope.

After the scale of each aerial photograph had been calculated, the exact dimensions of each study site were determined by geometric triangulation from at least two recognizable points on each aerial photograph.

The outlines of each study site were drawn directly onto the aerial photographs and the outlines of each mapping unit were traced onto transparent film overlays on the aerial photographs.

The total area of each study site was determined in the following ways :

7.2.1 By averaging five repeated measurements using a Kontron AM 02 digitizer (TAry).

7.2.2 By averaging five repeated measurements using a Summagraphics TD digitizer (TBry).

7.2.3 By summing the areas of each mapping unit which had been measured with the Kontron digitizer (TCry).

7.2.4 By cutting out the maps of each study site and weighing on a top-loading chemical balance (Mettler PC 440). These weights were transformed into areas by comparison with the weight of a known area of mapping material.

Another relatively inexpensive method to measure areas would be to use a planimeter. However, this is more time-consuming than using a digitizer and was not used for this study.

7.3 Results and Discussion

From Table 7.1, it can be seen that numerous discrepancies still occur in the data. If it is assumed

Table 7.1. The total area (ha) of each study site as measured by methods 7.2.1 (TAry), 7.2.2 (TBry), 7.2.3 (TCry) and 7.2.4 (TDry)

Study Site	Year	Total Area (ha)			
		TAry	TBry	TCry	TDry
Buffels (west)	1944	39,47	37,94	35,39	39,49
	1979	36,77	35,18	35,40	35,59
Elsies	1944	37,00	36,86	36,23	36,59
	1958	38,70	37,63	38,04	38,24
	1979	39,53	37,49	38,90	39,23
Silvermine	1944	49,12	50,88	47,52	49,67
	1958	52,67	48,17	50,51	50,90
	1979	49,01	46,74	48,60	47,23
Sandvlei	1944	53,91	48,80	52,89	52,64
	1958	50,69	47,58	49,74	50,52
	1979	49,60	49,50	48,60	48,44
Zeekoe	1938	43,24	46,86	42,92	42,93
	1958	49,49	46,64	50,23	49,85
	1979	49,19	47,97	48,55	48,53
Eerste	1938	54,27	49,38	50,93	52,15
	1953	50,33	48,16	49,97	50,93
	1979	51,81	49,35	51,72	51,90
Lourens	1938	31,16	31,79	32,64	29,98
	1953	37,52	40,33	37,01	36,14
	1979	35,37	34,18	34,87	34,22
Sir Lowry's Pass	1938	22,13	22,37	21,73	21,50
	1961	24,58	24,07	20,09	23,63
	1979	24,29	22,88	23,90	23,95
Steenbras	1938	52,75	48,70	53,11	54,75
	1979	52,49	49,38	52,44	52,01
Rooiels	1938	49,19	44,87	47,47	45,82
	1979	44,57	43,48	44,98	43,66
Buffels (east)	1938	40,33	37,48	39,77	41,76
	1979	40,27	37,21	39,11	39,56

that method 7.2.4 (by weight, see Section 3.2.2) is the most accurate way of determining areas, these areas can be used to determine the accuracy of the other methods. By using a Wilcoxin rank-sum test for paired data (Armore, 1973), the total areas obtained by using methods 7.2.1, 7.2.2 and 7.2.3 were compared with the total areas obtained by using method 7.2.4 (TAry, TBry, TCry and TDry respectively). The following z-scores were thus obtained :

TAry with TDry : -2,497

TBry with TDry : -2,368

TCry with TDry : -0,875

In other words, the results of the different methods are significantly different from TDry at the 50,64%; 50,91% and 69,22% levels respectively.

From these z-scores, it can be assumed that :

a) The more intricate the outline of each mapping unit, the more accurate the results using the digitizer.

b) Although the Summagraphics digitizer can measure up to 0,1 mm^2 (as opposed to 1 mm^2 for the Kontron digitizer), it is not more accurate. The reasons for this are not known, but could be as a result of differences in the functioning of the equipment.

c) Using a digitizer to measure the areas of the mapping units can result in an error of 30,78% to

49,36%.

7.3.1 Correction of Errors

In an attempt to standardize the areas of each photograph of a temporal series, the following was undertaken :

Points A, B, C and D (see Figure 7.1) were determined on the aerial photographs of 1979 (Job 326/79) so that ABCD is the study site.

Points E and F were determined so that AE = BF = 200 m in real terms. The length of AE and BF, therefore, varied on the photographs according to the scale.

Points A ,B, C, D, E and F for each study site were transferred by geometric triangulation to the orthophotos and to the aerial photographs of preceding years for each temporal series.

The areas of CDEF were calculated for each photograph and orthophoto using the weighing method (7.2.4) (see Table 7.2).

From Table 7.2 :

Let PDry = the area of quadrangle CDEF for each aerial photograph of a temporal series as determined by the weighing method (7.2.4).

Let PDro = the area of quadrangle CDEF as measured from each orthophoto by weight.

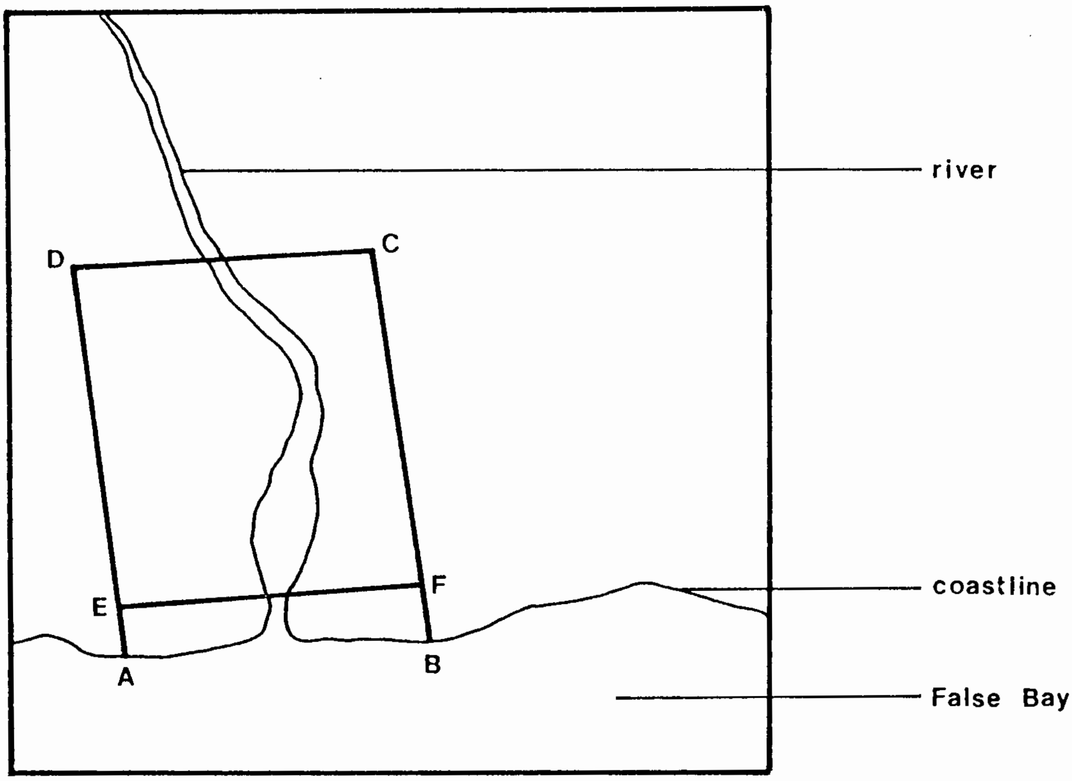

FIG. 7.1 An aerial photograph of 1979 showing the study site (ABCD) and Pry (CDEF, see text).

Table 7.2. The areas of quadrangle CDEF (ha) as measured from each aerial photograph of a temporal series (PDry), from the orthophotos (PDro) and the number of aerial photographs in each temporal series (N)

Study Site	PDry			PDro	N
	1938/1944	1953/1958/1961	1979		
Buffels (west)	34,40		31,75	29,93	2
Elsies	32,51	34,19	36,47	34,21	3
Silvermine	39,85	41,82	42,32	35,20	3
Sandvlei	44,18	41,06	40,06	39,14	3
Zeekoe	36,58	40,89	38,20	41,45	3
Eerste	38,90	42,10	40,94	39,98	3
Lourens	26,38	27,33	28,64	28,29	3
Sir Lowry's Pass	15,62	15,95	17,28	13,98	3
Steenbras	41,44		41,85	35,03	2
Rooiels	42,97		40,45	40,79	2
Buffels (east)	32,75		35,94	34,21	2

Let N = the number of photographs in a temporal series.

From Table 7.1 :

Let TDry = the total area of each study site as measured by weight.

When measuring PDry, inaccuracies due to photographic and methodological error might occur (see Section 3.2.3). However, the orthophoto does not contain photographic error and, for each photograph, where i = 1 to N, an estimate of the photographic error :

$$(\text{photographic error}) = PDry_i - PDro_i$$

As deposition and erosion of sand at the shore is the only reason why the real area of a study site should change within a temporal series,

$$PDry_i = PDry_{(N-1)} = PDry_N$$

and the average of these would be a closer approximation of the area of CDEF, i.e.

$$PDra = \sum_{i=1}^{N} \frac{PDry_i}{N} \qquad (1)$$

(see Table 7.3)

Similar methods were used to measure areas from all the aerial photographs and orthophotos, thus, methodological error would be similar. The average methodological

Table 7.3. The average measured (PDra) and the average corrected (Pra) area (ha) of quadrangle ABFE

Study site	PDra	Pra
Buffels (west)	33,08	31,51
Elsies	34,39	33,64
Silvermine	41,33	39,43
Sandvlei	41,77	40,89
Zeekoe	38,56	39,30
Eerste	40,65	40,43
Lourens	27,45	27,73
Sir Lowry's Pass	16,28	15,51
Steenbras	41,65	38,35
Rooiels	41,71	41,25
Buffels (east)	34,35	34,44

error would be :

$$PDro - \left[PDra - \frac{\sum_{i=1}^{N} \left(PDry_i - PDro \right)}{N} \right]$$

The corrected area of CDEF would be :

$$Pry_i = PDry_i - \left[(\text{photograhic error})_i + \left(\begin{array}{c} \text{average} \\ \text{methodological} \\ \text{error} \end{array} \right) \right]$$

Alternatively,

$$Pry_i = PDry_i - \left\{ PDro - \left[PDra - \frac{\sum_{i=1}^{N} \left(PDry_i - PDro \right)}{N} \right] \right\} + PDry_i - PDro$$

$$= PDry_i - \left\{ PDro - \left[PDra + \frac{\sum_{i=1}^{N} \left(PDro - PDry_i \right)}{N} \right] + PDry_i - PDro \right\}$$

$$= PDry_i + \left[PDra + \frac{\sum_{i=1}^{N} \left(PDry_i - PDro \right)}{N} \right] - PDry_i$$

$$= PDra + \sum_{i=1}^{N} \frac{\left(PDro - PDry_i\right)}{N} \qquad (2)$$

Now, the measured area of ABFE :

$$QDry_i = TDry_i - PDry_i$$

and the corrected area of ABFE :

$$Qry_i = Try_i - Pry_i$$

Thus, the ratio

$$\frac{Pry_i}{PDry_i} = \frac{Qry_i}{QDry_i}$$

therefore,

$$Qry = \frac{\left(Pry_i\right)\left(QDry_i\right)}{PDry_i}$$

$$= \frac{Pry_i\left(TDry_i - PDry_i\right)}{PDry_i} \qquad (3)$$

For each photograph,

the corrected area of ABCD = CDEF + ABFE i.e.

$$Try_i = Pry_i + Qry_i$$

Substitute (2) and (3) :

$$PDra + \sum_{i=1}^{N} \frac{(PDro - PDry_i)}{N} + \frac{(Pry_i)(TDry_i - PDry_i)}{PDry_i}$$

substitute (1) :

$$= \sum_{i=1}^{N} \frac{(PDry_i)}{N} + \sum_{i=1}^{N} \frac{(PDro - PDry_i)}{N} + \frac{(Pry_i)(TDry_i - PDry_i)}{PDry_i}$$

$$= PDro + \frac{(Pry_i)(TDry_i - PDry_i)}{PDry_i}$$

However, the areas of ABFE should be the same (see above) and the average of Pry would be a closer approximation of ABFE, i.e.

$$Pra = \sum_{i=1}^{N} \frac{Pry_i}{N}$$

(see Table 7.3)

and

$$Try_i = PDro + \frac{(Pra)(TDry_i - PDry_i)}{PDry_i}$$

(Try = the corrected total area of each study site; PDro = the area of quadrangle CDEF on the orthophoto as measured by method 7.2.4 (by weight); Pra = the average corrected area of quadrangle CDEF from the aerial photographs; TDry = the total area of each study site from the aerial photographs as measured by method 7.2.4 (by weight); i = 1 to N; N = the number of photographs in a temporal series).

The results of this correction procedure are shown in Table 7.4 and, as can be seen, there does not seem to be any observable pattern in the difference between TDry and Try for each study site. Height distortion is the most serious type of displacement (Paine, 1981). Points above the photographic datum line would be displaced away from the centre of the photograph while points below the photographic datum line would be displaced towards the photographic centre. Measured distances and areas would, therefore, be an overestimate of the true distances and areas, depending on the distance from the centre of the photograph (see Section 3.2.3.2). However, measurements taken at, or close to, the centre of the photograph would be an underestimate of true measurements as height differences are being projected onto a flat plane.

Table 7.4. Total uncorrected (TDry) and total corrected (Try) area (ha) for each study site for each aerial photograph of a temporal series

Study site	Year	TDry	Try
Buffels (west)	1944	39,49	38.87
	1979	35,59	38,02
Elsies	1944	36,59	38,43
	1958	38,24	38,19
	1979	39,23	36,76
Silvermine	1944	49,67	44,92
	1958	50,90	43,76
	1979	47,23	39,77
Sandvlei	1944	52,64	46,97
	1958	50,52	48,56
	1979	48,44	47,69
Zeekoe	1938	42,93	48,27
	1958	49,85	50,06
	1979	48,53	52,07
Eerste	1938	52,15	53,71
	1953	50,93	48,46
	1979	51,90	50,80
Lourens	1938	29,98	32,07
	1953	36,14	37,23
	1979	34,22	33,69
Sir Lowry's Pass	1938	21,50	19,82
	1961	23,63	21,44
	1979	23,95	19,97
Steenbras	1938	54,75	47,36
	1979	52,01	44,34
Rooiels	1938	45,82	43,53
	1979	43,66	44,06
Buffels (east)	1938	41,76	43,68
	1979	39,56	47,68

A t-test for related samples (Miller, 1978) shows that the changes brought about by this correction procedure are significant at the 95% level.

7.4 Conclusions

It is not possible to determine the accuracy of Try without extensive field observations. However, the Steenbras River enters the sea on a rocky coast and there should be no difference for Try_1 and Try_N for this site. Furthermore, sedimentary changes at the Buffels (west) River appear to be under the control of local current, wave and wind conditions (Heinecken _et al_., 1982). The differences between Try_1 and Try_N for these sites should be minimal. However, from Table 7.4, the percentage difference between Try_1 and Try_N for these sites is 6,68% and 2,23% respectively. Both these sites have a highly variable topography, but the Steenbras River runs through an incised valley, much of which is in shadow on the aerial photographs. Measurements at this site, therefore, are prone to a high degree of error. Nevertheless, this correction procedure has a maximum error of less than 10%. By comparison, Turner (1982) used computer methods to analyse digitized aerial photographs and found a 62% correspondence between the computer analysis and the real state. After a visual correction procedure, he obtained an 82% (75% for vegetated areas) correspondence which he accepted. For the correction procedure described above, it is not possible to determine the degree of correspondence between the photographic interpretation and the real state, particularly for the older photographs. However, discrepansies between the photographs of a temporal series are acceptable. would seem that the correction procedure described above produces acceptable results.

This methodology does not require complicated verification techniques nor sophisticated equipment to quantify land-use areas and changes. It is also versatile and can be applied to dynamic areas such as coastal and estuarine habitats. This methodology is, therefore, well suited to the collection of data by environmental managers.

Chapter 8. <u>Evaluating Land-use Changes</u>

8.1 Introduction

False Bay was discovered by the early Portuguese seafarers and the first management proposal, that a channel be built between False Bay and Table Bay, was made in 1655 (Burman, 1977). The first permanent structure was erected on this coast in 1673 (Malan, 1982) and numerous minor developments affected this coast until the First British Occupancy of the Cape (1795) initiated the development of the coast between Simonstown and Muizenberg (Malan, 1982).

Although facts such as those above can be gleaned from archival records, the environmental changes caused by these developments can only be deduced. For example, the name of the Elsies River could have been derived from the 'Wit-els' (<u>Platylophus trifoliatus</u>) or 'Rooi-els (<u>Cunnonia capensis</u>) trees (Burman, 1962), which might have been found in this river valley. However, no traces of these trees are to be found in this valley at present.

Much data can also be gleaned from personal observations. For example, the lower Elsies River valley, due to poor soil conditions, was not subjected to intensive farming activities (D. de Villiers, pers. comm.). This area is a wetland at present , but might have been covered by heath-like vegetation during the late 19th to early 20th century (Burman, 1962).

Unfortunately, these sources of historical information are not very reliable. For example, in 1687, Simon van der Stel discovered that the lower Silvermine River valley was well wooded (Bekker, 1980). However, the marshiness of this area prevented the coastal road from being continued past Kalk Bay until late last century (Dickson, 1974). In this area, one does not find wooded wetlands and to circumvent such discrepancies in the historical record, one could rely on the writings of the early botanists and explorers, e.g. Sparrman (1776), Thunberg, (1793) and Patterson (Forbes and Rourke, 1980). Although the observations of these travellers might be more objective, they are usually too specific to allow conclusions to be drawn about the general state of the vegetation.

Although some scientific and semi-scientific data might exist for the area (e.g. Stephens, 1929), it was not until the advent of aerial photography in the 1930s that a reliable source of environmental data became available. By using aerial photographs and some of the above information sources, some of the environmental changes around the estuaries of False Bay can be explained.

8.2 Methods

The study area was selected as consisting of eleven study sites, each approximately 250 m on either side of each river mouth, by 1 km inland from the coast.

The methods outlined in chapter 7 were used to obtain the following data :

MCrym = the area of each mapping unit as measured by the Kontron AM 02 digitizer.

TCry = the total area of each study site as ascertained by summing the areas of MCrym for each study site for each aerial photograph (from Table 7.1).

Try = the corrected area for each study site (from Table 7.3).

From these data, the corrected area for each mapping unit for each aerial photograph of a temporal series was determined by using the formula (Table 8.1) :

$$Mrym = \left(\frac{MCrym_{ij}}{TCry_{i}} \right) Try_{i}$$

(Mrym = corrected area for each mapping unit on each aerial photograph of a temporal series (ha); MCrym = area of each mapping unit on each aerial photograph of a temporal series as measured by the Kontron digitizer (ha); TCry = total area of each study site for each aerial photograph of a temporal series as measured by method 7.2.3 (ha); Try = corrected total area of each study site for each aerial photograph of a temporal series (ha); i = 1 to N; j = 1 to U; N = number of aerial photographs in a temporal series; U = number of mapping units on each aerial photograph of a temporal series).

8.3 Results and Discussion

8.3.1 Explanation of Changes

Many of the changes observed in Table 8.1 can be explained by referring to aerial photographs (Appendix 8.1), archival documentation and personal communication. To illustrate this, some of the changes in two of the mapping units are discussed further.

8.3.1.1 Water and Wetlands : the factors affecting the surface area of water in an estuary are numerous and varied. However, wetland areas are affected by water flow characteristics and numerous changes have taken place within these units.

By 1979, a wetland of 7,94 ha (Table 8.1) had become established at the Elsies River. Prior to 1910, this river flowed directly to the sea, or might have, at times, formed a small lagoon (E. McKie, pers. comm.; D. de Villiers, pers. comm.). The building of rail and road embankments across the river (c. 1910) restricted water flow, although water could still enter the sea via a culvert at the southern end of the beach (Job 61/44, Photo 189) and by seepage. By 1958, this road had been rebuilt and the base and embankments were presumably improved (Job 424/58, Photo 7009). This would have

Table 8.1. The corrected areas (ha) of each mapping unit (Mrym) and the number of mapping units on each aerial photograph of a temporal series (U)

River	Year	Mapping Unit 1	2	3	4	5	6	7	8	9	10	11	12	13	Total	U
Buffels (west)	1944		0,84	16,37	5,74			5,62	10,14					0,16	38,87	6
	1979		0,66	4,66	0,68			2,34	28,98			0,44		0,26	38,02	7
Elsies	1944		0,35	15,10	12,06			1,69	4,36		3,51			1,36	38,43	7
	1958	0,33	0,33	8,06	12,18			2,08	10,24		3,81			1,16	38,19	8
	1979		0,36	4,86	2,61	7,94		1,02	9,37		6,78	0,46		3,36	36,76	9
Silvermine	1944	0,20		24,40	1,26	4,62		2,33	8,16		1,92	0,19		1,84	44,92	9
	1958	0,32		11,14	7,93	4,78		0,66	11,50		5,38	0,14	0,15	1,76	43,76	10
	1979	0,02		4,90	14,25	2,73		0,45	7,07		5,50	2,33	0,85	1,67	39,77	10
Sandvlei	1944	3,04		6,22	9,93	10,43			1,29		11,28	2,23		2,55	46,97	8
	1958	5,52		4,04	4,23	7,54			5,79		15,04	3,94		2,46	48,56	8
	1979	7,02		5,32	2,02				0,05		18,13	14,64		0,31	47,69	7
Zeekoe	1938			21,64	23,36				3,27						48,27	3
	1958	2,68		13,26	27,02	0,24			6,24					0,82	50,06	6
	1979	1,28		12,36	7,79	0,50			7,41				22,10	0,63	52,07	7
Eerste	1938	0,83		19,95	17,55	2,58			12,80						53,71	5
	1953			11,94	9,15	2,91			24,46						48,46	4
	1979	6,38		5,16	3,29	2,70			7,18				26,09		50,80	6
Lourens	1938	3,73		4,90	5,81	0,08			8,26	3,11	2,30	2,78	0,19	0,91	32,07	10
	1953	2,13		10,57	5,16	0,08			5,10	2,96	3,06	1,69	5,71	0,55	37,23	10
	1979	1,41		5,63	1,50	0,14			3,35		8,57	3,88	8,68	0,55	33,69	9
Sir Lowry's Pass	1938			6,51	0,30					9,89	3,12				19,82	4
	1961	0,13		2,36	3,31				0,05	9,61	5,98				21,44	6
	1979	0,19		2,45					0,62		12,85	3,86			19,97	5
Steenbras	1938	0,40	4,45	0,40			2,23	38,77	0,17			0,43		0,51	47,36	8
	1979	0,26	2,28	0,48			2,78	35,48	1,17			1,38		0,57	44,34	8
Rooiels	1938	1,74	0,77	11,72	4,15	4,09		21,06							43,53	6
	1979	2,03	0,44	8,06	3,69	5,84		21,63	0,70		0,16	0,56		0,95	44,06	10
Buffels (east)	1938	9,77	0,40	6,12	8,66	1,47		16,81	0,24					0,22	43,68	8
	1979	4,59	0,55	6,46	6,78	1,70		21,61	2,66		0,90			2,43	47,68	9

reduced the seepage, and, together with increased run-off from hard surfaces, caused the wetland to become established.

At the Silvermine River, there has been a reduction of 1,89 ha in wetland areas between 1944 and 1979 (Table 8.1). During earlier years, the lower part of this river formed a marshy wetland (Dickson, 1974; Burman, 1962; Job 61/44, Photo 193). However, the lower part of this river has been channelled in recent years (Heinecken, 1982a; Job 424/58, Photo 7010; Job 326/79, Photo 369/3), bringing about a demise of wetland vegetation.

Wetland vegetation has disappeared from the study site at Sandvlei (Table 8.1). The manipulations which changed the configuration of this vlei are summarized by Morant and Grindley (1982). By 1961, 32 ha of vegetated wetlands had been destroyed by dredging in this vlei and, by 1981, more than 100 ha of wetlands had been destroyed by further dredging, residential and recreational development (Job 391/81, Photo 271/4, 272/4, 273/4).

There has been an increase of 0,50 ha in wetland vegetation at the Zeekoe River (Table 8.1). This river was constructed in 1942 as an overflow channel for Zeekoevlei (Bickerton, 1982). By 1944, an estuarine lagoon had formed on the beach (Job 61/44, Photo 1208). The coastal road (Baden-Powell Drive) had restricted this lagoon to the hind-dune area by 1958 (Job 424/58, Photo 6995) and the development of the sewage works in the early 1960s (Summers _et al_., 1976) increased the water flow in this river, thus allowing the wetlands to increase.

The increase in wetlands measured for the Eerste River between 1938 and 1958 could be related to the decrease in water surface area for this period (Table 8.1). However, there was a large increase in water surface area between 1958 and 1979, caused by increased run-off due to developments in the catchment and the discharge of treated sewage effluent.

Prior to a bridge being built across the Rooiels River in the early 1950s, this river followed a meandering course across the floodplain (Heinecken, 1982b). This bridge relocated the main flow channel towards the northern side of the floodplain. A meander was re-established on the seaward side of the road and the damming effect of this bridge brought about a slight increase in wetland area (Table 8.1).

In 1938, the Buffels (east) River formed a large backshore lagoon (Job 126/38, Photo 12807). The considerable reduction of this lagoon was probably by the enlargement of the Buffels Dam in 1972 (Heinecken _et al_., 1982).

8.3.1.2 Alien Vegetation : by 1979, alien plants, mainly in the form of acacias were found at every study site (Table

8.1). Acacias were introduced into the Cape between 1845 (Shaughnessy, 1980) and 1870 (Roux and Middlemiss, 1963).

In the study area, acacias were planted by official bodies at the following sites :

1885 - Eerste River Mouth (Shaughnessy, 1980)

1893 - Retreat Station, north of Sandvlei (Shaughnessy, 1980)

1936 - Zeekoe River : vicinity of mouth (Bickerton, 1982)

1942 - Sandvlei coast (Shaughnessy, 1980).

In addition to the above plantings, Opie (1967) maintains that aliens were planted by a farmer at the Buffels (west) River during the mid-19th century to stabilize deep sands in the area (Coke, 1963). Acacias might also have been planted at the Elsies River by the De Villiers family who have farmed the area since the 1870s. Although this farmer planted hakea at the Elsies River and acacias on the western coast of the Peninsula, no record of the planting of acacias at the Elsies River exists (D. de Villiers, pers. comm.).

The presence of alien plants at other sites is likely to have occurred by natural encroachment (Glyphis et al., 1981). At the Silvermine River, major alien plant encroachment seems to have occurred from the south (Job 61/44, Photo 193) where these plants are still used as hedges, windbreaks and shade in the Fish Hoek town development, established in 1918 (Burman, 1977). At the Lourens River, alien plants appear to have entered the study site along the river course from neighbouring farms (Job 126/38, Photo 12611). At the Steenbras River, alien plants were first found on disturbed areas near the road (Job 126/38, Photo 12696), while at the Rooiels (Job 326/79, Photo 354/3) and Buffels (east) (Job 126/38, Photo 12807) Rivers, the presence of these plants can be related to the advent of residential development.

The effect of development can be determined by using the above methods. For example, at the Zeekoe River, even though much of the area covered by alien plants was incorporated into the unit 'Industrial Area', 7,54 ha of the study site is still covered by by acacias which were originally planted by official bodies. From 1936 to 1958, there was a 94% increase in alien plants. From 1958 to 1979, there was an 18% increase in acacias, even though 42% of the area was developed as a sewage works. In total, there has been a 130% increase in aliens at this site and the planting of aliens should be prohibited.

8.3.2 Environmental Values

The present status and suitability for development of each study site can be determined by using the data in Table 8.1. To achieve this, a value must be given to each mapping unit.

During any evaluation of the environment, values vary according to the education and socio-economic status of the evaluator. Sandbach (1980) maintains that the value of parts of the environment is perceived according to the significance thereof to the evaluator, to the society and to the environment. Although the practice of giving values to the environment is common, care should be taken to exclude personal bias from these evaluations.

It is recommended that evaluation of the environment be undertaken by a team of specialists. This might be accomplished by using an established technique such as the Delphi System of Environmental Analysis (Helmer, 1963) In this study, three biologists involved in coastal management and two botanists involved in coastal ecology were asked to evaluate the mapping units without being told the study area. Each assessor was asked to give each unit a relative value from -10 to 10 according to how an increase in the unit would affect the functioning of the estuary and immediate environs (a negative value would mean a detrimental effect on the environment). The values thus obtained were averaged for each unit to obtain a relative environmental importance factor (Im) for each mapping unit (Table 8.2).

8.3.2.1 Relative Environmental State : as each mapping unit has a relative importance value, the relative environmental state of each study site can be determined for each year, according to the area of each mapping unit

Table 8.2 The environmental importance factor (Im) of each mapping unit

Mapping Unit	1	2	3	4	5	6	7	8	9	10	11	12	13
Im	8,2	3,2	1,4	5	10	2,8	4,8	-6	-8,75	-6	-5,25	-9,5	-6

present. This was accomplished by firstly adding eleven to each relative importance factor so as to obtain positive values. Secondly, each of the positive values was multiplied by the area of the mapping unit for each river for each year. Thirdly, the values thus obtained were summed for each study site for each year. This sum was divided by the total corrected area of the study site for each year. This process is represented by the following formula :

$$Ery_i = \left(\frac{\sum_{j=1}^{U} [Mrym_j (Im_i + 11)]_j}{Try_i} \right)$$

(Ery = environmental state for each study site for each aerial photograph of a temporal series; $Mrym$ = area of each mapping unit for each study site for each aerial photograph of a temporal series (ha); Im = environmental importance factor for each mapping unit; Try = corrected total area of each study site for each aerial photograph of a temporal series (ha); i = 1 to N; j = 1 to U; N = number of photographs in each temporal series; U = number of mapping units for each study site for each aerial photograph of a temporal series).

These results are presented in Table 8.3. As can be seen, the environmental state of all the study sites has

Table 8.3. The environmental state of each study site for each photograph of a temporal series (Ery), the co-efficient of change for each study site (Ar) and the conservability of each study site (Cr)

Study site	Ery			Ar	Cr
	1983/1944	1953/1958/1961	1979		
Buffels (west)	11,50		6,89	-2,20	31,20
Elsies	11,92	10,86	10,61	-0,66	51,93
Silvermine	11,60	10,88	11,04	-0,29	54,63
Sandvlei	12,62	10,73	8,62	-2,10	36,60
Zeekoe	14,02	13,73	7,42	-3,35	23,13
Eerste	12,33	9,86	7,30	-2,48	31,07
Lourens	9,59	8,76	6,57	-1,27	35,77
Sir Lowry's Pass	6,22	6,36	6,19	-0,04	30,85
Steenbras	15,31		14,86	-0,37	70,88
Rooiels	15,50		15,45	0,00	77,50
Buffels (east)	16,17		14,51	-0,64	70,50

decreased during the study period. However, slight increases took place at the Silvermine River between 1958 and 1979 and at the Sir Lowry's Pass River between 1938 and 1961. These increases are due to open sand becoming stabilized by dune scrub at the Silvermine River and agricultural areas being developed as residential areas at the Sir Lowry's Pass River (see Table 8.1).

These values for environmental state enable the determination of those sites where the most environmentally detrimental change has occurred. For example, from 1938/44 to 1979, the environmental state of the Zeekoe River has decreased by 6,99 while that of the Sir Lowry's Pass River has decreased by 0,04.

8.3.2.2 Co-efficient of Change : when planning management policies, it is important to have an indication of the environmental state and the amount of change which has taken place at the study site. However, it is particularly useful, especially for conservation policies (Roome, 1984), to determine the present state of the environment in terms of the historical state of the environment and thus the amount of change that has taken place relative to each site.

This can be accomplished by establishing a co-efficient of change (Ar) for each study site as follows :

The area of each mapping unit on the photographs of 1938/44 (the earliest available) was subtracted from the area of the mapping unit in 1979. This difference was expressed as a fraction of the sum of the total areas of the study site for these two years and multiplied by the relative environmental importance factor for each mapping unit. The values thus obtained were summed for each study site. This process can be expressed as follows :

$$Ar = \sum_{j=1}^{U} \left[\frac{(Mrym_N - Mrym_1)Im_j}{Try_N + Try_1} \right]_j$$

(Ar = co-efficient of change for each study site; $Mrym_N$ = area of the mapping unit for 1979 (ha); $Mrym_1$ = area of the mapping unit for 1938/44 (ha); Im = environmental importance factor for each mapping unit; Try_N = total corrected area of the study site for 1938/44 (ha); j = 1 to U; U = number of mapping units).

These coefficients of change are presented in Table 8.3. As can be seen, the Rooiels River is the only site where Ar is not negative. Wetlands and open sand have increased at this river and there has been little invasion by alien plants and environmental destruction by development.

All the other sites have a negative coefficient of change, showing that the changes that have occurred at each study site have had a net detrimental effect on the environment. The most change has occurred at the Zeekoe River ($Ar = -3,35$), where a large area has been developed as a sewage works and much invasion by alien acacias has taken place.

8.3.2.3 Conservability : the 'conservability' (Cr) of each study site was determined by obtaining positive values for each co-efficient of change by adding five to each Ar. This positive value was multiplied by the environmental state (Ery) of each study site for 1938/44. In other words :

$$Cr = (Ar + 5)Ery_1$$

The values of Cr are presented in Table 8.3 and it can be seen that :

a) All the study sites on the Cape Flats (i.e. Sandvlei, Zeekoe, Lourens and Sir Lowry's Pass) have relatively low values. This is expected as major developments for recreation (Sandvlei), housing (Lourens, Sir Lowry's Pass, Sandvlei) and industry (Zeekoe, Eerste, Lourens) have taken place at these study sites.

b) The value for the Buffels (west) River is relatively low, primarily as a result of much invasion by alien plants.

c) The Silvermine and Elsies Rivers have similar values. Even though some residential development has taken place at these study sites, it is countered by increases in dune scrub and wetlands respectively.

d) The value of Cr for the Buffels (east) River is lower than the other rivers on the the east side of False Bay. Although some residential and road development has taken place at this study site, the large decrease in water surface area between 1938 and 1979 is more likely to have caused the observed trend of Cr than is environmental degradation.

e) The Rooiels and Steenbras Rivers have the highest Cr. In comparison with the other study sites (except Buffels (east)), these study sites are relatively undisturbed with only minor developments and small scale alien plant invasion.

8.4 Conclusions

These environmental coefficients are easily calculated and give clear indications of the state of the environment. Resultant data should be included in an information system as they facilitate decision making and policy formulation. For example, using the data presented above, management of the most easterly rivers of False Bay should be orientated towards conservation while smaller sanctuaries could be established at the Elsies and Silvermine Rivers, particularly the wetland areas. The rivers of the Cape Flats should be managed as developed areas and attempts should be made to remove acacias from the Buffels (west) River.

The most critical part of these calculations is the establishment of relative environmental importance factors. For example, if it was decided that residential developments were more detrimental to the environment than agricultural developments, the environmental state (Ery) of the Sir Lowry's Pass River would have decreased from 1938 to 1961. A statement concerning the importance of any part of the environment is subjective and could thus be a source of error. Although data can be collected by non-specialists, it is recommended that environmental values be established by making use of evaluations panels (Fuggle, 1983).

Chapter 9. Conclusions

Apart from physical aspects of the environment, some description of natural habitat types is necessary to develop conservation-orientated guide plans and guide management decisions. Any biotic component might be used to classify habitats for specific purposes. For example, habitats might be classified according to the presence of rare or endangered species. However, for management information systems, general descriptions of habitat types are necessary. Very few single species are restricted enough to serve as indicators of habitat types (Ward, 1978) and many species are mobile and can thus cross habitat boundaries. Consistent species assemblages (communities) are, therefore, better indicators of different habitats. Plant communities are relatively immobile, long-lived and react to a number of environmental factors and the use of plant communities to indicate habitat types is most effective.

Detailed analyses of the environment are not essential for the formulation of guide plans. On the contrary, detailed analyses of this type might hinder the formulation of policies.

The methodology proposed to sample vegetation gives ecologically significant results. As a result of its *a posteriori* nature, this technique is versatile and can be applied to various habitats. However, many of the disadvantages of an *a posteriori* approach have been overcome by establishing a preliminary classification of the vegetation according to physiographic/physiognomic attributes and by reducing the information content of the data.

It must be remembered that the aim of this classification methodology is to distinguish habitats for management purposes. The success of this methodology may be due to the nature of the study area. Coastal areas contain a wide variety of habitats, each with a peculiar floristic composition and management implications. In other environments (e.g. Mountain Fynbos), this methodology might only result in an indication of the diversity of plant communities. Although this may be ecologically less meaningful (Campbell, 1985), many fynbos communities have similar management requirements and this methodology, therefore, would retain its usefulness for the formulation of management policies.

Once habitat data are available, decisions concerning the environment are necessary for the establishment of guide plans. The techniques proposed in Chapters 7 and 8 enable the evaluation of a particular site according to the habitats present, the amount of change that has taken place, and the present state of the habitats in relation to past habitats at the site. In other words, these techniques determine the intrinsic value of the study site, the amount of pressure that has been placed on the habitats, and the value of the site in relation to its historical intrinsic value.

Not only could these data be used to facilitate the formulation of guide plans and management policies, but they could also be used to supply basic data for environmental impact assessments.

There are numerous types of impact assessments (Helmer, 1963; McHarg, 1969; Munn, 1975; Ward, 1978; Fuggle, 1983; Stauth, 1983), but all are aimed at determining the impact of a particular development or developments on a particular environment. Considerable effort has usually been put into site selection and planning of the development by the time an impact assessment is carried out. However, the availabilty of an information system would allow for the establishment of guidelines for development, thus making impact assessment more efficient.

On a larger scale, these techniques could be used to guide regional development planning by regarding each site as a sample. However, some preliminary investigation would be necessary to ensure representative sampling of the region.

With the help of legislative support, the establishment of a managerial survey information system will lead to management and development policies based on the needs and restrictions of the environment.

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Appendix 4.1. Topographic maps showing the rivers entering False Bay.

South Africa 1:50 000 Sheet 3418 AB & AD Simonstown, 3rd edition, 1978. Government Printer, Pretoria.

South Africa 1:50 000 Sheet 3418 BA Strandfontein, 3rd edition, 1978. Government Printer, Pretoria.

South Africa 1:50 000 Sheet 3418 BB Somerset West, 3rd edition, 1978. Government Printer, Pretoria.

South Africa 1:50 000 Sheet 3418 BD Hangklip, 3rd edition, 1978. Government Printer, Pretoria.

Appendix 5.1. Aerial photographs used to determine vegetation units.

Buffels (west)	Job 326/79, Photo 374/3, 375/3; Col; 1979; Dept. Land Surveying, Univ. Natal.
Elsies	Job 326/79, Photo 372/3, 373/3, Col; 1979; Dept. Land Surveying, Univ. Natal.
Silvermine	Job 326/79, Photo 368/3, 369/3, 370/3; Col; 1979; Dept. Land Surveying, Univ. Natal.
Sandvlei	Job 391/81, Photo 271/4, 273/4, 273/4; Col; 1981; Dept. Land Surveying, Univ. Natal.
Zeekoe	Job 326/79, Photo 363/3, 364/3; Col; 1979; Dept. Land Surveying, Univ. Natal.
Eerste	Job 326/79, Photo 363/3, 364/3; Col; 1979; Dept Land Surveying, Univ. Natal.
Lourens	Job 326/79, Photo 360/3; Col; 1979; Dept. Land Surveying, Univ. Natal.
Sir Lowry's Pass	Job 326/79, Photo 358/3; Col; 1979; Dept. Land Surveying, Univ. Natal.
Steenbras	Job 326/79, Photo 356/3; Col; 1979; Dept. Land Surveying, Univ. Natal.
Rooiels	Job 326/79, Photo 354/3; Col; 1979; Dept Land Surveying, Univ. Natal.
Buffels (east)	Job 326/79, Photo 352/3; Col; 1979; Dept. Land Surveying, Univ. Natal.

Appendix 5.2. Species recorded in each vegetation unit, sorted according to similarity in distribution between units.

Vegetation Units: 878812355670134513500233455666655671477223473001244667700111122247445566712233400 / 130280809057179199328856668534257905389232274467458181215023415914042467666701373 9

Genus and species	Vegetation units
Potamogeton pectinatus	5
Ruppia cirrhosa	.4
Ruppia maritima	..21
Phragmites australis	...5555435.....r.....r.....+r
Paspalum vaginatum	...51+5+
Scirpus maritimus	...15+
Triglochin bulbosa	...1.1
Typha capensis	...1..25+4r5.....+.....+...+
Polygonum salicifolium	...+..r13
Rumex spathulatus	...++.....r
Thamnochortus gracilis	...11
Cliffortia ruscifolia	...1+
Erica longifolia	...++
Olea capensis	...r1.....+
Sympieza articulata	...+1
Phylica buxifolia	...+.....+
Leucodendron salignum	...1.+
Restio cuspidatus	...1.+
Protea repens	...1+
Tetraria cuspidata	...+1
Polygala myrtiflora	...+1..r
Helichrysum 1	...++
Phylica ericoides	...1+1.....r
Myrica quercifolia	...1++
Chondropetalum microcarpum	...2.+
Cassytha ciliolata	...1.+..+
Senecio laevigatus	...+.+
Protea compacta	...++
Pelargonium angulosum	...+1
Podalyria calyptrata	...+r
Psoralea pinnata	...++
Cliffortia lanceolata	...r.....1
Rhus lucida	...21
Secamone alpinii	...++
Cassine barbara	...r..+.++1
Leucospermum conocarpodendron	...++.+
Widdringtonia nodiflora	...+...1
Linociera foveolata	...+...r
Sideroxylon inerme	...r4
Pterocelastrus cuspidatus	...1.+
Cussonia thyrsiflora	...1+1..3
Chasmanthe aethiopica	...+..+1
Maytenus oleoides	...+..1
Euclea racemosa	...2..1.....+
Senecio halimifolius	...+r.....++3123
Metalasia muricata	...+2+..2r++.1..++...r..3+.1+..111r.r.....r
Chrysanthemoides monilifera	...1.+1.21.1..++..+..1+...+..1..r+2+r..r
Carpobrotus edulis	...+...r+.1..++...1++..1.+...r+1+...r
Tetragonia fruticosa	...1.r.2..+1...+..22.....1+...++
Colpoon compressum	...++...r.++...+..1.....+.1.1...r
Rhus glauca	...1...+1+.++...+.....1..4.....r
Rhus laevigata	...2.1.1..+..2.++
Plecostachys serpyllifolia	...+.....1.1.....2+.....+.++
Oxalis pes-caprae	...+.....+r.r..+1.....+1
Helichrysum crispum	[illegible]
Geranium incanum	...++.....1.....+.....2..+.....r
Chironia baccifera	...1.....++.....1.....2..1.+
Myrica cordifolia	...+r.+.....1..2
Nidorella foetida	...+.....+.....1.....+..r.....+
Myoporum serratum	...1..+.....+.....1.....+
Nylandtia spinosa	...++.....+..+.....r
Cullumia setosa	...1..+.....++1
Psoralea fruiticosa	...r+..+.....+
Ficinia dunensis	...r.+.....+.....r
Kedrostis nana	...r+.r..+.....r
Passerina falcifolia	...r...+...+
Samolus porosus	...+...+.....+
Passerina vulgaris	...r.....1.....+
Passerina rigida	...1.....1
Restio callistachyus	...+.....1
Pteridium aquilinum	...+.....+.....r
Briza maxima	...+.....2
Senecio elegans	...+.....1
Agropyron distichum	...++..1++r1++.+...++
Arctotheca populifolia	...11r...+..+..12..12
Ammophylla arenaria	...11r...+1r+.....+
Psoralea repens	...311+12
Hebenstretia cordata	...1
Chenolea diffusa	...+..+.....++
Cotula coronopifolia	...+.....++.....1.....+
Heteroptilis suffruticosa	...1...r.....1.....r....1
Plantago carnosa	...r+..1
Manulea tomentosa	...+..+.....+.....r.+.....r
Senecio littoralis	...+.....+.....+
Juncus laevigatus	...+..+
Tetragonia decumbens	...1.....+...+
Ehrharta villosa	...+..+.....1..3.12r1+.+2.+..+3.1++.4..33
Carpobrotus acinaciformis	...+...2...2.1.....11.....1+2+...2...1...+31
Trachyandra divaricata	...r+..1..1..++...r+.....+.r..+r.....++
Solanum quadrangulare	...+..1.....+..+.r++++r...1+..++
Paspalum vaginatum	...+.....+.....+.....+
Juncus acutis	...+.....1.....51...1
Atriplex vestita	...r.....+.....2.....+
Helichrysum metalasioides	...1..+
Gazania rigens	...+.....+
Lolium multiflorum	...+.....++
Thesium fragili	...+.....r..r
Stoebe plumosa	...+.....+.....+.....r.3
Juncus drageanus	...2.....r
Paspalum urvillei	...1
Juncus kraussii	...+.....1
Orphium frutescens	...1.....1.....2
Lagurus ovatus	...+.....1
Senecio maritima	...+.....+
Acacia cyclops	...+.....+.....+3
Scirpus nodosus	...1.....1..1.....1.+2..+r1.5..2r.133.31111.2+4..1++11rr+..+.....5...4.55
Pennisetum clandestinum	...1...+..1..2.+r+.....r..1...1...+.3.+..3.++.1.....+...+.+
Acacia saligna	...3...3...1.....1..+.....54..44.....1+.+2...+...2.5+
Cynodon dactylon	...+..+1.....++.....41.+...+.+21.....+..3+
Pelargonium capitatum	...2...2.....4...++.+..11.+.....+...+..21...3.....3
Zantedeschia aethiopica	...+.....1.....1..+...+.+.+.+.....+r11++.r
Sporobolus virginicus	...r11.....1.r.r..+.1..1.3.....r..+.....+.+.r
Stenotaphrum secundatum	...1.....2.....3..3+..+..+.....1.+.3.....2.3...5+
Sonchus oleraceus	...1.....+.....+...11.+1++.....1+...1.....3
Acacia longifolia	...+.....r.....+.....1+.rr.+.....rrr1
Lobelia anceps	...1.....1
Cyperus longus	...+.....+.....+
Acacia mearnsii	...+.....+
Rorippa nasturtium-aquaticum	...+.+
Urtica urens	...+.....+.....+
Sarcocornia perennis	...r.....1.....r
Chenopodium ambrosioides	...+
Sonchus asper	...+
Mariscus congestus	...+
Salicornia 1	...r
Cyperus textilis	...+
Annesorrhiza 1	...+
Cliffortia graminea	...r
Cliffortia odorata	...r
Populus canescens	...r
Sarcocornia natalensis	...r
Limonium foliosum	...2
Gnidia spicata	...+
Scirpus littoralis	...+
Juncus rigida	...+
Aster subulatus	...+
Cyperus sphaerospermus	...+
Cyperus 1	...2
Samolus valerandii	...2
Conyza pinnatifida	...1
Epilobium hirsutum	...+
Triglochin striata	...+
Berula thunbergii	...+
Schoenoplectus triqueter	...+
Hydrocotyle verticillata	...2
Agathosma capensis	...r
Protea nerifolia	...1
Protea nitida	...+
Thamnochortus punctatus	...+
Erica plukenetii	...+
Pinus pinaster	...+
Pinus pinea	...r
Asparagus rubicundus	...r
Eucalyptus globulis	...r
Hypolaena digitata	...1
Leucospermum bolusii	...1
Saltera sarcocolla	...+
Passerina 4	...+
Nagelocarpus serratus	...+
Phylica paniflora	...+
Muraltia satureioides	...+
Coleonema juniperinum	...2
Disperago ericoides	...+
Felicia bergerana	...+
Struthiola dodecandra	...+
Sutera integriflora	...+
Rhus 2	...+
Zygophyllum 1	...+
Elegia stipularis	...+
Erica imbricata	...+
Phylica stipularis	...+
Salvia 1	...+
Passerina 5	...+
Helichrysum 3	...+
Leucodendron coniferum	...+
Coleonema album	...+
Haemanthus rotundifolius	...+
Rhus 1	...+
Maurocenia frangularia	...+
Felicia fruticosa	...2
Rapanea melanophloeos	...+
Asparagus stipulaceus	...+
Helichrysum 2	...+
Lobostemon montanus	...+
Athanasia crithmifolia	...1
Berzelia lanuginosa	...+
Clutia pulchella	...+
Conyza scabrida	...+
Dodonea viscosa	...+
Metrosideros angustifolia	...2
Brabejum stellatifolium	...+
Restio subverticillatus	...+
Rhus tomentosa	...+
Brachylaena nerifolia	...+
Heeria argenteum	...+
Restio purpurascens	...+
Struthiola myrsinites	...+
Pycreus polystachya	...+
Rhus incinata	...+
Albizia lophantha	...+
Aloe arborescens	...+
Malvastrum scabrosum	...1
Passerina glomerata	...+
Helichrysum 5	...+
Indigofera brachystachya	...+
Rhus 3	...+
Salvia 3	...+
Chondropetalum tectorum	...2
Galenia secunda	...+
Knowltonia capensis	...+
Asparagus 1	...+
Pentzia pilulifera	...+
Passerina 7	...+
Stoeba sphaerocephala	...1
Selago spuria	...+
Pelargonium cucullatum	...1
Helichrysum vestita	...+
Erica coccinea	...+
Crassula 1	...+
Graminae 1	...+
Carissa bispinosa	...2
Passerina 2	...+
Cissampelos capensis	...+
Leucojum aestivum	...+
Cliffortia obcordata	...+
Haemanthus 1	...+
Asparagus racemosus	...+
Aspalathus ericifolia	...+
Senecio 1	...+
Restio eleocharis	...+
Olea exasperata	...3
Passerina 6	...+
Agathosma 1	...+
Lobelia valida	...+
Nemesia psammophila	...+
Haemanthus 2	...+
Mariscus 1	...+
Psoralea capensis	...+
Polygonum 2	...+
Salvia aurea	...+
Chrysocoma coma-aurea	...+
Viscum capensis	...+
Helichrysum 1	...+
Sisymbrium capense	...+
Tropaeolum majum	...+
Senecio angularis	...1
Felicia 1	...+
Helichrysum teretifolium	...+
Passerina 3	...+
Restio 1	...+
Senecio burchellii	...+
Polypogon strictus	...+
[illegible]	[illegible]
[illegible]	[illegible]
Scirpus 2	...+
Juncus 1	...+
Aspalathus forbesii	...+
Pentaschistus eckloni	...+
Sporobolus africanus	...+
Salvia 2	...+
Cotyledon orbiculata	...+
Rhus 4	...+
Passerina 1	...+
Helichrysum 1	...1
Malva parviflora	...+
Polygonum maritimum	...+
Dimorphotheca pluvialis	...+
Bromus diandrus	...+
Cineraria geifolia	...+
Raphanus raphanistrum	...+
Ruschia geminiflora	...+
Avena sativa	...+
Senecio laxus	...+
Passerina ericoifolia	...+
Silene crassifolia	...+
Crassula glomerata	...+
Isolepis 1	...+
Arctotheca calendula	...+
Polygonum 1	...+
Chenopodium murale	...+
Eragrostis cyperoides	...+
Polygala fruticosa	...+
Dianthus 1	...+
Conyza 1	...+
Carex eckloni	...+
Felicia tenella	...+
Datura stramonium	...+
Asclepias physocarpa	...+
Juncus punctorius	...+
Solanum nigrescens	...+
Pinus 1	...r
Osteospermum fruticosum	...r
Limonium scabrum	...r
Ficinia lateralis	...2
Solanum guineense	...1
Indigofera procumbens	...+
Lavatera arborea	...3
Conyza ambigua	...2

Appendix 5.3. Abbreviated species list with some habitat data (see Section 5.3.2).

Habitat data must be read vertically.

Rivers	: 1 = Buffels (west); 2 = Elsies; 3 = Silvermine; 4 = Sandvlei; 5 = Zeekoe; 6 = Eerste; 7 = Lourens; 8 = Sir Lowry's Pass; 9 = Silvermine; 10 = Rooiels; 11 = Buffels (east)
Altitude	: Approximate altitude in metres
Vegetation Height	: Approximate average height in centimetres
Vegetation Cover	: Approximate total vegetation cover (%)
Number of Species	: Number of species recorded per vegetation unit
Soil Type	: MAR = predominantly water-logged soils; TMS = Table Mountain Sandstone derived soils; CAL = Calcereous sand
Habitat Form	: SUB = Submerged; TID = Tidal; SEA = Seasonally flooded; RIP = Riparian; HUM = Hummock dunes; FOR = Fore dunes; HIN = Hind dunes; MOU = Mountain slopes

```
Vegetation Unit          8788123556701345135002334556666556714772234730012446677001111222474455667122333400
                         13028080905717919932885666685342579053892322744674581812150234159140424676667013739
...............................................................................................................
River                    0101000011100000000000000000001110011001100001000000000111100000000000100001110000000000
                         4041346700123677468125557990000099003611445615223477000012333345561678800135555571 2
...............................................................................................................
Altitude (m)             0000121122111111211111111552222552211112211111121222211111121111111122111111111
                         0000505500555555050555555000000000555005555550550000555550555555550055555555 5
...............................................................................................................
Vegetation Height (cm)   0000123122100002000010101110121312103311101100010000103000021000000000100001000000 1
                         7343800550551310252728542505257080550002580281202257520124208842319355271126434552
                         5000000000000000000000000000005050000000000000000000005050000000000000000500000000 0
...............................................................................................................
Vegetation Cover (%)     0000011000010010001110001000000000000100101000100100000000000000000000000010010001 0
                         8620900966907807580003780844768957696089089804209747917376923709512572109909820 9
                         0005000000000000000000000000005000050000000500050000050000000500505000005500500000 5
...............................................................................................................
Number of Species        0000000000001001111100000122121312112012201301111111000101311211100011010000000000
                         1111121117110312311819681817917041400614274561315002085869447906887870051241689311
...............................................................................................................
Soil Type                MMMMMMMMMMMMMMMMMMMMMMMMMMMMMTTCTTTTCCCCCTCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
                         AAAAAAAAAAAAAAAAAAAAAAAAAAAAMMMAMMMMAAAAAMAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAA
                         RRRRRRRRRRRRRRRRRRRRRRRRRRRRSSSLSSSSLLLLLSLLLLLLLLLLLLLLLLLLLLLLLLLLLLLLLLLLLLLLLLL
...............................................................................................................
Habitat Form             SSSSSTTTSTTSSTTRSTSSSSSSSMMMMRRRRRRSHHHSSSSHSHSHHFHSFFFHHHFFFFSFTSFFSHHSHSSFHHHH
                         UUUUEIIIEIIEEIIIEIEEEEEEEOOOOIIIIIIEIIIEEEEIEIEIIOIEOOOUUUOOOOOEOIEOOOEUUEIEEOIIII
                         BBBBADDDADDAADDPADAAAAAAAARRRRPPPPPPANNNAAAANANANNRNARRRMMMRRRRRARDARRRAMMANAARNNNN
...............................................................................................................
Vegetation Unit          8788123556701345135002334556666556714772234730012446677001111222474455667122333400
                         13028080905717919932885666685342579053892322744674581812150234159140424676667013739
...............................................................................................................

Genus and species

Potamogeton pectinatus.............. 5
Ruppia cirrhosa..................... 4
Ruppia maritima..................... 21
Phragmites australis................ 5555435
Paspalum vaginatum.................. 51+5+
Scirpus maritimus................... 15+
Triglochin bulbosa.................. 1 1
Typha capensis...................... 25+4r5
Polygonum salicifolium.............. r13
Rumex spathulatus................... ++
Thamnochortus gracilis.............. 11
Cliffortia ruscifolia............... 1+
Erica longifolia.................... ++
Olea capensis....................... r1
Sympieza articulata................. +1
Phylica buxifolia................... +
Leucodendron salignum............... 1.+
Restio cuspidatus................... 1.+
Protea repens....................... .1+
Tetraria cuspidata.................. +1
Polygala myrtiflora................. +1
Helichrysum 1....................... ++
Phylica ericoides................... 1+1
Myrica quercifolia.................. 1++
Chondropetalum microcarpum.......... 2.+
Cassytha ciliolata.................. 1.+
Senecio laevigatus.................. +.+
Protea compacta..................... ++
Pelargonium angulosum............... +1
Podalyria calyptrata................ +r
Psoralea pinnata.................... ++
Rhus lucida......................... 21
Secamone alpinii.................... ++
Cassine barbara..................... r..+.++1.
Leucospermum conocarpodendron....... .++.+....
Widdringtonia nodiflora............. +....1...
Linociera foveolata................. ...+...r.
Sideroxylon inerme.................. .....r4.
Pterocelastrus cuspidatus........... .....1.+
Cussonia thyrsiflora................ 1+1...3.
Chasmanthe aethiopica............... .+..+1..
Maytenus oleoides................... +..1....
Euclea racemosa..................... ..2..1..
Senecio halimifolius................ ++3123
Metalasia muricata.................. 2+...2r+++.1..++....r...3+.1+..111r.r
Chrysanthemoides monilifera......... 1.+1.21.1..++..+..1+...+..1..r+2+r..r
Carpobrotus edulis.................. .+...r+.1..++....1++..1.+....r+1+...r
Tetragonia fruticosa................ ....1.r.2..+1....+...22.......1+...+
Colpoon compressum.................. ...r.++.....+..1.......+.1.1...r....
Rhus glauca......................... ...+1+.++...+......1..4.......r....
Rhus laevigata...................... .2.1.1..+...2.++....................
Plecostachys serpyllifolia.......... .......1..1.......2+.........+.++...
Oxalis pes-caprae................... ...........+r.r..+1..........+1....
Helichrysum crispum................. ..+.............1.........+......2..
Geranium incanum.................... ...........++........1.....2..1.+...
Chironia baccifera.................. ................1...2...............
Myrica cordifolia................... .......+...........1..........+..r
Nidorella foetida................... ..1..+..........+........1.........
Myoporum serratum................... ...........++.....+...+.......r....
Nylandtia spinosa................... ................1...+.........++1...
Cullumia setosa..................... +..+............+..................
Psoralea fruiticosa................. .+...................+...........r
Ficinia dunensis.................... ...............r+.r...+.........r..
Kedrostis nana...................... .r....+.....+......................
Passerina falcifolia................ .+....+.....................+......
Samolus porosus..................... .....r.................1...........
Passerina rigida.................... +...........................r.....
Restio callistachyus................ ..+....................+...........
Pteridium aquilinum................. ..+....................2...........
Briza maxima........................ ..........+.................1......
Senecio elegans..................... ++..1++r1++.+...++
Agropyron distichum................. 11r...+..+..12..12
Arctotheca populifolia.............. 11r...+1r+.......+
Ammophila arenaria.................. ..311+12..........
Psoralea repens..................... [illegible]
Hebenstretia cordata................ [illegible]
Chenolea diffusa.................... [illegible]
Cotula coronopifolia................ [illegible]
Heteroptilis suffruticosa........... .......r.+.......r
Plantago carnosa.................... .+.............+..
Manulea tomentosa................... ...........+..+...
Senecio littoralis.................. ..............+...+
Tetragonia decumbens................ .....+..+.........1...3.12r1+.+2.+..+3.1++.4..33
Ehrharta villosa.................... +....2...2.1.....11..........1+2+....2....1...+31
Carpobrotus acinaciformis........... r+...1..1..++...r+...........+.r..+r...........++
Trachyandra divaricata.............. .....+..1..............+..+.r++++r....1+..++....
Solanum quadrangulare............... ..+.............+.......+..................+.....
Paspalum vaginatum.................. ...........1.......................51...1........
Juncus acutis....................... +.....................2..................+.......
Atriplex vestita.................... .........1..+...................+................
Helichrysum metalasioides........... .............+...............++..................
Gazania rigens...................... ...............+........r..r....................
Lolium multiflorum.................. ..............................+................r.3
Thesium fragili..................... ..+..........+....................................
Stoebe plumosa...................... .............2..................r................
Juncus drageanus.................... .....1...............................1...........
Paspalum urvillei................... ........+..............................+.........
Juncus kraussii..................... .............1.....................2.............
Orphium frutescens.................. .......................+...........1.............
Lagurus ovatus...................... ..................+............+..................
Senecio maritima.................... ...................................+3
Acacia cyclops...................... 1..........1..1......1.+2..+r1.5..2r.133.31111.2+4..1++11rr+..+......5...4.55
Scirpus nodosus..................... ....1...+..1..2.+r+....r..1...1...+.3.+..3.++.1.......+......+.+
Pennisetum clandestinum............. ......3.....3....1............1..+....54.+44.........1+.+2....+.....2.5+...
Acacia saligna...................... .......+...+1................++......41.+....+.+21.....+..3+
Cynodon dactylon.................... .......2.....2................4...++.+..11.+...............+....+...21....3......3
Pelargonium capitatum............... ..........+........1............1..+....+..+..+..+.......+r11++.r
Zantedeschia aethiopica............. ................r11.........1.r.r..+.1...1.3.................r...+.........+.+.r.
Sporobolus virginicus............... ....1.........2....................3...3+...+...+........1.+.3.......2.3....5+...
Stenotaphrum secundatum............. ....1.........+.................+.....11.+1++........1+....1.......3
Sonchus oleraceus................... .......+........r...................+.......................1+.rr.+..............rrr1
Acacia longifolia................... ..........1...............1.......................................+
Lobelia anceps...................... .......+.......+
Cyperus longus...................... ..........+....................+
Acacia mearnsii..................... ..........+..+.......................................................+
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Appendix 6.1. Aerial photographs and orthophotos used to determine land-use changes.

Buffels (west)	South Africa, 1:10 000 orthophoto 3418 AD 10 & 15, Cape Point, 3rd edition. Government Printer, Pretoria, 1978. Job 326/79, Photo 374/3; Col; 1979; Dept. Land Surveying, Univ. Natal. Job 61/44, Photo 374; B&W; 1944; Trig. Survey, Mowbray.
Elsies	South Africa, 1:10 000 orthophoto 3418 AB 19 & 20, Simonstown, 1st edition. Government Printer, Pretoria, 1978. Job 326/79, Photo 372/3; Col; 1979; Dept. Land Surveying, Univ. Natal. Job 424/58, Photo 7009; B&W; 1958; Trig. Survey, Mowbray. Job 61/44, Photo 189; B&W; 1944; Trig. Survey, Mowbray.
Silvermine	South Africa, 1:10 000 orthophoto 3418 AB 14 Vishoek, 1st edition. Government Printer, Pretoria, 1976. Job 326/79, Photo 369/3; Col; 1979; Dept. Land Surveying, Univ. Natal. Job 424/79, Photo 7010; B&W; 1958; Trig. Survey, Mowbray. Job 61/44, Photo 193; B&W; 1944; Trig. Survey, Mowbray.
Sandvlei	South Africa 1:10 000 orthophoto 3418 AB 15 Muizenberg, 1st edition. Government Printer, Pretoria, 1978. Job 326/79, Photo 366/3; Col; 1979; Dept. Land Surveying, Univ. Natal. Job 424/58, Photo 6997; B&W; 1958 Trig. Survey, Mowbray. Job 61/44, Photo 105; B&W; 1944; Trig. Survey, Mowbray.
Zeekoe	South Africa 1:10 000 orthophoto 3418 BA 6 Zeekoevlei, 1st edition. Government Printer, Pretoria, 1973. Job 326/79, Photo 364/3; Col; 1979; Dept. Land Surveying, Univ. Natal. Job 424/58, Photo 6995; B&W; 1958; Trig. Survey, Mowbray. Job 126/38, Photo 11793; B&W; 1938; Trig. Survey, Mowbray.
Eerste	South Africa 1:10 000 orthophoto 3418 BB 6 Firgrove, 2nd edition. Government Printer, 1979. Job 326/79, Photo 361/3; Col; 1979; Dept. Land Surveying, Univ. Natal. Job 335/53, Photo 6114; B&W; 1953; Trig. Survey, Mowbray. Job 126/38, Photo 11697; B&W; 1938; Trig. Survey, Mowbray.

Lourens	South Africa 1:10 000 orthophoto 3418 BB 7 Somerset West and 3418 BB 12 Strand, 2nd editions. Government Printer, Pretoria, 1979. Job 326/79, Photo 360/3; Col; 1979; Dept. Land Surveying, Univ. Natal. Job 335/53, Photo 6113; B&W; 1953; Trig Survey, Mowbray. Job 126/38, Photo 12610; B&W; 1938; Trig. Survey, Mowbray.
Sir Lowry's Pass	South Africa 1:10 000 orthophoto 3418 BB 18 Gordon's Bay, 1st edition. Government Printer, Pretoria, 1979. Job 326/79, Photo 358/3; Col; 1979; Dept. Land Surveying, Univ. Natal. Job 461/61, Photo 433; B&W; 1961; Trig. Survey, Mowbray. Job 126/38, Photo 12665; B&W; 1938; Trig. Survey, Mowbray.
Steenbras	South Africa 1:10 000 orthophoto 3418 BB 17 Steenbras Mouth, 1st edition. Government Printer, Pretoria, 1979. Job 326/79, Photo 356/3; Col; 1979; Dept. Land Surveying, Univ. Natal. Job 126/38, Photo 12696; B&W; 1938; Trig. Survey, Mowbray.
Rooiels	South Africa 1:10 000 orthophoto 3418 BD 2 Rooiels Bay, 1st edition. Government Printer, Pretoria, 1981. Job 326/79, Photo 354/3; Col; 1979; Dept. Land Surveying, Univ. Natal. Job 126/38, Photo 12775; B&W; 1938; Trig. Survey, Mowbray.
Buffels (east)	South Africa 1:10 000 orthophoto 3418 BD 7 Pringle Bay, 1st edition. Government Printer, Pretoria, 1981. Job 326/79, Photo 351/3; Col; 1979; Dept. Land Surveying, Univ. Natal. Job 126/38, Photo 12807; B&W; 1938; Trig. Survey, Mowbray.

Appendix 7.1. Final scale of aerial photographs used to correct mapping unit areas.

Buffels (west)	Job 326/79, Photo 375/3; Col; 1979; 1:9 700; Dept. Land Surveying, Univ. Natal. Job 61/44, Photo 374; B&W; 1944; 1:9 820; Trig. Survey, Mowbray.
Elsies	Job 326/79, Photo 372/3; Col; 1979; 1:9 600; Dept. Land Surveying, Univ. Natal. Job 424/58, Photo 7009; B&W; 1958; 1:9 900; Trig. Survey, Mowbray. Job 61/44, Photo 189; B&W; 1944; 1:10 240; Trig. Survey, Mowbray.
Silvermine	Job 326/79, Photo 369/3; Col; 1979; 1:9 600; Dept. Land Surveying, Univ. Natal. Job 424/58, Photo 7010; B&W; 1958; 1:9 180; Trig. Survey, Mowbray. Job 61/44, Photo 193; B&W; 1944; 1:10 400; Trig. Survey, Mowbray.
Sandvlei	Job 326/79, Photo 367/3; Col; 1979; 1:9 820; Dept. Land Surveying, Univ. Natal. Job 424/58, Photo 6997; B&W; 1958; 1:9 420; Trig. Survey, Mowbray. Job 61/44, Photo 103; B&W; 1944; 1:9 200; Trig. Survey, Mowbray.
Zeekoe	Job 326/79, Photo 363/3; Col; 1979; 1:9 800; Dept. Land Surveying, Univ. Natal. Job 424/58, Photo 6995; B&W; 1958; 1:9 600; Trig. Survey, Mobray. Job 126/38, Photo 11723; B&W; 1938; 1:10 848; Trig. Survey, Mowbray.
Eerste	Job 326/79, Photo 362/3; Col; 1979; 1:9 610; Dept. Land Surveying, Univ. Natal. Job 335/53, Photo 6114; B&W; 1953; 1:9 660; Trig. Survey, Mowbray. Job 126/38, Photo 11697; B&W; 1938; 1:9 460; Trig. Survey, Mowbray.
Lourens	Job 326/79, Photo 359/3; Col; 1979; 1:9 620; Dept. Land Surveying, Univ. Natal. Job 335/53, Photo 6113; B&W; 1953; 1:10 790; Trig. Survey, Mowbray. Job 126/38, Photo 12611; B&W; 1938; 1:10 280; Trig. Survey, Univ. Natal.
Sir Lowry's Pass	Job 326/79, Photo 358/3; Col; 1979; 1:9 640; Dept. Land Surveying, Univ. Natal. Job 461/61, Photo 433; B&W; 1961; 1:10 100; Trig. Survey, Mowbray. Job 126/38, Photo 12665; B&W; 1938; 1:10 320; Trig. Survey, Univ. Natal.
Steenbras	Job 326/79, Photo 356/3; Col; 1979; 1:9 220; Dept. Land Surveying, Univ. Natal. Job 126/38, Photo 12696; B&W; 1938; 1:10 160; Trig. Survey, Mowbray.

Rooiels	Job 326/79, Photo 354/3; Col; 1979; 1:9 800; Dept. Land Surveying, Mowbray. Job 126/38, Photo 12775; B&W; 1938; 1:9 500; Trig. Survey, Mowbray.
Buffels (east)	Job 326/79, Photo 352/3; Col; 1979; 1:9 460; Dept. Land Surveying, Univ. Natal. Job 126/38, Photo 12807; B&W; 1938; 1:9 760; Trig Survey, Univ. Natal.

Appendix 8.1. Aerial photographs seen for this study.

Job 61/44; B&W; 1944; Approximate Scale 1:18 000
Photo No 103, 104, 105, 189, 193, 194, 374, 556, 557, 577, 601
1193, 1208
Trig. Survey, Mowbray.

Job 126/38; B&W; 1938; Approximate Scale 1:25 000
Photo No 11697, 11707, 11723, 12611, 12660, 12661, 12665, 12696
12774, 12775, 12807
Trig. Survey, Mowbray.

Job 326/79; Col; 1979; Approximate Scale 1:10 000
Photo No 351/3, 352/3, 353/3, 354/3, 355/3, 356/3, 357/3, 358/3
359/3, 360/3, 361/3, 362/3, 363/3, 364/3, 365/3, 366/3
367/3, 368/3, 369/3, 370/3, 371/3, 372/3, 374/3, 375/3
Dept. Land Surveying, Univ. Natal.

Job 335/53; B&W; 1953; Approximate Scale 1:36 000
Photo No 5754, 6113, 6114, 6123, 6124
Trig. Survey, Mowbray.

Job 374/73; B&W; 1973; Approximate Scale 1:10 000
Photo No 251, 252, 253, 253, 255, 256, 257, 258, 259, 260
Dept. Land Surveying, Univ. Natal.

Job 391/81; Col; 1981; Approximate Scale 1:20 000
Photo No 353/3, 354/3, 355/3, 356/3, 357/3, 358/3, 359/3, 360/3,
361/3, 362/3, 363/3, 364/3, 365/3, 366/3, 367/3, 368/3,
271/4, 272/4, 273/4, 274/3
Dept. Land Surveying, Univ. Natal.

Job 424/58; B&W; 1958; Approximate Scale 1:30 000
Photo No 6986, 6995, 6997, 7008, 7009
Trig. Survey, Mowbray.

Job 461/61; B&W; 1961; Approximate Scale 1:36 000
Photo No 0426, 0429, 0431, 0432, 0433
Trig Survey, Univ. Natal.

Job 534/67; B&W; 1966/67; Approximate Scale 1:36 000
Photo No 456, 457, 470, 497
Trig. Survey, Mowbray.

Job 620/68; B&W; 1968; Approximate Scale 1:20 000
Photo No 502, 558, 573
Trig. Survey, Mowbray.

Job 719/73; B&W; 1973; Approximate Scale 1:50 000
Photo No 1709, 1710, 2133, 2137
Trig. Survey, Mowbray.

Job 786/77; B&W; 1977; Approximate Scale 1:50 000
Photo No 0522, 0651, 0655, 0656, 0657, 0658, 0659, 0660, 0661,
0662
Trig. Survey, Mowbray.