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The Biophysical Integrity of the Biogeographic Regionalisation for Western Australia.

First Report

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Summary

This report provides a review of methodologies for integrating and analysing a variety of local and/or State-wide spatial and tabular data sets. The underlying objective of the analyses will be to identify correlations in patterns of distribution with the IBRA regions and with Beard’s districts and sub-districts.

1. Introduction

1.1 Project objectives

The principal aim of the present project is to evaluate the biophysical basis of the Western Australian component of the Interim Biogeographic Regionalisation of Australia.

This is a pilot project to develop methodologies for integrating and analysing a variety of local and/or State-wide spatial and tabular data sets. The underlying objective of the analyses will be to identify correlations in patterns of distribution with the IBRA regions and with Beard’s districts and sub-districts.

Reports from this project will:

- document appropriate methodologies for integrating land data of various standards of resolution and quality and for making them accessible to managers, researchers and decision-makers;
- document methodologies for analysing spatial and tabular data sets to identify relationships between sets;
- through the analysis of a number of sub-sets of data, determine which sets warrant further attention (and derive estimates of time and cost of any further work); and
- review the present state of knowledge about the current IBRA framework and make recommendations for changes and/or further work.

2 Methodologies for the integration of land data of various standards of resolution and quality

2.1 Introduction.

Information about the spatial distribution of features on the earth’s surface has been collected since organised societies began: the oldest surviving map dates from 3500 BC. The initial purposes for collecting geographical data were to aid navigation, for military reasons and later, for census and taxation. These early maps were topographic and cadastral, containing general information about the configuration of the landscape and about land ownership.

Modern developments in the assessment and understanding of natural resources, including vegetation and geology, have provided new data to be mapped. A new generation of map products has emerged: in these, qualitative or quantitative information about a specific theme is expressed as areas of equal value separated by boundaries. These are known as chloropleth maps.

For most sciences the first aim of many surveys was inventory - observation, classification and recording; this was unavoidable given the huge amount of complex data. Qualitative measurements were also hindered by the lack of samples, the need for huge data volumes and the lack of mathematical and statistical tools for the analysis of spatial data. These techniques began to be developed in the 1930s and 40s, but were of limited usefulness because the published map and accompanying memoir were still effectively the database. The increasing use and complexity of maps led to a number of problems.

a). The world is complex and users will have different needs, causing any map to have some redundancy and maps may need to be customised to the requirement.

b). The need for various scales, and the ability to move between scales.

c). Integration of further data (such as tabular) onto a map.

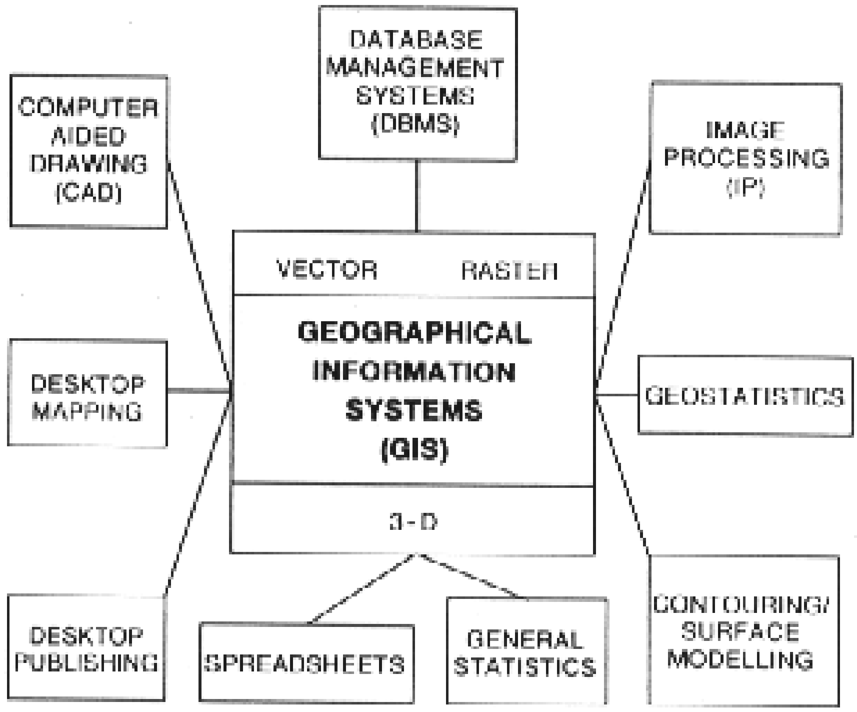
d). Data is usually out of date before a map is even published, there is a need for up to date information.

In the 1960s and 70s with the realisation that many different ecological processes were not independent, mapped information about natural resources began to be evaluated in a more holistic way. Concurrent trends in using computers for drafting and analysis has led to the development of information systems based on the spatial location of data or Geographic Information Systems (GIS).

2.2 Geographic Information Systems

A Geographic Information System (GIS) is an organised collection of computer hardware and software; designed to efficiently capture, store, update, manipulate, analyse and display all forms of geographically referenced data.

Figure 1. GIS and related software systems.



The organisation of data is important, it can be structured in many ways. However the principle characteristic for the organisation of data in a GIS is by its spatial location or reference to a spatial location. The ability to calculate and store attributes spatial as information relating to a spatial feature distinguishes a GIS from other interactive graphics software. Geographic data can be represented by two data models, *spatial* an*d non-spatial*. Any data base will handle the attributes, but in a GIS spatial and attribute data are handled concurrently.

2.3 Terrestrial Coordinate Systems.

Spatial information must be referenced to a coordinate system, ensuring that there is a known relationship between a locus on a map, to enable it to be consistently located. In a survey data is referenced to a single coordinate system. Over a small-scale it may be from an arbitrary defined location such as distance from a river, but for larger scale work spatial data is referenced by its position on the earth’s surface,

However, the shape of the earth is irregular and can only be accurately described by a series of mathematical equations that define the potential surface (simular to mean sea level). Due to its complexity, it is not suitable for general use in calculations for surveying and mapping, and for most practical purposes, the shape of the earth is approximated by an ellipsoid of revolution. This ellipsoid (often called a *spheroid or* *geoid*) is generally described in terms of its major (equatorial) and minor (polar) axes, from which other parameters such as flattening can be determined.

Historically, different ellipsoids have been adopted to suit the local requirements for individual countries, but these often vary considerably affecting distances, leading to difficulties when comparing data. With the advent of satellites and global positioning systems, better values have been obtained for a universal ellipsoid that can be used to represent the world as a whole.

Western Australia currently uses the Australia Geodetic Datum based on the WGS84 (World Geodetic System, 1984) which was up dated in 1984 from the previous 1966 datum (still used in some states). The AGD is based on the Australian National Spheroid which is the geometric figure which best fits the geoid in the Australian region. In November 1994 the Inter-Governmental Committee on Surveying and Mapping recommended the progressive implementation of a new datum for Australia by the 1st January 2000. This will be called the Geocentric Datum of Australia (GDA) and it will have its origin at the earths centre of mass, which is directly related to the orbits of satellites. The new GDA will be based on a global spheroid, the Global Reference 1980, which best fits the figure of the geoid over the whole earth.

The location of spatial entities on a large scale is defined in mathematical terms using either geographic coordinates or plane coordinates according to some projection of this surface onto a plane. This position is directly dependant on the definition and fundamental parameter used in specifying the coordinate system.

2..3.1 Geographic Coordinate System.

The principle system for defining points on the surface of the earth (relative to the ellipsoid) is the geographic system of **latitude** ϕ, **longitude** λ and **height** h above the datum (generally mean sea level). A line joining the north and south pole is called a meridian and longitude is a measure of the angle at the centre of the earth between any meridian and the central meridian (through Greenwich, England). Latitude is the angle between the equator and a point along its meridian, and lines of constant latitude are called parallels. The network making up the intersecting meridians and parallels is called a graticule. Latitude is measured in degrees, minutes and seconds (DMS) north and south of the equator. Longitude is measured in degrees, minutes and seconds (DMS) east and west of the central meridian.

Latitude/longitude is a geographic reference system, not a two dimensional (2-D) or planer coordinate system. So the length of 1 degree of longitude varies from 111 km at the equator to 0 km at the poles. Because degrees are not associated with a standard length they can not be used as a measurement of distance or area. Although most GIS can store and manipulate spatial data in geographics, data is more usually stored in planer coordinates to avoid repeated transformations every time the data is output to s video screen or plotter.

2.3.2 Map Projections.

Locations on the plane are defined by polar or, more usually, Cartesian coordinates. Because measurements of length, angle and area will be constant across the two dimensions projective transforms from the geoid to a plane will produce distortions, and much of the earth’s surface will be represented smaller than the nominal scale.

Various mathematical models exist to project the earth's spherical surface onto a flat 2-D surface, this transformation is called a *map projection*.

These mathematical projections can be broadly classified according to the type of surface used for the projection (plane, cone or cylinder) and the orientation of this surface with respect to the earth (normal, oblique or transverse). However map projections are generally classified according to the type of distortion that occurs from the mathematical transformation of the 3-D coordinates (λ, ϕ, h) to the equivalent 2-D coordinates (x,y).

a) Equal Area Projections. Equal area projections imply that area can be accurately portrayed on the map. However distances and angles will be distorted, and can not readily be determined from measurements on the map, also shapes will be distorted. (eg Alber Equal Area Projection).

b) Equidistant Projections. Equidistance projections are used for representing selected distances correctly on the map and are therefore sometimes applicable for mapping transport routes, but areas, angles and shapes are distorted. (eg Azimuth Equidistant Projection).

c) Conformal Projections. Conformal projections have useful properties that angles project truly, and that scale distortion is uniform in all directions at a point, however distances and areas (and thus shapes) are distorted. These projections have generally been used for surveying purposes. (eg Universal Transverse Mercator Projection).

2.3.3 The Australian Map Grid (AMG).

The National Mapping Council has adopted the AMG, which is a plane or rectangular coordinate system based on the Universal Transverse Mercator Projection (UTM). The UTM was established in 1936 by the International Union of Geodesy and Geophysics. It uses the Mercator projection which is produced by wrapping a cylinder around the poles instead of the equator (in the ordinary Mercator).

The Earth is divided into 60 zones numbered from east to west starting with zone 1 at 180^0 W. Each zone is 6 degrees of longitude and extend from 80^0 N to 80^0 S. Different zones are needed because as the width of the zone increases (east-west extent), so does the difference on the map and the corresponding ground distance. Displacements in the x and y directions are called UTM Eastings and Northings respectively. The true origin of each zone is the intersection of the central meridian and the equator although by convention a false origin, offset to the west by 500,000m, is used so that within each zone Eastings are always positive. In the southern hemisphere the false origin is also offset from the true origin by 10,000,000m to the south to avoid negative Northings. To minimise geometric distortions across each zone the scale of the central meridian is reduced by a scale factor of 0.9996 producing two parallel lines of zero distortion approximately 180km either side of the central meridian.

The UTM is an excellent system for regions covered by maps at scales of 1:250,000 and larger, but at smaller scales the distortions are unacceptable. Western Australia covers all or a portion of four zones from 49 to 52.

2.3.4 Coordinate Grid.

Each projection has its own rectangular coordinate system, or *coordinate grid*, associated with it and which is different from the graticule. The grid facilitates calculations on the actual projection, as simple geometry can be used to represent position relative to the projection origin. However all values, such as distances and areas derived directly from these mapping coordinates maintain the inherent distortions associated with the projection type. The true origin is where the central meridian crosses the equator, but as this will lead to negative numbers a false origin is located at the lower left corner.

2.4 Geo-Referenced Coordinates in GIS.

The selection of a base coordinate system for the storage and manipulation of data in a GIS will depend on:

a) The purpose of the GIS.

b) The size of the graphical database.

c) The accuracy of the data required.

d) The type of calculations to be carried out.

e) The form in which the data is to be displayed.

The choice of a general coordinate system is not important for small areas, and it is usually possible to apply a single uniform grid to the project, neglecting any distortions. However, the use of a GIS involving nation-wide data presents additional requirements.

a) The data should be stored in the same coordinate system.

b) The data must be referenced to a unique ellipsoid.

c) It must contain a measure of the accuracy spatial accuracy in addition to the accuracy of the attribute data..

Data can either be stored with each point referenced to latitude, longitude and height above the mean datum, or stored on a projection.

2.5 Sources of Geographic Information

A major proportion of the effort involved in setting up a GIS is in assembling the data in a digital form and creating a spatial database in which all the maps, raster images and data tables are properly geocoded and spatially registered.

a) Paper maps and drawings. Maps do not have to have the same scale or adjacent areas that match precisely, as long as a map has points for which accurate geographic coordinates can be measured, it can be entered into a GIS.

b) Records, lists, charts, tables, survey information, or even stacks of applications or forms. This textual information is generally entered into the database and attached to certain features as attributes in a GIS.

c) Images and measurements from aerial photographs and satellite-based remote sensors.

d) Geolocated data (eg GPS, total stations).

These data can be divided into primary data sources (usually digital) and secondary data sources (usually analog). Primary data is recorded by instruments operating in the laboratory, in situ or by remote sensing. Most GIS projects use secondary data which is data gathered, interpreted and stored usually non-digitally. Particularly in disciplines like Geology and Botany maps are interpretive and subjective, making it difficult to establish standards. A published map represents an interpretation by one or a few scientists at one moment in time. Even adjacent regions mapped by the same scientist over a gap of a few years may be incompatible because new concepts have been developed affecting the underlying interpretation and the resulting map model. The data model also changes with the scale of mapping at units appropriate at 1:250,000 are too generalised for 1:25,000 scale mapping and vice versa. Metadata, that is data about the data are even more critical for derived data that has been extensively manipulated and combined in a GIS.

The interpretation of data will be affected by the type of measurement system. These may be broken into four types:

a) Ratio. Values are divided relative to a fixed zero point on a linear scale.

b) Interval. Values along a linear scale but not relative to a true zero point in time or space.

c) Ordinal. Values determine position, but they do not establish magnitude or relative proportions.

d) Nominal. Values are qualities and may identify instances, groups, classes or categories, but they are not quantities and have no relation to a fixed point or linear scale.

2.6 Spatial Data structure.

The major components of a location on a map are two coordinates indicating the position of the location in two dimensions. In Cartesian coordinates the first is a horizontal value indicating the ordinal position with respect to the left edge and the second is a vertical value indicating its ordinal position with respect to the lower edge.

The simplest way of storing locational data is to explicitly record the two values (x,y) as well as the attribute (ie height) of each location. However this will lead to an enormous the volume of data to be stored for each location. Data storage can be reduced by storing one value per location, utilising the regularity of the cartographic grid (defined in a header) and the position of the location in it, to establish implicit, rather than explicit, associations between locations and their coordinates. This scheme is termed *raster*, and each point attribute refers to a regular grid around it.

The large file sizes common in handling raster data often requires ways of compressing the data.

a). <u>Chain codes</u>. The boundary of a region is given by its origin and a sequence of unit vectors in the carinal directions with superscript numbers representing the number of pixels. The model is good for region representation, estimation of areas, perimeters and detection of sharp turns and concavity, but It is bad for overlay operations, as union/intersections are difficult to perform and all regions/boundaries are stored twice.

b). Run length encoded. The points of each mapping unit are stored per row interval from left to right. It is most efficient when the pixels are large with respect to the regions, as complete coding is achieved by 22 numbers. Particularly useful for small computers with small disk space, but too much compression may require increased processing in cartographic operations.

c). Block codes. The idea of run-length encoding can be extended to 2-D, each region of pixels is encoded with an origin and radius. It is good with large simple shapes, and when the number of pixels/region increases.

d). Quadtrees. Successive division of regions into quadrants (pixels x 4). Regions can be efficiently and easily computed, but it is not translation invariant - poor for pattern recognition as two quadtrees may have the same size and shape.. But it is the most efficient method as the for large data sets, and has the added advantage of variable resolution.

However despite any method of compression any increase in the precision of location results in a huge increase in the volume of data. Another scheme of storing data, provides for the aggregation of locations that share a common value into groupings that need not be rectilinear. Sequences of locations along boundaries and other linear configurations are recorded as either chains (a series of directional codes describing the relationship of each location to the next adjacent location in the sequence) or the coordinates of only those locations at which the straight line segments change direction. The encoding methods are usually referred to as *vector* because each line segment has magnitude and direction.

Raster is a space filling model, identifying spatial locations before defining objects, whereas vector structures are theme orientated, and are more associated with characteristics. Thus raster data are ideally suited for themes of high variability, whereas vectors are better for low variability. For data capture and presentation the merits of raster and vector data depend on the type of information. Images are generally in raster format, whereas drawings are more suitable in vector.

The vector data model is more often used to represent discrete (sometimes called discontinuous or categorical) objects. A discrete object has known or locatable boundaries, it is easy to define where the object begins and ends. The raster data model is more often used to represent continuous (non-discrete or surface) data where each location is a measure of its relationship to a fixed value. One form of the vector model that can be used to model surfaces, called Triangulated Irregular Network (TIN), uses line features to join up points to create Delauney triangles. These are based on a proximal distance criterion producing a low variance in edge length.

The vector model is well suited for representing graphical objects on maps, because smooth curves are better approximated by vertices that are not constrained by the coarse Cartesian coordinates of a lattice; and small polygons and points can be represented precisely. It is the most logical method of translating graphical data but is also the most resource intensive and mathematically complex. Capturing and analysis of data in raster form is quick and easy, but ultimately it is a simplification that reduces accuracy.

However the indication of position by coordinates does not cover all aspects associated with location, and should include information about the scale, resolution, precision and accuracy. Scale is the order of magnitude or level of generalisation at which the phenomena are perceived or observed while resolution is the size of the smallest recording unit. The resolution detail of recording and the accuracy is the correctness of measurement.

2.7 The spatial characteristics of entities.

Entities (sometimes called objects) may be classified according to their spatial properties, in particular, dimension. These are **point**, **line**, **area** and **volume** or zero, one, two and three dimensions. A point entity is assumed to be independent of every other point, unless derived statistics such as neighbours or distances are involved. Line entities are separately occurring phenomena unrelated to each other in any way. However lines will also have spatial properties of interest like length, sinuosity and orientation.

Area entities encompass two dimensions, and are bounded, spatial units which may or may not include the boundaries (necessary for demarcation purposes) for carrying information. If the boundary is excluded the term *inner area* is used, if the boundary is included and the area consists of the inner area and outer ring the term polygon is used. A polygon may be simple if it has no interior rings or complex if it has atleast on interior ring. It is often useful to represent a polygon by a single point, either for simplifying distance measurements or labelling purposes. A position, called a centroid, is defined which is usually within the polygon. This may be chosen intuitively or derived by various means (ie from the vertices).

Conditions that can be regarded as punctual (point) or linear may become areal when mapped at a more detailed scale. In addition most scientific data are collected at points, or along traverses. But difficulties arise when a comparison is made between two independently collected datasets with different sample locations. Any method for data integration must be able to resolve these problems.

2.8 Microstation.

Microstation is a sophisticated computer assisted design (CAD) package. Spatial entities are entered onto a design plane (or space) of finite size consisting of a network of absolute positional units. Since MicroStation is designed to run on 32 bit computers, and each coordinate value takes up 1 storage location (word), there are over 4.2 billion positional units in the three dimension (x,y and z). This is equivalent to setting the design plane to cover the distance from Perth to Auckland with a resolution down to 1cm.

The standard MicroStation drafting entities are called graphic elements or often just elements. Although Microstation, like all CAD, consists of very few element types a huge number of composites can be created allowing complex diagrams to be constructed.

a) Vertex. A position in the design plain that is the join between two elements (sometimes called a node).

b) Line. The shortest distance between two points selected by the operator.

c) Circle. Consists of a center and radius (an ellipse is a centre, 2 radii and an axis.

d) Arc. A center, radius and two end points (being joined anticlockwise from the first to the second point).

e) Linestring. Not a number of lines but a single entity containing a number of coordinate pairs.

f) Curves. Simular to linestrings but splines are fitted to the vertices..

g) Polygon. Linestrings joined up into one entity.

h) Text. Attached to a node, or point.

Elements can be placed with a variety of symbology (width, color etc) and on different levels from 1 to 63.

2.9 The representation of graphic data in MGE.

Integration is the ability of a system to work directly with different spatial data types providing tools to link and/or convert between the different forms of representation. Integration also encompasses the combining of data for raster and vector representations in one database, for mutual updating or editing. The Spatial Resource Information Group (SRIG) at Agriculture Western Australia uses Intergraph's Modular GIS Environment which provides sophisticated representation of vector and raster data models as well as links to a corporate Oracle database. In addition the modular approach with the associated graphic user interfaces (GUI) allows an operator to perform analyses without the need to look through manuals for commands.

MGE is uses the MicroStation CAD engine to provide the method for representing entity types and also provides the coordinate framework for the GIS. MGE/SX adds a GIS capability, and encompasses MicroStation, using RIS (Relational Interface System) to connect with the a relational database in this case Oracle. The grid (MGGA) and image processing (ISI) packages run under or are independant of MGE/SX. More modelling (MSM) and spatial analysis (MGA) packages are also used. Because Microstation is 3-D other packages like ERMA and Voxel Analyst can be used for true three dimensional modelling.

Graphic information in MGE is stored in MicroStation design files and represented as maps. A geographic element is represented on a map as a feature, and is usually linked to attribute information in a relational database table or tables. A feature is a spatially located geographic element, it represents something located in space (over, on, or under the ground) for the purpose of recording and tracking.

For consistency, the graphic information of the feature are stored in a corresponding record in the feature database table. Each feature in the feature table has a unique feature name and a unique feature code. The feature table provides a reference for MGE how to draw and use the feature in the design file and what linkage to put on the graphic element. The tie that binds features to their associated feature records, and vice versa, is the feature linkage. The feature linkage is four (or eight) words of information appended to the end of the element that contains the entity number (identifying the feature table) and one or more mslink values pointing to the feature table record or table records with which it is linked.

All features are linked to at least one record in the feature table. The use of a single table for features allows easy comparisons of a feature instances because they all share common attributes. However, nongraphic attributes of features do not appear graphically on a map and are stored in attribute tables. Creating and maintaining these features and attributes and linking them together is a primary function of MGE Base Mapper.

Features always contain a graphic definition and there are a variety of element types available to an item. In addition characteristics such as color weight and level, known as the symbology, can be used to distinguish different features that contain the same element type. This allows visual differentiation of features in the graphics environment. Layering by graphic level enables the display of any combination of features that have been placed on any map, a similar result is achieved with transparent overlays.

Features in MGE can be either a point, a line, an area boundary, an area centroid, or undefined.

A **point** represents the location of a geographic element defined by 1 x,y coordinate, such as a spot height or bore hole, which is too small to be displayed as a line or area. A point can be displayed on a map as a MicroStation point (zero-length line), text node, text, or cell element.

A **line** represent a feature that has no width or that is shown as having no width at the scale of the map used. If straight line segments are short enough, a line appears to be curved. Streets and property lines are typical linear features.

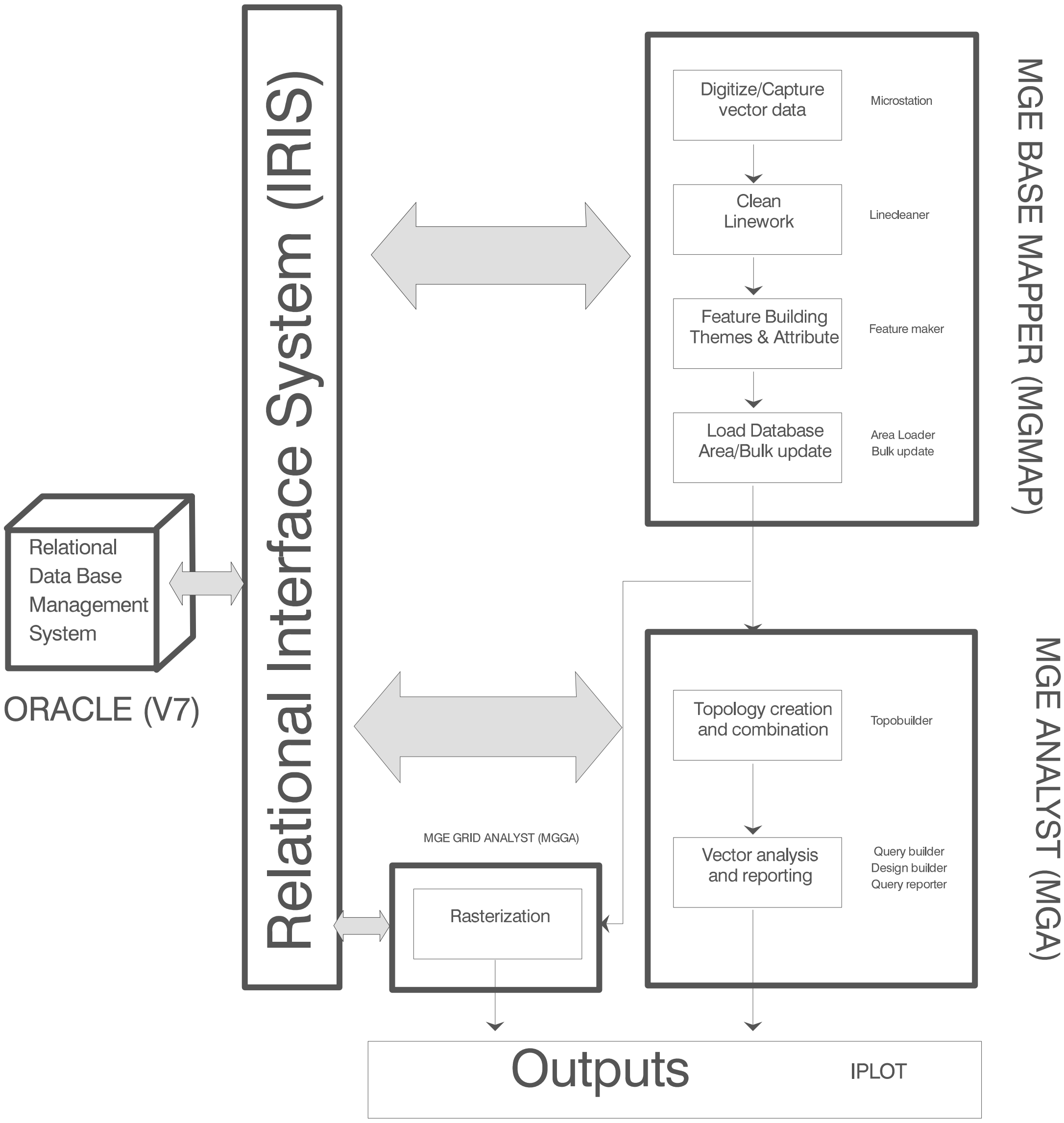
An **area boundary** is a set of lines enclosing a geographic region, such as the shoreline of a lake or a city limit. Boundaries can be shared by adjacent areas and the graphic element need not be duplicated.

An **area centroid** contains attribute information about an area and must be placed somewhere within the area boundary. In MGE attribute tables are created to contain this information and linked to features. A centroid can be displayed on a map as a MicroStation point, text node, text, or cell element.

An **undefined** feature can be anything for example a grid.

How a feature looks on a map may provide more of an indication of what the geographic entity represents. The size of a point, for example, may relate to the size of the city's population. The thickness or colour of the line representing a road may show its capacity to accommodate traffic.

Figure 2. Schematic diagram of the MGE suite of software.



2.10 The representation of attribute data in MGE.

Data in the attribute tables reflects instances of features. Attributes of a feature that are not displayed must still be represented in another manner. They are stored in Oracle tables but likned to existing features using the mslink (map sheet link), an addtional record created in the table that will be linked to graphics by MGE. These attributes can be loaded into the graphics files as labels, the symbology of which is stored in the feature table.

One attribute table record can be linked to a graphic element per feature linkage. If a graphic element is a vegetation feature, it may contain only one attribute linkage pointing to a vegetation attribute table record. However a graphic element can sometimes have multiple feature linkages. Such as the case where a road is also part of a boundary between two counties (ie Watling St, a n old Roman road between Warwickshire and Leicestershire).

The valueentered depends on the type specified for the row and can be an inetger, character, double, real or a decimal. These relate to the number of bytes used to store the information. Also stored in the attribute table record is a value called the mapid, this identifies the design file containing the graphic element associated with the attribute table record.

The beard vegetation graphics table, beard_vege is set up

mslink	integer
mapid	integer
cell_no	char
beard_num	integer
beard_area	double
veg_code	char
grid_load	integer

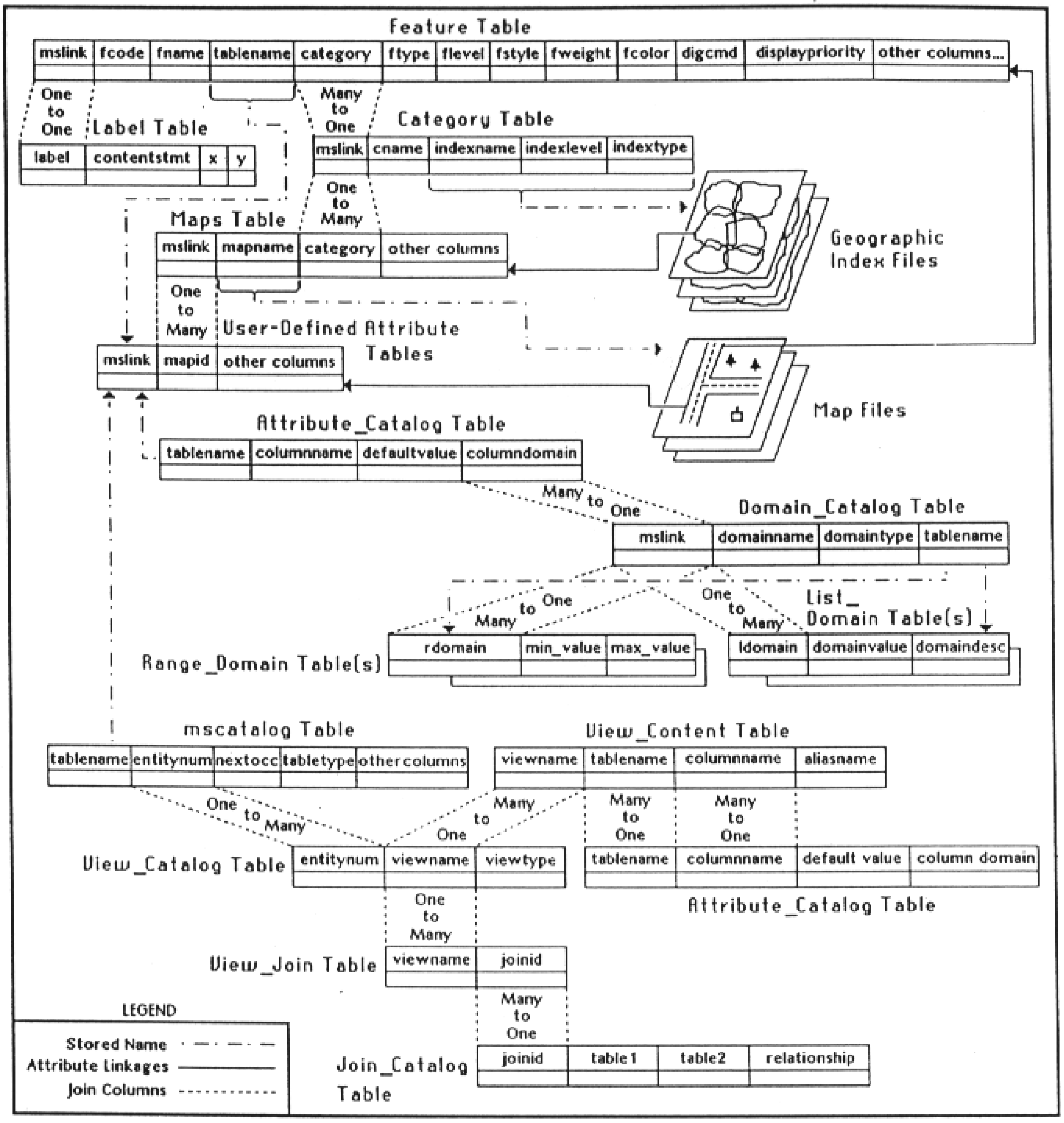
in this example the attribute table is linked to a beard vegetation centroid.

Most features are linked to records in a relational database attribute table; although, this is not required it is a simple way of standardising the graphic characteristics of some element depicted in the GIS landscape but that is so common no record is wanted the attribute tables. Trees or shrubs could be examples of these nonattributed features. A feature that is composed of both graphic elements and a database record is referred to as a attributed feature.

Geographic information from all sources is combined in a GIS into a project. A project is usually associated with a study area and is a collection of geographic information (maps and tables) related to that study area. Each GIS project can have its own schema (a collection of tables and privileges owned by the project on a database), or several projects can share a schema. on a networked system.

Features and non-graphic tables are the components of the MGE data model that describe user data representing the real world. A category is a group of thematically or geographically related maps; features are also grouped into the same categories as the maps on which they appear. Categories describe system storage, domains define acceptable attribute values and joins define relationships between data. Categories are a technique to group features, usually from a presentation point of view, but more usefully for a administration. In an MGE project, maps are grouped into related categories. Features are grouped into the same categories as the maps on which they appear. Therefore, a map of a particular category can only contain features that are associated with that same category.

Figure 3. MGE Project Data and Relationships.



Note : the *attribute_catalog* appears twice for the purposes of illustration

2.11 Spatial data verification and correction.

2.11.1 Vector data.

In the process of creating and using spatial information many changes will occur in the state of the information. There will be changes in media (ie digitising paper maps), form (loading tables to graphics) or representation (vector to raster and vice versa). There may also be changes in conceptualisation or digital coding. Errors can also arise during the encoding and input of spatial and non-spatia data.

In manual digitising data can often be entered more than once leading to duplication, or omitted leading to incomplete linework. Data can often be where an automated process has failed to join up all the lines (Arc/Info conversions to design files have a maximum number of vertices). Vector data that has been sourced from raster data may also be incomplete because not all the lines have been joined up.

Mislocation of spatial data can range from minor placement errors to gross spatial errors. The former are the result of careless digitising and the latter may be the result of scale or origin changes that occurred during digitising. If all the data is at the wrong scale it is usually because the digitiser was set up incorrectly and can usually be changes by a simple multiplier. Even the most accurate digitising is only accurate to 0.5 mm or 125m on the ground for a 1:250,000 mapsheet.

Very often the spatial data is distorted because the base maps used for digitising are not scale correct in both x and y. This may be because the original aerial photographs were not orthophotos or because the paper maps suffered from stretch which is generally greater in one direction than others. In other cases the original map was an illustration in a paper with no coordinate information.

For spatila data from different sources to be combined in order to describe spatial associations requires that all positions be located to a common frame of reference. The input data must all be in a known projection with a known geodetic datum etc and will preferably be digitised using the same baseline (ie DOLA stanardized coastline)

Most GIS provide capabilities for data maintenance and manipulation in order to register a faulty map to an accurate base map. The faulty map is compared to an accurate base map and a number of points on the original map are linked by vectors to the correct positions. Algorithms are used to stretch or compress the original map, until the linking vectors have shrunk to zero and the tie points are registered to each other. It is then assumed that the other points on the original map have been relocated correctly.

Whereas reprojection is a systematic translation from one known coordinate to another, warping is often a nonlinear translation in that some coordinate values change more than others. The term warping is preferred to *rubber sheeting* is often used, but since this implies discontinuous distortion and the term *warping* implies continuous distortion.

2.11.2 Transforming geographic coordinates.

There are many conversion techniques that can be used to match positional information.

a) Rotation and reflection. Both transformations preserve areas, rotation is undertaken by a trigonometric operation where the angle specified is the angular change in orientation of the set of entities. Reflection can be either using a point or line as the mirror surface.

b) Scaling and translation. Object shape and similarity is preserved but in the former case the object size is changed and in the latter case the coordinate system is changed by a shift along one or more of the x,y or z axes.

a) and b) may be combined by use of the Helmert transformation which provides a uniform scaling, rotation and translation. Since it is a similarity transform the ratios of distances are preserved by the transformation thus preserving shapes and angles.

c) Affine May also be known as a 1st order polynomial and allows for changes in scale, rotation and origin. Although the parallelism of any lines is preserved there may be angular distortion.

$$x = a + bx_1 + cy_1$$
$$y = d + ex_1 + fy_1$$

where : a,b,c,d,e are coefficients determined from ground control points (GCP)

d) N-degree polynomials Account not only for scaling, rotation and translation between plane coordinate systems but also takes warping effects into consideration.

e) Projective. The geometry (coordinate distances) are changed without altering the topological spatial relations. Any entities maintain their figure definition (ie number of sides or points) but more or just one of them can change in length and/or orientation.

Coordinates are identified on the base map and input map and the coefficients are determined exactly. Subsequently the coefficients are determined by using a least squares fit between the GCP and the predicted points have residual errors, defined by the Pythagorean distance between the observed and predicted positions.

$$\text{residual} = \sqrt{((X - X_{obs})^2 + (Y - Y_{obs})^2)}$$

2.11.3 Raster data

Distortions can be either systematic or random. Systematic distortions (due to the camera lens or scanning motion) are well understood and are corrected by applying formulas mathematically modelling the source of the distortion. The random and the residual unknown systematic distortions are corrected using the polynomial equations.

Rubber sheeting is not used for rasterized data because of the rigidity of the data leading to a distortion of the rigid grid. The problem can be solved by assuming that the grided data are discrete samples from a continuous statistical surface and a new surface is obtained by using an interpolation technique (convolution) to convert the attribute data from the original array to the new array.

The attribute value is determined by a resampling of the original pixels. A nearest neighbour (First order) takes the value of the nearest pixel. The second order (bilinear) takes a distance weighted values from the nearest four pixels. The third order (cubic convolution) takes a distance weighted value from the nearest 16 pixels.

2.12 Outputting Geographic Information

Once geographic information is entered and stored in a project, it can be output in many forms. For example:

a) As an interactive display on the computer screen, where maps and features can be selectively merged and displayed, coordinate readouts and other measurements performed, zooms in or out, and graphic elements manipulated

b) As map files to be output to a plotter or printer

c) As text files in the form of tables for use in reports and documents

d) As an archive file to be stored

e) data exchange formats to other GIS.

7. References

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Regionalisations

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1.4 Biogeographic regionalisations

1.4.1 Background

The idea that it is possible to recognise biogeographic regions or natural ecological regions within Australia and/or Western Australia, or groups of organisms with particular geographical affinities, has existed since the time of the earliest biological explorations of the continent. A range of schemes has been proposed over the years: these fall loosely into three streams in a manner that generally reflects the component of the environment of interest to the particular author. The three streams centre on botanical, zoological and physical/biophysical aspects of the environment.

1.4.2 Phytogeographic regionalisations

Botanical interpretations began when Ferdinand von Mueller drew attention to the special character of the south western flora and suggested a boundary running from Shark Bay to Israelite Bay (von Mueller 1867, 1983). A similar observation was later made by Ludwig Diels who divided the southern part of the State into two Botanical Provinces, the Southwest Province and the Eremaean Province, with the boundary between the two (again a crescentic line from Shark Bay to Israelite Bay) being climatically determined (Diels 1906). Diels went on to subdivide the South-west Province into six Botanical Districts and the Southern Eremaean Province into two, with each District being characterised by a range of climatic, floristic and vegetation factors. C A Gardner extended these concepts throughout the State, recognising a Northern Botanical Province with five Districts, adding a further three Districts to the Eremaean Province and adjusting the boundary of the South Western Province further to the east (Gardner 1942, Gardner and Bennetts 1956).

In her seminal work on the phytogeography of the Australian region, N T Burbidge (1960) proposed a treatment, based essentially on climate, which extended the Northern Botanical Province (renamed the Tropical Zone) around the northern coast of the continent and down the east coast into northern New South Wales. A Temperate Zone which included the South Western Province extended from the eastern side of the Great Australian Bight around the south coast (and including Tasmania) and up the east coast to south eastern Queensland. The area of overlap between the Tropical Zone and the Temperate Zone was named the MacPherson MacLeay Overlap (Burbidge 1960). The central arid and semi-arid core of the continent continued to be named the Eremaean Zone and Burbidge recognised three interzone areas, one of which coincides closely with Gardner and Bennett's (1956) Coolgardie District. This phytogeographic regionalisation picks up on some of the earlier zoogeographic proposals in a manner that appears to provide a satisfactory blend, although it clearly lacks the local detail of Gardner and Bennett's (1956) Botanical Districts.

The work of Burbidge was subsequently refined by H Doing in a treatment that combined an analysis of plant species patterns with one of vegetation patterns (Doing 1970). Doing recognised some 25 regions, of which seven fall within Western Australia, conforming roughly with the Northern Province (Enw), the Eremaean Province (Cmn, Cmw, Emn) the South Western Province (Ewh, Ewf) and the Coolgardie District/Interzone (Emw).

Johnson and Briggs (1975) proposed a scheme of ecogeographic regions for Australia, based on an analysis of patterns of distribution of Proteaceae. This scheme has a Northern Monsoon Zone across northern Australia picking up Burbidge's (1960)

Tropical Zone and some of her Interzone but terminating on the east coast near Rockhampton, a Non-tropical East Zone, which includes Burbidge’s Temperate Zone and associated Interzone, and a Southwest Zone which includes the SW Focal Area of Burbidge’s Temperate Zone and the associated Interzone. The central part of the continent continued to be the Eremaean Zone, and areas of rainforest along the east coast were mapped.

In the course of the Vegetation Survey of Western Australia project which is outlined above, Beard developed a deep insight into the ecological basis for the phytogeographic regionalisation that had been proposed previously and was able to refine the concepts and the boundaries. Beard began to incorporate redefined boundaries on his published 1:1,000,000 vegetation maps (eg.see Beard 1974a) and, in 1978 compiled the first detailed, State-wide map of his regionalisation at the scale of 1:2,500,000 and it was subsequently published with detailed explanatory notes (Beard 1980). The Phytogeographic Regions represent a very considerable refinement of the scheme of Gardner and Bennetts (1956) with boundaries that are largely coincident with boundaries of vegetation units mapped by Beard at the scale of 1:250,000, selected on the basis on factors such as geology and climate (and perhaps even lizards, see Pianka 1969, 1981) as well as vegetation. Beard recognises three major Provinces and an Interzone, and, within these, 21 Districts: the Northern Botanical Province comprising Gardner, Fitzgerald, Dampier and Hall Districts; the Eremaean Botanical Province comprising Canning, Mueller, Carnarvon, Fortescue, Keartland, Carnegie, Giles, Ashburton, Austin, Helms, and Eucla Districts; the Southwestern Interzone or Coolgardie District; and the Southwestern Botanical Province comprising Irwin, Darling, Avon, Roe and Eyre Districts. Beard also recognises Subdistricts: these are shown on the individual 1:250,000 map sheets. The 1:2,500,000 map of the Phytogeographic Regions includes considerable geographical detail so it is possible to locate other work quite precisely in relation to regional boundaries.

1.4.3 Zoogeographic regionalisations

The first zoogeographic interpretation of relevance to Western Australia was that of R Tate (1887) who distinquished the south-west corner of the State, the Autochthonian, from the Eremian or desert region, with the boundary between the two coinciding approximately with the 20 inch rainfall isohyet. The south-east and east coastal parts of the continent were described as the Euronotian region. Baldwin Spencer (1896) erected a Torresian sub-region running from New Guinea through Cape York and down the east coast of Australia to the Clarence River, and taking in the tropical/monsoonal part of northern Australia including the Kimberley, a Bassian sub-region running along the remainder of the south-east coast east to the Great Divide and including Tasmania, and dispensed with the Autochthonian region, incorporating this last area within his Eyrean (desert) sub-region. Serventy and Whittell (1948) accepted this proposition insofaras it related to northern and central Western Australia. However, they suggested that the emphasis should be on characteristic faunal elements (which may move from time-to-time) rather than rigidly defined geographic regions, a view well supported by the work of Gentilli (1949). Using their data on bird distributions, Serventy and Whittell (1948) went on to argue that the south-west is a zone of intermingling of Eyrean and Bassian elements. Their crescentic line delimiting the distributions of most of the Bassian elements runs from around Geraldton (ie. south of Diel’s line) to Israelite Bay. A numerical analysis of data on presence/absence of land birds at 121 sites throughout Australia by Kikkawa and Pearse (1969) gave four subgroups along the east coast from the Gulf of Carpentaria, including Cape York, around to Adelaide. Subdivisions of the remainder were, in order, the two subgroups comprising the remainder of northern Australia, Tasmania, and inland south-eastern Australia. The subgroup associated with a broad area of southwestern Australia was found to be very similar to the two remaining desert subgroups but very dissimilar to the southeastern group, results which suggest that the avifauna of that area is much more Eyrean and much less Bassian than Serventy and Whittell (1948) considered it to be. (See also the work of Campbell 1943 derived from an analysis of the patterns of distribution of birds and the commentary on that scheme in Keast 1959, and the modification of the Kikkawa and Pearse scheme proposed by Horton 1973 based on reptiles and amphibians).

Two recent contributions to the debate on the evolutionary biogeography of the Australian avifauna deserve mention with the hope of stimulating further discussion later on. Cracraft (1986) has examined patterns of distribution of groups of closely related taxa of birds and has proposed a series of nodes separated by evolutionary isolating barriers. In the north and east, the nodes are Kimberley Plateau, Arnhem Land, New Guinea, Cape York, Atherton Plateau and the eastern rainforests. Nodes in the remainder of mainland Australia are Western Desert, Eastern Desert, southwestern corner and southeastern corner. Cracraft suggests that the barrier between the southwestern fauna and the desert fauna predates the barrier represented by the arid, marine limestone of the Nullarbor plain. These nodes or areas of endemism have been refined to include Northern Desert and Pilbara nodes and and the southeastern corner has been subdivided into three: Southern Forest, Adelaide and Eyre Peninsula in Cracraft (1991), wherin the congruence with patterns of endemism of other elements of the vertebrate fauna is highlighted. Gentilli (1992) has analysed patterns of land bird species richness in relation to biophysical factors. Major nodes of richness are identified in the Kimberley and the area of the wet forests and woodlands of the coastal plain and near-coastal mountain ranges of eastern Australia. The south west corner of Western Australia is a minor node. Gentilli draws attention to a conspicuous barrier in the Pilbara of Western Australia and suggests that it is reason to recognise the Pilbara as a distinct Eyrean sub-region.

Biogeographic regionalisations based on other elements of the fauna have been advanced or variously discussed by Iredale (1929), Iredale and Whitley (1938), McMichael and Hiscock (1958)(freshwater mussels), McMichael and Iredale (1959) (snails), Paramonov (1959) (Dipterofauna), Sloane (1915) (carabeid beetles), Whitley (1959) (freshwater fish), Walker (1981)(freshwater mussels) and Key (1959) (grasshoppers); some of these have been reviewed in relation to reptiles by Keast (1959). Main *et al*. (1958) and Tyler (1981) discussed the evolutionary biogeography of the southern Australian frogs in the context of the Baldwin Spencer scheme (and the modification proposed by Horton 1972, 1973 for reptiles and amphibians) while Tyler *et al*. (1981) produced a generalised scheme more representative of the distribution of Australian frogs as a whole.

The map of Pianka (1969, 1981), based on patterns of distribution of desert lizards, shows a total of 13 sub-regions of the Australian desert or Eremaean Zone/Eyrean Sub-region, with nine sub-regions in Western Australia.

It would seem that, with the exception of some of the authors already mentioned, Australian zoogeographers have exhibited a reluctance in recent years to locate boundaries; rather they have been content to identify nodes of endemism or species richness (eg. Cogger and Heatwole 1981, Kitching 1981, Lee *et al*. 1981, Keast 1981a, Main 1981, Pianka and Scholl 1981). The comprehensive review of the existing schemes, the richness data and other relevant information by Keast (1981b) does not give a satisfying synthesis but it does provide a solid foundation for future work in this direction.

1.4.4 Regionalisations based on biophysical parameters

In 1914, J T Jutson proposed a division of Western Australia into six distinct areas based mainly on geological and geomorphological features but taking into account patterns of drainage and vegetation (Jutson 1914). He subsequently (Jutson 1934) subdivided the Kimberley into three: North Kimberley, Fitzroyland and Ordland, and the North-West into two, Pilbaraland and Murchinsonia. The South-West or Swanland was more-or-less defined by the catchments of rivers draining to the coast between Geraldton and Esperance. The remaining inland part of the State was divided into Sandridge (with the Great Sandy Desert, Gibson Desert and Great Victoria Desert), Euclonia (with the Nullarbor Plain) and Salt Lake or Salinaland (with the internally drained parts of the agricultural region and the goldfields). Revised boundaries for Jutson's regionalisation are given by Gentilli (1979), and detailed up-to-date descriptions are included in Pilgrim (1979).

An alternative regionalisation based on physiography, geology and climate, in order of priority, by E deC Clarke (1926) distinguished 15 so-called natural regions and one sub-region. A further region was added in 1935 (Clarke 1935, see also Clarke *et al*.1948). This scheme keeps the North Kimberley and Ordland (now called Antrim), the Euclonia (now called Nullarbor), extends the Fitzroy, subdivides the Sandridge into Canning (Canning Sedimentary Basin/ Great Sandy Desert), Carnegie (Gibson Desert and Great Victoria Desert) and Warburton (Warburton Ranges), separates off the Carnarvon Region from the North-West, divides the South-West or Swanland into Greenough, Perth both west of the escarpment, Jarrah (containing the main forested area) and Stirling along the south coast and subdivides the Salt Lake or Salinaland into Wheat Belt, Kalgoorlie and Murchison. New boundaries have been delimited using up-to-date geological data and satelite imagery, but based on Clarke's defining principles, by Gentilli (1979).

L J H Teakle recognised nine major soil zones in the State (Teakle 1938) and, in collaboration with C A Gardner with his botanical perspective, identified 33 Soil and Ecological Regions (see Gentilli 1979). Four Regions within the Kimberley soil zone are Drysdale, Brockman, Hann and Fitzroy. The Carnegie soil zone which includes much of Clarke's Canning and Fitzroy is not subdivided further; neither is the contracted Nullarbor soil zone. The north west soil zone includes Warralong, Nullagine, Hamersley and Lyndon Regions. The broad swathe from Carnarvon through to the Nullarbor is subdivided into Asburton, Gascoyne, Minilya, Murchison, Yalgoo, Barlee, Warburton and Giles. Within the broad south west, three soil zones were recognised: a semi-arid/goldfields zone containing the Hartogsi, Ningham, Merridin, Corrigin, Coolgardie, Fitzgerald and Zanthus Regions, a narrow wheatbelt zone containing the Irwin, Avon, Dwarda, and Stirling Regions and the coastal plain and Darling Plateau zone containing the Swan, Darling and Franklin Regions.

Two papers by J Macdonald Holmes describe 19 Regional Landscapes (Holmes 1938) or Landform Regions (Holmes 1944) based on physiographic relief and landform characteristics, together with 12 types of coast. Congruence with Clarke's Natural

Regions is limited to the south west and up to Onslow. In the Kimberley, Holmes delimits three types of plain types and one each of upland and plateau. The Pilbara consists of one mountains type and one plateau type. South of the Pilbara through to the south coast there are four plain types, and four upland types, the Nullarbor is a plain type, and the central arid/semi-arid comprises three plain types and one small mountain type.

The Physiographic Regions of Gentilli and Fairbridge (1952) are perhaps better termed Structural Regions (Gentilli 1979) since definition of those Regions is based first and foremost on solid geology, with consideration being given to lithology, sculpture and texture. The 14 Regions that occur within Western Australia are 1 Yilgarn Block, Stirling-Mt Barren Block and Darling Hills; 2 Donnybrook Sunkland and Leeuwin-Naturalist Horst; 3 Swan Coastal Belt, Dandaragan Block and Greenough Block; 4 Carnarvon Basin and Shark Bay-Byro Plains; 5 Nullagine Platform, Pilbara Block, Fortesque Rift, Hamersley Plateau and Onslow Coastal Plain; 6 Canning Basin, Pindan Country, Fitzroy Valley and Eighty Mile Beach; 7 Kimberley Block, King Leopold Range and Durack Range; 8 Antrim Region and Ord Basin; 12 unnamed in Gentilli (1979); 13 MacDonnell Fold Belt; 14 Amadeus Sunkland; 15 Musgrave Block; 16 Nurrari Plain and 17 Eucla Basin and Eucla Coastal Plain.

Laut *et al*. (1975) analysed biophysical attributes (terrain, lithology, soils, vegetation and climate) of 4591 catchments covering the whole land surface of the Australian continent. Of the 300 biophysical regions recognised for the continent, 64 occur in Western Australia. Because the study is based on catchments, where the catchments are small the regions tend to be small eg the Kimberley, whereas where catchments are large the regions are also large eg. inland Pilbara. The scheme proposed by Laut *et al*. (1980) combines the results of this analysis with local government areas (LGAs) for ease of use: this identifies 16 provisional environmental regions for Western Australia.

Tinley (1986) has also used drainage/hydrological characteristics as the first criterion to identify Ecological Regions in Western Australia. Tinley's map shows four Regions: Northern (≈ Jutson's original Kimberley), Northwest (≈ Jutson's original North-West), Southwest and Central, while the text describes 14 Subregions within those.

A similarly detailed analysis based on characteristics of landforms and associated surficial sediments has produced a scheme of Physiographic Regions for the whole of Australia (Jennings and Mabutt 1977, 1986). Under this scheme, Western Australia is divided into nine Provinces and 69 Regions (see also Wyrwoll and Glover 1989). The detailed line work for this scheme can most be related to that of the geology map of the State (Myers and Hocking 1988). Consequently, as noted by Gentilli (1981), most of the Provinces are similar to the major divisions recognised by Jutson (1914 and subsequent versions) and Clarke (1926 and subsequent versions)- Kimberley, Pilbara, Yilgarn Plateau, Nullarbor Plain- but the Sandland and Western Coastlands Province differ greatly. The map does not show much in common with the Soil and Ecological Regions of Teakle and Gardner (1938). Surprisingly too, the 11 landform-soil regions of Western Australia proposed by McArthur and Bettenay (1979), developed by amalgamating soil units mapped at 1:5, 000,000 scale, do not match well with the Regions of Teakle and Gardner (1938) or Jennings and Mabutt (1977).

The Department of Agriculture, Western Australia has recently embarked on a program for integrating soil mapping data for the State and has developed an heirarchical classification for this purpose (N Schoknecht, personal communication 1995). The highest level of the classification is the soil landscape regions of CSIRO Division of Soils (DoS 1983) of which there are three within Western Australia: Sandy Desert Region, Western Region and Kimberley - Arnhem - Cape York Region. At the next level are the provinces described by Bettenay 1983, Isbell 1983, Northcote and Wright 1983. Below this are zones defined on geomorphological and geological criteria and below this again are systems which delimit areas of recurring patterns of soils, landforms and vegetation. The basic regionalisation differs from those of Jennings and Mabutt 1977 and McArthur and Bettenay (1979) particularly; presumably since it post-dates those schemes and includes input from those authors it represents an improvement based on increased knowledge.

Various versions of the map of major geological units of Western Australia have been produced, with the most recent being the 1:2,500,000 map by Myers and Hocking (1988). The 19 major Morphometric-Geological Divisions (*sensu* Wyrwoll and Glover 1989) and Subdivisions plus seven sedimentary basins (including three offshore) are described in GSWA (1975) (see also McArthur and Bettenay 1979).

Regionalisations have also been proposed solely on the basis of climate. The scheme of Gentilli (1978) shows 19 Climatic Regions grouped into five zones for Western Australia: Summer Seasonal Rain Zone (4 Regions), Episodic But Occasionally Heavy Rains (1), Double Rainy Season Zone (2), Winter Maximum Rain Zone, Summer Drought (9), and Arid Zone (4). Beard (1990) has also prepared a Bioclimatic Map of the State using the classificatory scheme of Bagnouls and Gaussen (1957) based on season and length of the dry period and individual ombrothermic diagrams for individual stations. Beard's map shows 10 bioclimatic zones with boundaries that bear some relationship to his phytogeographic regions: Desert/Eremean (3 zones), Semi-Desert/Sub-Eremean (3 zones), Mediterranean/Thermoxeric (3 zones) and Tropical/Thermochimenic (1 zone).

1.4.5 Development of IBRA

The concept of environmental regionalisation has been embraced by the Australian National Parks and Wildlife Service (now Australian Nature Conservation Agency) as the basis for planning and setting priorities for funding for land acquisition and research. In particular, it was thought that defining regions based on environmental factors rather than using existing political and administrative boundaries would provide a sound basis for designing a national network of nature conservation reserves. In the first approach, data in four themes- terrain (elevation), temperature and precipitation, soil (initial moist-state permeability and available soil water-holding capacity)- were analysed to produce a set of groups for the Australian continent and Tasmania (Thackway and Creswell 1992). The three maps showing the different levels of groupings show, for Western Australia, a strong latitudinal banding which is not evident in any earlier scheme and which suggests that temperature had an excessive influence in the analysis.

A subsequent approach involved development of a scheme based on matching the biogeographic regionalisations developed separately by each of the States and Territories (Thackway and Cresswell 1994). The Western Australian input to the national scheme is based on Beard's Phytogeographic Regions (Beard 1980e), with minor changes derived from new knowledge and contributed by N L McKenzie, G J

Keighery, K F Kenneally, G Wardell-Johnson and J S Beard. The scheme resulting from this second approach has recently been used as the basis for an assessment of conservation status (Thackway and Cresswell 1995, see Table 2 above).

1.4.5 Conclusions

This review has revealed the existence of many different regional frameworks for considering environmental planning and management in Western Australia. The various authors have brought their particular perspectives to bear, considered different data sets and given different weightings to factors such as palaeoclimates and evolutionary processes. The precision with which boundaries can be defined is obviously a function of the kinds of data being used: the geological boundaries are fairly static, whereas the climatological patterns move, both from year to year, over a period of years as well as over geological time and the patterns of distribution of plants and animals track those climatological ones at speeds that reflect the mobility of the organisms in question. There does not yet seem to be a single scheme that brings all these aspects together although the most recent version of the Interim Biogeographic Regionalisation for Australia (Thackway and Cresswell 1995) has broad acceptance.

The advent of modern and powerful computational tools, particularly numerical analytical tools and Geographic Information Systems, provides an opportunity tocompare regionalisations in considerable detail and to attempt integration with other spatial data, in order to develop a biologically meaningful synthesis. Such an approach would ensure that the conceptual basis for decisions is made explicit and that, therefore, there is a sound basis for on-going development.