Identifying Locations of Potential High Biodiversity Value in the Gascoyne Murchison Strategy Area of Western Australia: An Ecosystem Approach

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Findings from across the region, statements, views, or recommendations expressed in this report are those of the author (or others referred to), hence, do not necessarily accord with Gascoyne Murchison Strategy, Department of Planning and Infrastructure, Department of Agriculture, or Department of Conservation and Land Management policies or legislation.

Ken Tinley DSc (Ecology)
Ecosystem Management Understanding (EMU)
Off-reserve Conservation Program

Contents

1. Environmental disaster occurring in the Bass rangelands through over-grazing. Goats are exasperating situation

2. EMW project critical to turn this around. Need to "institutionalise" it rather than it being seen as outside core business.

3. Need to accumulate hard evidence => data, photographs, etc. Establish ~~and~~ ~~a~~ network of exclusion zones (small ones - ~~[illegible]~~ 1 ha 100m x 100m). Initially.

4. Look to satellite imagery, BW photographs for evidence

PLATES

TABLES

FIGURES

Acknowledgements

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1 Introduction

(1.1) PROJECT BRIEF

In 1997, the Western Australian Government adopted a strategy aimed at delivering a range of rural reconstruction programs over a major portion of the State's rangelands: the Gascoyne-Murchison Strategy. A major issue that emerged in the development of the Strategy was the inadequate provision for biodiversity conservation in the Region. In response to this, funds were allocated to purchase pastoral leases (or parts thereof) to extend the conservation reserve system. In addition an off-reserve biodiversity conservation program was developed; this subsequently gave rise to the Ecosystem Management Understanding (EMU) Program.

The greater GMSA area is well known at the survey level by the earth and life sciences, but the most comprehensive coverage is mainly geological and that of the rangeland surveys. The challenge, therefore, was to develop the framework for biodiversity conservation planning and management for the whole Strategy Area.

(1.2) GEOGRAPHICAL SETTING

The Gascoyne-Murchison Strategy Area (GMSA) occupies a broad central band of Western Australia, lying mostly between the south tropic and 29^{0}S latitude. The area extends from the east Indian Ocean coast between Exmouth gulf and the Murchison River mouth near 113^{0}E, and reaches inland across 1400km to the $124^{0}30'$E meridian on the Interior Continental Plateau at 500 to 600m elevation. The area, about 573 000 sq.km in total, varies in width from north to south between 400 and 700km and is outlined by the artificial administrative boundaries of nine shires (Figs. 1c, 2).

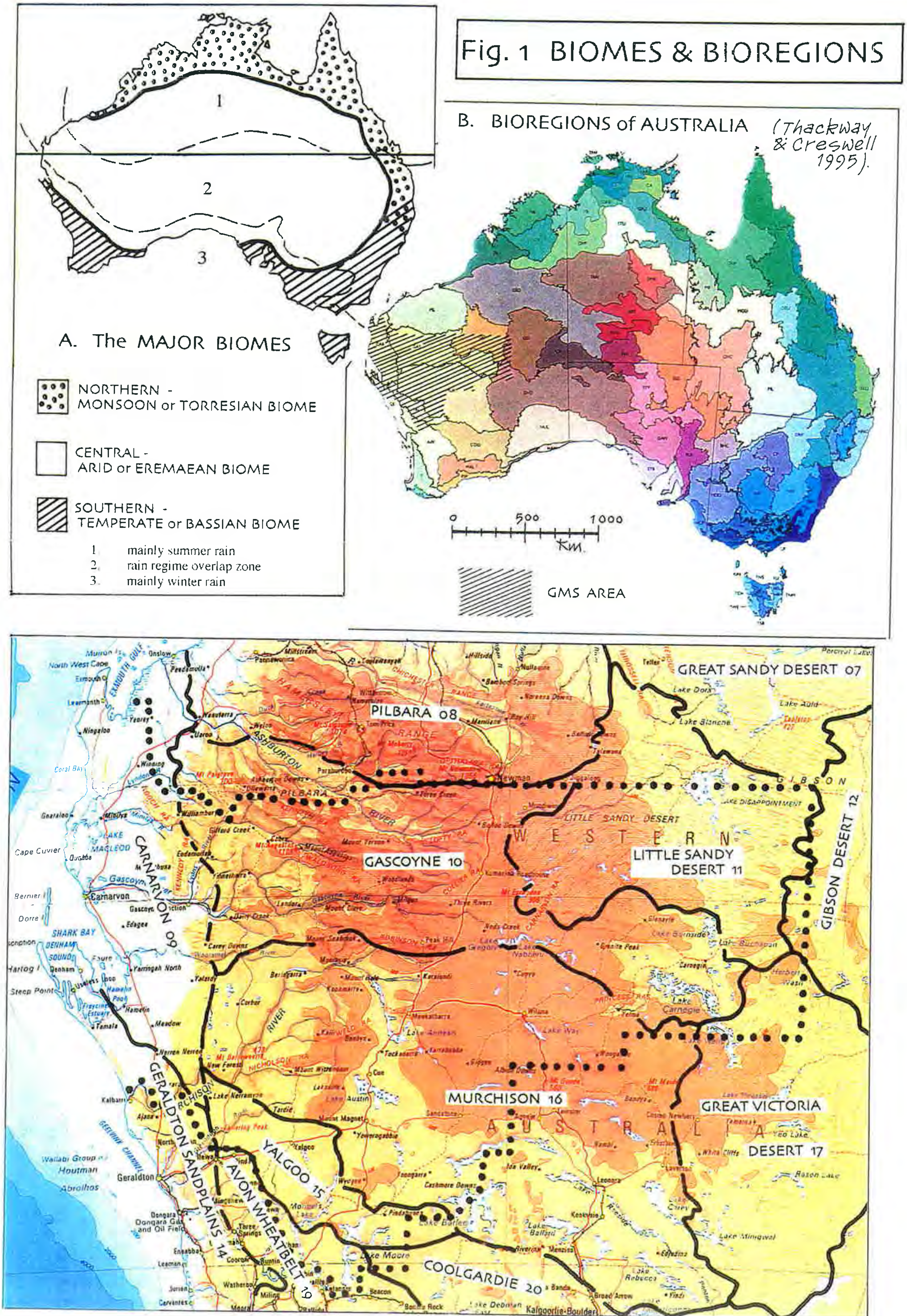
The area is arid and predominantly of rolling plainslands that form part of the broad bioclimatic overlap zone between northern and central tropical summer rain and southern temperate winter rain systems (Figs. 1a, 6).

(1.3) CONSERVATION STATUS

Despite the apparent physiognomic homogeneity of vegetation cover over vast areas, the GMSA contains an extraordinary flora biodiversity which is of continental significance as together with the Pilbara Region it occurs at the confluence of Australia's three main biomes and lies at the western limit of the great central arid.

At the time of commencement of the Gascoyne-Murchison Strategy in 1997, 72% of the region was land under pastoral lease (253 leases). 2% was land managed

Fig. 1 BIOMES & BIOREGIONS



C. BIOREGIONS COVERED by the GMS AREA

Table 1. Land Tenure within the GMS Area (573.000 sq km)

	sq. km.	%total
Total area pastoral leases (253 stations)*	414.647	72%
Total area of unallocated Crown Land	145.923	25%
Total area Conservation Estate	11.130	2%
		99%

*Total area leased by Mining Companies	33.457
Total area leased by Indigenous Land Corporations	24.063

Data from AgWA and DoLA (June 2001). The land area also include s rivers, lakes, roads and other Crown reserves .

Table 2. BioRegions (IBRA*) Regions of the GMS Area

IBRA Region	Area Sq.Km.	%GMS Area	Priority for Reservation Action
Murchison	174.416	31	High
Gascoyne	157.494	28	High
Little Sandy Desert	79.668	14	Low
Carnarvon	71.842	13	High
Yalgoo	38.472	7	V.High
Gibson Desert	14.015	3	Low
Geraldton Sandplain	12.703	2	Mod.
Gt.Vic.Desert	11.973	2	Low
Avon Wheatbelt	4.321	1	High
Pilbara	2.044	0.4	High
Coolgardie	.378	0.1	Low

(from Hopkins 2000)

*IBRA = Interim Biogeographic Regionalisation for Australia (Thackway & Cresswell 1995).

by the Department of Conservation and Land Management (CALM) and 25% unallocated Crown land (UCL) (Table 1). Up to that date the GMSA contained five national parks (Cape Range and Ningaloo Reef, Kennedy Range, Mt. Augustus, Collier Range, Francois Peron and Shark Bay World Heritage Site), and two nature reserves (Toolonga and Burnerbinmah).

A summary of the conservation status by Brandis (2000), reported that, of the 251 vegetation types occurring within the GMSA, only 90 (35%) were protected within the reserve system.

Some of the 251 vegetation types of interest to the aquisition program occur on unallocated Crown land or pastoral leases held by Aboriginal or mining interests. Although the latter two are not available for acquisition they may be managed for conservation under some form of formal agreement. The land aquisition program is based on biodiversity values contained within stations in relatively reasonable condition. Some station areas which contain biodiversity values are undesirable for conservation acquisition due to the predominance of invasive buffel grass *Cenchrus ciliaris* (eg. Gascoyne River delta) and/or by widespread terrain degradation. Thus the activities and achievements of the acquision program should be seen in the context of those constraints (McNamara *et al.* 2000, Brandis 2000, Brandis & Mitchel 2000)

In arid regions protected areas on their own are unlikely to conserve the full range of biodiversity (Morton et al. 1995; Pringle 1995, 1998; Commonwealth of Australia 1999). Shifts in distribution of biodiversity components will confound any strategy based purely on reservation, given the reality of changes in climate, landsurfaces, land useage, and invasive plants and feral animals. To this end conservation and protection solutions in this survey focused on actual and potential high biodiversity areas on each station that need to be developed as part of the overall ESP management approach within the regional conservation strategy (Pringle 2002).

(1.4) KEYPOINT SUMMARY

(i) Location of Project Survey Area

The GMSA as defined by the administrative outer boundary of nine shires, is about 573 000 sq km in size. Lying in a broad central band of the State, mostly between the south tropic and 29^{o} S latitude, it extends from the Indian Ocean coast between Exmouth Gulf and the Murchison River mouth inland for some 1400km to the Gibson Desert on the Interior Continental Plateau.

(ii) Purpose of this survey.

The Gascoyne Murchison Strategy derived from a WA government program of rural reconstruction adopted in 1997. A major issue identified by the strategy forum was the inadequate provision for biodiversity conservation in this diverse region. Until this point there were only seven main nature conservation areas, five of which are rocky eminences, one a sandplain and one on the major embayment of Shark Bay.

Due to the vastness of the region under pastoralism that forms the matrix to the isolated and generally small protection areas the brief of this GMS project was twofold:

1.develop the framework for biodiversity conservation and management for the whole GMSA that would also act as a guide to the pastoral lease acquisition program's final stages.

2.develop with the pastoralists an off-reserve conservation program on the stations that would engender ecologically sustainable pastoralism and protection of biodiversity values.

At commencement of the GMSA program in 1997, 72% of the area was pastoral lease of 253 stations, 25% unallocated Crown Land and and 2% under nature conservation. As at mid-2003 the area under formal conservation protection is now 7.5% or 35 000sq km, comprising 18 acquired pastoral leases plus parts of 17 others (Tony Brandis pers. com.).

(iii) Natural Regions of the Survey Area

The GMSA is composed of 5 major GeoEcological Regions: (a) Carnarvon Belted Coastal Plain, (b) Crystalline Shield Planation Surfaces, (c) Sedimentary Fold Ranges, (d) Little Sandy Desert, and (e) Interior Desert Margin (Fig 2).

The latter four together form part of the Interior Continental Plateau, of which the Shield region of granite-gneiss and associated N-S belts of metamorphic greenstones occupies the larger area. The greater part of the GMSA landsurface comprises sand-mantled duricrusts, with rocky isolates of inselbergs, ranges and ridges, interspersed with saltlakes or saline floodplains. The latter occur mainly on the coast, in the centre, down the eastern margin, and in the southern part.

Five river systems drain seaward with irregular flow from an inland watershed. From north to south these are the Ashburton, Gascoyne, Wooramel, Murchison and Greenough. All other drainage is either areic on sandplains or endoreic to saltlake endpoints. Except for the bare surfaces of saltlakes the entire region is covered by a mosaic of natural arid savanna scrublands (2-10m ht.) of acacia, mallee, or heaths over grass groundlayer and chenopod shrublands (<1.5m ht). Tall eucalypt woodlands (to 20m) line the creek systems.

(iv) Approach: the Synoptic Ecosystem Method.

A synoptic ecosystem approach is used to identify areas of highest landscape diversity (geomorphic plus vegetative cover) as potential biodiversity 'hotspots' across the template of natural regions. The method uses a map overlay technique composed of 7 layers of different information; the layers being superimposed interchangeably or altogether to derive a graphic composite.

The 7 layers comprise;

(1) Geology/rock type Diversity.

(2) Climatic Diversity.

(3) The Geomorphic Landscape: Terrain Surface Diversity.

(4) Soil Type Diversity

(5) Ecosystems.

(6) Landscape Processes and Patterns.

(7) Unique Features and Components.

Composites of all or various layers depicts where most to least coincidence between factors occurs. This graphic record also provides base information for developing land conservation management and monitoring programs. The coincident occurrence of the largest number of systems or biophysical features from each layer indicates areas of highest landscape diversity at all scales. These in turn identify where hubs of potential high biodiversity occur.

Prior to the map overlay exercise, a stereo-airphoto scrutiny of the entire region was undertaken to visually identify areas of high landscape diversity. This provided a focused basis to the interactive overlay exercise.

Central to the overlay exercise is identifying nodes of confluence between a number of different landscape systems, referred to here as ecojunctions. At the local station-size scale catena landsystems are used as ecosystem proxies. High local ecojunction diversity value in the GMSA is where 6+ landsystems adjoin within a 10x10km grid of the region (Fig.16).

(v) Results

The stereo-airphoto scrutiny combined with the mapped information (1:250 000 scale) of topography,geology, land systems and vegetation identified 34 areas of highest landscape diversity (Fig. 17, Table 11). This included 8 in the belted coastal plain , 15 in the Shield, 8 in the Fold Ranges, 2 in the Little Sandy Desert and 1 in the Interior Desert Margin. Existing parks and reserves were excluded. Coincidence of highest diversity between topographic relief, rock types, soils, vegetation and landsystems (Fig. 9) in a radius of 100km occur on (i) the northern part of the belted coastal plain centred on Winning Station, (ii) in the bioregion ecojunction area in the SW centred on Coolcalalaya Station in the lower murchison River, and (iii) in the south centred on Thundelarra Station. Highest landsystem ecojunction interspersion in 10x10km grid of the GMSA occurs across the south and southeast parts (Fig. 16).

Using the composite distribution pattern shown by the endemic flora of five main woody vegetation components (acacias, chenopods, eremophilas, eucalypts and heaths) superimposed over the greatest landscape diversity at the whole region biome ecojunction scale, the overall area of highest biodiversity is indicated in a 350km radius centred on Pt Quobba and reaching inland to about Mt. Augustus.

(vi) Conclusions:

The crucial requirment is for the pastoral land matrix to take part in conservation of biodiversity at the whole catchment and regional scales whilst ensuring their own means of managing land in an ecologically sustainable manner “stewardship of all species on all the landscape with every activity we undertake as human beings – a task without spatial and temporal boundaries" (Franklin 1993).

This means (as most everywhere else in the world) the present and future survival of biodiversity, ecosystem health and integrity of parks and reserves, lies in the hands of the rural people who live on the stations and are in everyday contact with them.

The opportunity then is for the development of cooperative conservation between the pastoralists and the land agencies. Reliable technical support to improve pastoralists' ecological land management capabilities can produce a generational entrainment of ecological understanding and ecosystem management in the Outback.

2 GMSA Terrain Template

From the sea coast the strategy area rises gradually inland for some 600km across three broad topographic steps to the main regional watershed on the Interior Continental Plateau at 500 to 650m elevation. The landscape is mostly gently undulating plainsland surmounted by low isolated ranges and hills that rise up to 300m above the surrounding plains (Table 3). In the north, ranges attain a higher density and are more continuous, where Mt. Augustus, at 1105m, is the highest eminence in the GMSA. Many of the summit areas are remnants of previous landsurfaces and are thus of biogeographic significance.

The regional watershed that runs down the centre of the GMSA divides drainage into two major compartments. Westward external drainage to the Indian Ocean is on a steeper gradient, and eastern internal drainage to saltlakes of the interior on flatter gradients. This difference in gradient is the fundamental determinant underlying the dissimilar rates of landscape flux and hence of resilience to damage.

A large number of small creeks flow episodically into chains of saltlakes in the broad dry valleys of now extinct river systems that drain eastwards off this divide. In exceptional rainfall years some of the flooded saltlakes may link up and flow temporarily southeastwards towards Lake Boonderoo on the western margin of the Nullarbor (Van de Graaff *et al.;* 1977, Beard 1998).

The greater part of the GMSA is pastoral country of 293 stations supported by natural landscapes and vegetation. Small areas of cleared land for orchard farming occur on the alluvia of the Gascoyne and Wooramel deltas, near Gascoyne Junction and Wiluna, and on Austin Downs and Wydgee Stations.

Except for the bare surfaces of saltlakes and the small cleared areas, the entire region is covered by a mosaic of native arid scrub*, shrub and grass vegetation with highly variable layering and spacement. These are prodominantly:

(a) Acacia dominated scrublands (2-8m ht) in savanna, woodland and thicket form covering the greater part of the region on both acid and alkaline soils.

(b) Halophytic chenopod shrublands (mostly <1m)

(c) Sandplain acacia, cypress pine, eucalypt tree and mallee forms (3-10m) over wanderrie tussock or spinifex hummock grasses, with or without heath components.

(d) Alluvial tussock grasslands

(e) Eucalypt tall woodland (up to 20m ht) along main drainage lines, and low melaleuca paperbark woodland around depressions and on alluvial flats.

*The term scrub as used here means a combination of short trees and tall shrubs forming the toplayer.

3 Western Australian Data Sets

The most comprehensive landscape mapped coverage of natural features in the State, all available at 1:250.000 scale, are:-

(1) topographic relief and drainage (50m contour interval),
(2) geology,
(3) vegetation types,
(4) land system maps (pastoral leases only)

Relief contours at 20m intervals are printed on the 1:100.000 topographic series maps.

The physical and biotic make-up of the GMSA is well known at the survey level, of which the most in-depth are:-

(i) Rock types and groundwater resources by the Geological Survey.

(ii) Landforms, soils and flora by the Rangeland Survey teams from station by station traverses, and

(iii) Of flora and fauna by biologists from the WA Herbarium, Museum, environmental consultants' mining survey and rehabilitation, and by CALM in the Little Sandy Desert, Shark Bay area and the national parks and reserves of the GMSA.

There is no comprehensive coverage of the distribution and/or relative abundance of the flora and fauna species, including endemic and/or rare components. There are, however, small maps (without coordinates or bar scales) available in WA Museum and other publications exist on termites, land molluscs, frogs, reptiles, birds and mammals.

The WA Herbarium maintains a regularly updated FloraBase database which includes the georeference of each plant specimen's collection location. From these it is possible to identify a first approximation of both broad patterns and focal areas of species richness and endemism (eg. Figs. 12, 13. 14).

A comprehensive GIS analysis of flora or fauna distribution patterns of the GMSA has yet to be undertaken.

A detailed quadrat based biological survey of the southern Carnarvon and adjoining northern Geraldton Sandplain BioRegions has been done (Burbidge *et al.*. 2000). This covers a small part of the GMSA within 200km of the west coast and about 300km from north to south. This survey sampled 63 terrestrial and 56 aquatic sites and recorded the following numbers of taxa:

flora: 2,133 species;

frogs: 16 species;

reptiles: 146 species (19 new to science);

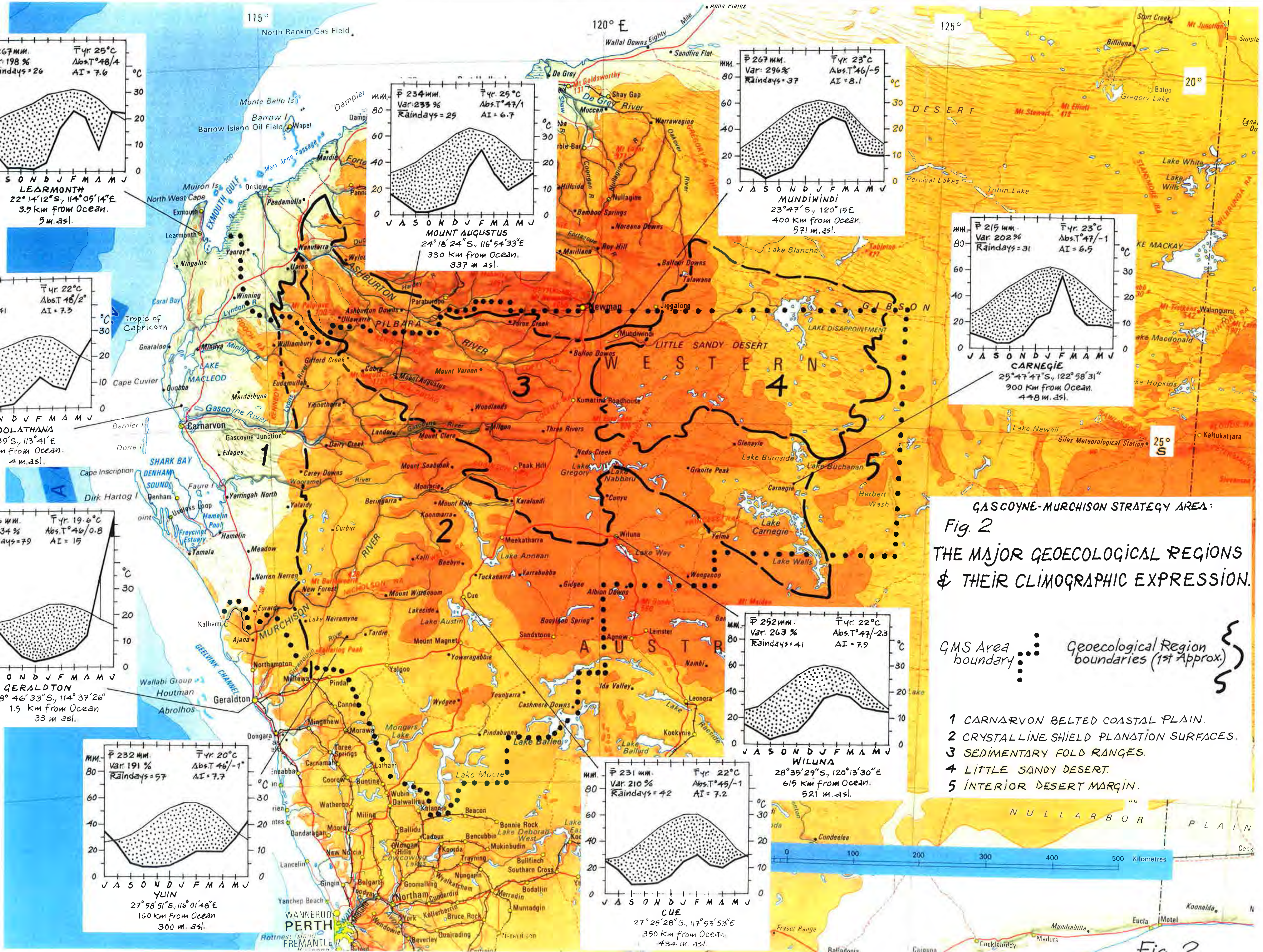

GASCOYNE-MURCHISON STRATEGY AREA:
Fig. 2
THE MAJOR GEOECOLOGICAL REGIONS & THEIR CLIMOGRAPHIC EXPRESSION.
GMS Area boundary
Geoecological Region boundaries (1st Approx.)
1 CARNARVON BELTED COASTAL PLAIN.
2 CRYSTALLINE SHIELD PLANATION SURFACES.
3 SEDIMENTARY FOLD RANGES.
4 LITTLE SANDY DESERT.
5 INTERIOR DESERT MARGIN.
P̄ 267mm. Var: 198 % Raindays = 26 Tyr. 25°C Abs.T°48/4 AI = 7.6
LEARMONTH 22° 14' 12" S., 114° 05' 14" E. 3.9 Km from Ocean. 5 m. asl.
P̄ 234mm. Var: 233 % Raindays = 25 Tyr. 25°C Abs.T°47/1 AI = 6.7
MOUNT AUGUSTUS 24° 18' 24" S., 116° 54' 33" E 330 Km from Ocean. 337 m. asl.
P̄ 267mm. Var: 296 % Raindays = 37 Tyr. 23°C Abs.T°46/-5 AI = 8.1
MUNDIWINDI 23° 47' S., 120° 15' E 400 Km from Ocean. 571 m. asl.
P̄ 215 mm Var. 202 % Raindays = 31 Tyr. 23°C Abs.T°47/-1 AI = 6.5
CARNEGIE 25° 47' 47" S., 122° 58' 31" 900 Km from Ocean. 448 m. asl.
P̄ 232 mm. Var: 252 % Raindays = 41 Tyr. 22°C Abs.T 48/2° AI = 7.3
BOOLATHANA 24° 39' S., 113° 41' E 12 Km from Ocean. 4 m. asl.
P̄ 456 mm. Var: 134 % Raindays = 79 Tyr. 19.6°C Abs.T°46/0.8 AI = 15
GERALDTON 28° 46' 33" S., 114° 37' 26" 1.5 Km from Ocean 33 m asl.
P̄ 232 mm. Var: 191 % Raindays = 57 Tyr. 20°C Abs.T 46/-1° AI = 7.7
YUIN 27° 58' 51" S., 116° 01' 48" E 160 Km from Ocean 300 m. asl.
P̄ 252 mm. Var: 263 % Raindays = 41 Tyr. 22°C Abs.T°47/-2.3 AI = 7.9
WILUNA 28° 35' 29" S., 120° 13' 30" E 615 Km from Ocean. 521 m. asl.
P̄ 231 mm. Var: 210 % Raindays = 42 Tyr. 22°C Abs.T°45/-1 AI = 7.2
CUE 27° 25' 28" S., 117° 53' 53" E 350 Km from Ocean. 434 m. asl.
J A S O N D J F M A M J
mm.
°C
115°
120° E
125°
20°
25° S
Tropic of Capricorn
LITTLE SANDY DESERT
W E S T E R N
A U S T R
D E S E R T
G I B S O N
N U L L A R B O R
P L A I N
Kilometres
PERTH
Geraldton
Carnarvon
Newman
Wiluna
Meekatharra
Cue
Lake Carnegie
Lake Disappointment
SHARK BAY
EXMOUTH GULF
Lake Moore
Lake Barlee

Fig. 2

birds: 279 species (of which 117 are migrant and 25 waterbirds); and
mammals: 37 species (including 12 species of bats).

This survey enabled species-rich isolines to be constructed for 13 terrestrial communities and 8 wetland types in the area, indicating quantitatively where conservation efforts should be focused (McKenzie *et al.*. 2000; McKenzie, Halse & Gibson 2000).

A quadrat based flora survey at a local station size was made of Burnerbinmah Station (599 sq km) in the Yalgoo Bioregion. From four field expeditions the survey recorded: a total vascular flora of 550 taxa of which 494 were native and 57 introduced; 9 Priority Flora, and 48 taxa range extensions (Patrick 2002).

4 Major GeoEcological Regions

The GMSA is composed of 5 major natural *GeoEcological* Regions:

1. Carnarvon Belted Coastal Plain — Continental Piedmont
2. Crystalline Shield Planation Surfaces
3. Metasedimentary Fold Ranges
4. Little Sandy Desert
5. Interior Desert Margin

(2–5: Interior Continental Plateau)

These natural regions are identified by particular composites of geomorphic and ecological features that characterize each. Intrinsically these are: their geologic foundation, geomorphic expression in landform (Table 6), geomorphological processes (Table 7), and terrain catena complexes (vegetation-edaphic associations (seeTable 8). These form the biophysical template and landscape process context for the map overlay analytical method used in this survey.
The boundaries of these geoecological regions are only nearly coincident with those of certain bioregions such as part of the coastal plain and the Little Sandy Desert (cf. Figs. 1c, 2). The major area of crystalline geology is treated as a single unit despite the difference in age and provenance between the Yilgarn Block and that of the Gascoyne.

4.1 Carnarvon Belted Coastal Plain

(a) Terrain

The coastal plain is close to 600km in length from the Ashburton Delta in the north to the Wooramel Delta in the south, it is between 50 and 200 km wide (in the centre) and rises inland to the 200m contour along the oldland junction.

South of the Wooramel, the Carnarvon Bioregion extends southwards onto the Victoria Plateau, a low sand-mantled duricrusted tableland geomorphically related to the summit plateau of the Kennedy Range (Hocking et al. 1985b). The GMSA coastline is deeply indented by two major embayments, Shark Bay in the south and Exmouth Gulf at its northern end. The coastal plain is a Continental piedmont or deltaic, outwash and pediment plainsland overlain in large part by north-trending curvilinear dunefields of red sands from the south-east. These desert dunes reach close to the coast where they abutt, or are partly overlain by, recent calcareous coastal dunes of pale beige to white sands. The latter form mostly vegetated hairpin or ascending parabolic dunes, typically nested where sandy shorelines curve seaward to face the strong southerly winds of summer (eg. east of Quobba Pt. and Pt. Cloates).

The plain is interrupted at irregular intervals by belts of up to seven coast-parallel cuesta and mesaform ranges. These occur in series from the coast inland to the oldland junction and comprise Tertiary, Cretaceous, Permian, Carboniferous and Devonian sedimentary rocks (Figs. 4,12). The highest and largest of these massifs are the Cape Range (314m), Kennedy Range (366m) and a northern cuesta outlier, the Moogooloo (Gooch) Range (333m). Most of these rocks are calcareous and fossiliferous of marine, shelf, littoral, deltaic and fluviatile origin, including Permian glacial tillites and conglomerates. The limestones of the anticlinally folded Cape Range have undergone karst weathering and have subterranean caverns and drainage that contain unique stygofaunal assemblages (Humphreys 1993).

(b) Drainage features

(1) Exoreic (external drainage to the sea):

There are five rivers in the GMSA that traverse the coastal region to reach the sea. From north to south, with their catchment basin sizes (sq km), these are: Ashburton (75 700), Gascoyne (73 700) and Wooramel (7 502) that cross the belted coastal plain, the Murchison (90 000) that enters the sea through a deep gorge tract, and the Greenough that crosses the Geraldton Sandplain. The latter is the smallest system; its lower part passing through cleared farmlands and the mid to upper catchment of 6 292 sq km rising on pasture country of the Yalgoo District. All of these rivers flow at irregular intervals westwards into the Indian Ocean. Except for the Wooramel and Greenough the others all rise from off the major regional watershed (Fig. 3).

Semi-permanent pools remain in many parts of these river after floods have abated. Those on the Lyons tribuary of the Gascoyne remain freshest longest where it passes through the Sedimentary Fold Ranges. Whilst the remainder, whose catchments rise on a traverse of the Crystalline Shield with its abundance of alkali adamellitic granites, become hypersaline.

(2) Endoreic (draining to landlocked endpoints):

The largest *endoreic* system in the coastal region is represented by MacLeod Saltlake. This single coast barrier-lake system is 130km long and situated on the

Ningaloo coast sector of the region. It forms the drainage endpoint of the Lyndon and Minilya Rivers. In exceptional flood events northern distributaries of the Gascoyne Delta debouch into the southern end of the lake. In the north between the Lyndon and Ashburton Rivers are the Yannarie and Rouse Creeks which run out into dunefields and claypans of the greater Ashburton delta area. Claypans and saltpans are mostly internal draining except during exceptional floods when they may link up temporarily, as in dune troughs. The largest areas of nested panfields occur on the deltaic plains of the Wooramel and Gascoyne rivers, and on the coast between the Yannarie and Ashburton Rivers.

(3) Areic (little to no lateral surface drainage)

Areic systems occur on the linear dunefields and other sand mantled surfaces over large areas of the coastal region between the lower river courses that reach the sea (Fig. 3). In the north an isolated dunefield of some 84sq km lies 25km east of the coast - oldland junction near Nanutarra.

(c) Coastform Sectors

The Carnarvon Coastline is composed of 7 distinctive coastform sectors (Tinley 2000). From north to south these are:

(i) Ashburton Delta Coast merging southwards into the Exmouth Gulf
(ii) Exmouth Gulf, with a mangrove and dune coast along the eastern and southern shore, and a limestone hard coast along the western side. It includes twelve small islands.
(iii) Ningaloo cliffed limestone, dune and barrier reef coast facing the open ocean between the NW Cape and Quobba Point.
(iv) Dune Coast (from Quobba Point SE to Gascoyne Delta)
(v) Gascoyne and Wooramel Delta Coast
(vi) Shark Bay Peninsula and Embayed Coast (Ria type with islands).
(vii) Zuytdorp Cliffed Coast.

Present-day mean tidal range during spring tides is 1.8m in Exmouth Gulf, and 0.8m in Shark Bay (although seiche effects are caused by strong onshore or offshore winds, Bob Prince pers. com.).

(d) Islands

There are 12 very small islands within Exmouth Gulf. The largest are Doole (5 x 0.5km) and Roberts (1.5 x 5km) in Gales Bay, at the head of the gulf. There are a pair of larger narrow islands in line with the NW Cape and 18km offshore. These are the Muirons (7 x 1km and 4 x 1.3km). Small islands dot the shelf sea between the Exmouth and NW Cape islands and those of the Barrow-Dampier archipelago.

Twenty seven islands occur in Shark Bay; formed by sundered ria peninsula segments. There are four larger islands. Dirk Hartog is the largest at 62.000ha (80 x 5km), with two narrow islands to the north, Dorre (26 x 2.5km), Bernier (31 x 3km with a very small island at its northern tip). The smallest, Faure (5000ha), is at the tip of Nanga Peninsula. Twenty-two small to very small islands occur in Freycinet Inlet west of the Peron Peninsula. The largest is Salutation Island with an area of 160ha.

(e) Vegetation (see Fig. 9)

The vegetation of this geoecological region occcurs in a reticulate pattern related to the longitudinal axis of the coast, the linear dunefields and coast parallel series of ranges, that are cut across transversely by the riverine systems.

The major area is covered by tropical arid acacia scrub formations interspersed with mosaics of chenopod shrublands and is representative of the Arid Biome at its western limit. This is overlain by the junction and overlap of elements from the two other major biomes. The influence of tropical monsoonal elements from the north, and of southwest temperate heaths and woodlands from the south. Hence there is a changing kaleidoscopic mix of species in the plant associations between the north and south and from the coast inland.

On a traverse from the central coast inland the following main vegetation types and landsystems are encountered (Beard 1975, 1976; Payne et al. 1987):

(i) Shelf Seas and Tidal Flats

Between the NW Cape and Gnaraloo Bay along 250km of the Ningaloo Coast is the only nearshore coral barrier reef system in Western Australia (CALM 1988).

The shallow shelf seas of the major embayments harbour seagrass meadows, in Shark Bay these cover some 4 000 sq km of seabed. Here major bank forming species are *Amphibolus antarctica* and *Posidonia coriacea* (Walker & Prince 1987; Walker 1991/92) with smaller softer *Halodule* and *Holophila* spp. that are important dugong pastures (Anderson 1991/92). The GMSA coast is an important seagrass biogeographic overlap zone between Tropical and Temperate species at their range limits (Walker & Prince 1987). Between Shark Bay's Nanga Peninsula and the mainland shore the seagrass beds as seen from the air occur in a striped pattern similar to mulga grove patterns on pediplains.

Mangrove woodlands and samphire shrubs occur on tidal flats mainly in the embayments. Five mangrove species occur along the mainland eastern shore of the gulf including *Aegialatus ovalis, Avicennia marina, Bruguiera exaristata, Ceriops tagal* and *Rhizophora stylosa* where certain species attain 7m in height (Semenuik et al. 1978; Johnstone 1990). Of these only the *Avicennia* occurs further south forming patches of low woodland (<3m) at the mouth of the Gascoyne River for example.

(ii) Coast Dunes:

On calcareous pallid coast dunes, of parabolic or beach ridge form, dense scrub patches of *Acacia coriacea, A. ligulata, A. sclerosperma* and *Melaleuca* spp. to between 2 and 3m height mostly on lee slopes. Beach foredunes are colonized by shrubs of *Olearia axillaris, Atriplex asitidea* and the grass *Spinifex longifolius.* (Coast land system).

(iii) Desert Dunes and Sandplains:

Linear red desert dunes of compact neutral to acid sands that rise 10 to 20m above the swales and support a cover dominated by scrub 2-3m in height of *Acacia ramulosa* and *A. sclerosperma* over *Triodia pungens*, and *T. schinzii* hummock grasses. *T. lanigera* is dominant northwards. With *Banksia ashbyi* other heath related elements that occur are species of *Calytrix, Thryptomene* and *Verticordia* (Cardabia, Giralia and Yalbalgo l.s.) On the backplain dunes and sandplain between the Gascoyne and Wooramel Rivers are 7-8m high savanna woodlands of the area-endemic *Acacia anastema* over *Eragrostis lanipes* and *Monochather paradoxa* wanderrie grasses.

(iv) Deltaic Alluvial Plains (Delta, Sandal, Ella, Yalbalgo l.s.):

Alternation of sandy banks with flats of red duplex soils of both neutral to alkaline trend. Scrub (2-4m ht.) of mainly *A. ramulosa* and *A. sclerosperma* on sand, and on the duplex *A. cuspidifolia, A sibilans, A. tetragonophylla, A. victoriae, A. xiphophylla, Alectryon oleifolius* and *Santalum lanceolatum* over shrubs of saltbush and bluebush (*Atriplex bunburyana, Maireana polyptergia*) and buffelgrass (*Cenchrus ciliaris*).

A unique occurrence of Mitchell grassland in the region occurs on the confluence floodplain of the lower Lyndon River and its Cardabia tributary. The tufted grass components typical of monsoonal Australia include: *Astrebla elymoides, A. pectinata, A. squarrosa, Chrysopogon fallax, Eragrostis setifolia, E. xerophila* and *Eulalia fulva* (Payne et al. 1987). (Marloo l.s.)

(v) Margins of Saltlakes and Pans:

Saline gypsiferous clays support low bushes of samphires, saltbush, bluebush and frankenia. For example: *Halosarcia halocnemoides, H. indica, H. pruinosa, H. pterygosperma, Muellerolimon salicornaceum, Atriplex vesicaria, Maireana tomentosa* and *Frankenia* spp. (MacLeod, Warroora, Birrida l.s.).

(vi) Riparian Woodland:

Up to 20m tall large boled trees, mainly river gum *Eucalyptus camaldulensis*, also coolibah *E. victrix* and coral tree *Erythrina vespertilio* over a midstratum of *Acacia citrinoviridis* and *A. coriacea* with a variable understorey of shrubs and buffelgrass.

(vii) Rocky Ranges:

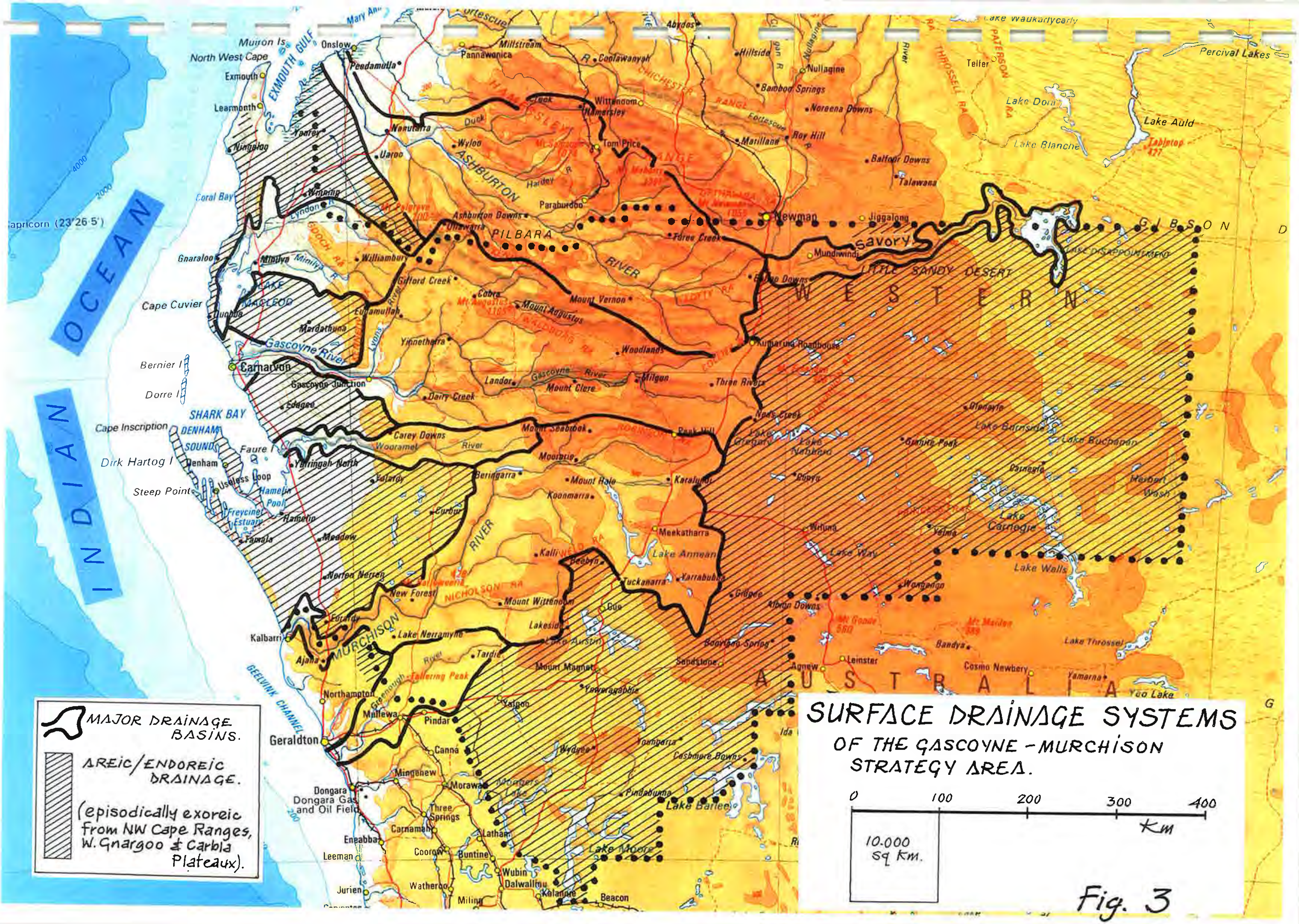
Cape Range on the coast has a sparse scrub savanna of 3 to 6m tall *Corymbia dichromophloia, E.oleosa, E. prominens, Brachychiton obtusilobus* over an open fieldlayer with large number of shrub species, including acacias, cassias, dodonaea, eremophilas, grevilleas and melaleuca. Here the groundlayer is composed of hard spinifex hummock grasses (Range l.s.).

On the backplain the Moogooloo Range, for example, has a denser scrub cover mainly of mulga *Acacia aneura* and gidgee *A. pruinocarpa* trees 4 to 6m tall over a shrub layer 2 to 4m in height of the same species plus *A. tetragonophylla* and *Alectryon oleifolius*, with a fieldlayer of cassias and eremophilas. Further inland close to the coastal plain-oldland junction are strike ridges of Devonian sandstones and siltstones. These have a sparse scrub cover of *Acacia cuspidifolia* and *A. tetragonophylla* over eremophila shrubs and mostly bare stoney groundlayer (Two Hills l.s.).

The Kennedy Range is a plateau with a summit mantled by linear dunefields covered in spinifex grassland of *Triodia basedowii* and *T. pungens*, a large diversity of shrub species including: *Acacia coriacea, A. ligulata, A. ramulosa, Calothamnus chrysantherus, Banksia ashbyi*, and *Grevillea* spp., with heaths on dune ridges and mallee patches in the swales. (Kennedy l.s.).

(viii) Southwest Temperate Heath and Woodland:

At its northern range limit to Shark Bay. Patchy to dense scrub in thicket and woodland form comprising trees to 8m height, tall shrubs 2-4m in height and low shrubs <2m. The vegetation is composed of a highly diverse flora susceptible to fire. Examples include: trees and mallee – *Eucalyptus eudesmioides, E. foecunda, E. jacunda, E. mannensis, Callitris columellaris, Banksia ashbyi*, and shrub species of: *Melaleuca, Thryptomene, Calothamnus, Acacia, Banksia, Grevillea* and *Calytrix*. (Nanga l.s.).



SURFACE DRAINAGE SYSTEMS OF THE GASCOYNE-MURCHISON STRATEGY AREA.

Fig. 3

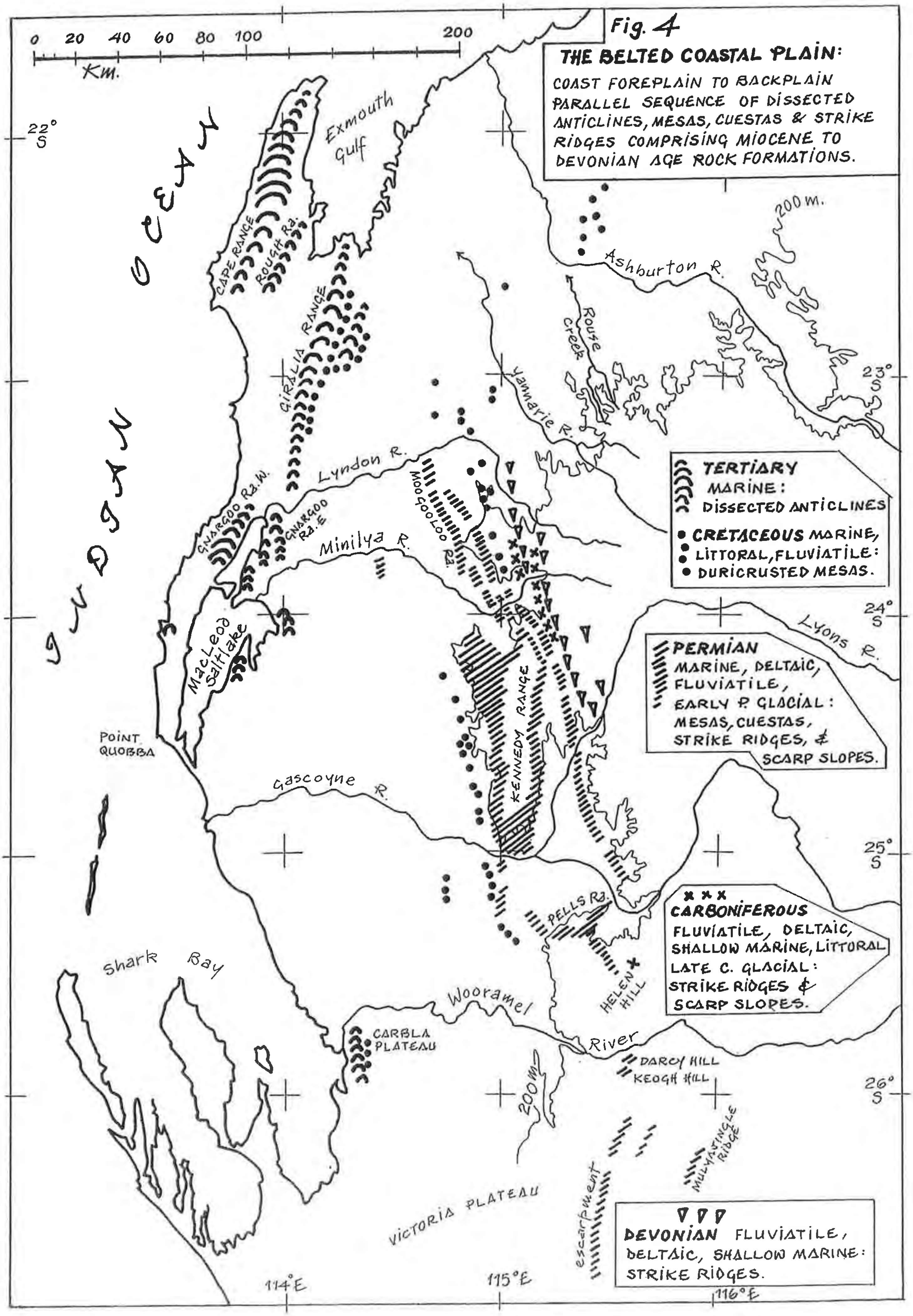


Fig. 4
THE BELTED COASTAL PLAIN:
COAST FOREPLAIN TO BACKPLAIN PARALLEL SEQUENCE OF DISSECTED ANTICLINES, MESAS, CUESTAS & STRIKE RIDGES COMPRISING MIOCENE TO DEVONIAN AGE ROCK FORMATIONS.
0 20 40 60 80 100 200
Km.
22° S
23° S
24° S
25° S
26° S
114°E
115°E
116°E
INDIAN OCEAN
Exmouth Gulf
CAPE RANGE
ROUGH Ra.
GIRALIA RANGE
Ashburton R.
200 m.
Rouse Creek
Yannarie R.
Lyndon R.
MOOGOOLOO Ra.
GNARGOO Ra. W.
GNARGOO Ra. E
Minilya R.
MacLeod Saltlake
KENNEDY RANGE
Lyons R.
POINT QUOBBA
Gascoyne R.
PELLS Ra.
HELEN HILL
Shark Bay
Wooramel River
CARBLA PLATEAU
DARCY HILL
KEOGH HILL
200 m.
MULYATINGLE RIDGE
escarpment
VICTORIA PLATEAU
TERTIARY MARINE: DISSECTED ANTICLINES
CRETACEOUS MARINE, LITTORAL, FLUVIATILE: DURICRUSTED MESAS.
PERMIAN MARINE, DELTAIC, FLUVIATILE, EARLY P. GLACIAL: MESAS, CUESTAS, STRIKE RIDGES, & SCARP SLOPES.
CARBONIFEROUS FLUVIATILE, DELTAIC, SHALLOW MARINE, LITTORAL LATE C. GLACIAL: STRIKE RIDGES & SCARP SLOPES.
DEVONIAN FLUVIATILE, DELTAIC, SHALLOW MARINE: STRIKE RIDGES.

4.2 Crystalline Shield Planation Surfaces:

(i) Terrain

The crystalline Shield forms the major body of the Interior Continental Plateau within the GMSA. There is a NW extension of younger Lower Proterozoic metamorphic crystalline rocks forming a wedge between the Sedimentary Fold Ranges and the Palaeozoic carbonate sediments of the Coastal Plain. The Shield is a broadly undulating plainsland, composed of two duricrusted planation surfaces of different ages and composition. These lie at an elevation of between 200 and 650m over Archean granite-gneiss, with steeply folded rocky eminences of greenstones (metavolcanics and metasediments) outcropping in N-S belts associated with major faultlines (Fig, 12).

The Shield is capped by remnants of an early Tertiary sand-mantled laterite duricrust over large areas which has been eroded back irregularly to form the multitudes of low breakaway escarpments that typify the country (Plate 4). The expanding pediment zone of faintly inclined plains below these scarps is formed by a silica duricrusted planation surface. An abundance of granite core isolates of low inselbergs and tors have been exhumed from beneath the laterite duricrust by scarp retreat. However there are only some eight major outcrop areas in the region, positioned on tributary headwater divides of the Murchison river and between the Greenough River and Yalgoo saltlake drainage. These areas and the main outcrops of greenstones are shown in Fig. 5. Isolated outcrops of Proterozoic sedimentary rocks occur between Permian carbonate rocks and the granites on the southwest margin of the Shield. An embayment of Permian rocks extends into the Errabiddy Shear Zone between the Yilgarn Block and Gascoyne crystalline rocks (refer Murgoo, Byro and Glenburgh 1:250 000 geological map sheets).

Also in the southwest part a large isolated area of panfields, developed on planed Permean carbonate sedimentary rock, occurs between the middle Murchison River's western divide and the eastern edge of the Victoria Plateau sandplain.

In the same area, running north-south along the buried course of the northern Darling faultline between Byro and Yallalong Stations, is the relic drainage of the Upper Wooramel River that was previously a tributary of the Murchison River. After stream capture by the Lower Wooramel, the valley is now occupied by the Muggon chain of lakes that are flooded irregularly from more local runoff.

A sinuous watershed down the centre of the interior plateau divides the Shield area into two distinct drainage terrain systems (Van de Graaf et al. 1977; Beard 1998, 2001).

(a) The large westward draining *exoreic* river systems of the Ashburton, Gascoyne and Murchison rivers and the smaller Wooramel and Greenough systems reach to the Indian Ocean. Due to the faintly steeper seaward gradients below the 500m contour, most of the laterite duricrust has been eroded away, resulting in the broad coalescence of valley-side stripped pediments that have formed on the exhumed kaolin and weathered granite capped by silica hardpan soils. (These show up as whitish-grey on LANDSAT satellite images). The lower pediment mantled by outwash sand fans (Wanderrie banks) are mostly reduced in size to remnants from either diminished sand input or increased erosion, or both.

(b) The *endoreic* catchments drain eastwards and southwards into the inland saltlake endpoints of Salinaland (Jutson 1950). At close to the 500m contour the greater area of the plateau has relatively flatter slope gradients. This results in larger lower pediment fan formation by accretion headwards smothering, and hence tending to stabilize, the upper pediment zone below the long-walled breakaway scarps of the larger Tertiary planation duricrust remnants (Mabbutt *et al.* 1963). The wanderrie accretion fans show up red-brown on LANDSAT images.

Discontinuous occurrences of valley calcretes occur along most rivers, particularly in headwater tracts, of both rivers, and the inland palaeodrainage systems (Commander 1989). Remnant groundwater laterites from past drainage flat (marshy) conditions are exposed by stream incision in some tributary heads of the Gascoyne and Murchison Rivers.

(ii) Vegetation (Fig 9)

The vegetation of the crystalline Shield region occurs in a typical catena pattern across its duricrusted planation surfaces (Jutson 1950; Mabbutt et al. 1963; Wilcox & McKinnon 1972; Beard 1975,1976; Curry et al. 1994; Pringle et al. 1994; Payne et al. 1998). Within each catena complex of landsystems there is a kaleidoscopic change in both physiognomy of the vegetation and its species composition across the region. Many species recurr in different combinations with components appearing or dropping out as one moves in N-S or E-W directions across the region ie. outreach influence of monsoon, Pilbara, temperate, Goldfields, desert or coast species from the surrounding bioregions. Particular associations of plant communities occurring on outcrops of granite, greenstones or breakaway scarps form islands within the matrix of broadly undulating planation surfaces. The typical catena sequence of these surfaces are from upland to bottomland:

(a) Sand mantled laterite surface typified by the Bullimore and Kalli land systems. Open to dense scrub with toplayer emergents 6-8m high of *Acacia aneura, Callitris glaucophylla, Corymbia lenziana, Eucalyptus leptopoda* and *E. kingsmillii*. Middle layer of scrub 2-5m tall dominated by bowgada *Acacia ramulosa/linophylla*, with *A. burkettii, A. cuthbertsonii, A kempeana, A murrayana* and *Grevillea* spp. A low shrub layer: *Eremophila forrestii, E. margarethae, E. granitica, Thryptomene decussata* (heath) over perennial tufted grasses of *Thyridolepis multiculmis, Monochather paradoxa.*

(b) Breakaway erosion scarps and footslopes characterized by the Challenge, Narryer, Sandiman and Sherwood land systems. The scarp habitat supports a varying density and composition of scrub and heaths. Examples include trees to 6m of mulga, *Callitris glaucophylla, Dodonaea viscosa, Acacia* *rhodophloia, Brachychiton gregorii, Santalum spicatum.* Tall shrubs (2-4m) of mulga, *Canthium spp., Acacia craspedocarpa, A. tetragonophylla, A. aulocophylla.* Low shrubs of *Scaevola spinescens, Rhagodia eremaea, Senna* spp, and *Eremophila* spp. The iron-rich outcrops of laterite and banded iron formation are special habitats harbouring heath species of the following genera: *Baeckea, Calytrix, Darwinia, Eriostemon, Kunzea, Micromyrtus, Thryptomene* and *Verticordia.* Below the scarp is a footslope zone of shallow friable duplex soils over hardpan on weathered granite. These support either low chenopod shrubland with potentially up to five bluebush species, or of mulga woodland where the duplex soil is mantled by red sand deposits (Plate 4a, b).

(c) Vast pediment washplains with sand fan (wanderrie banks). Typical land systems include Tindalarra, Woodline, Yandil and Yangaroo. The pediment washplains of neutral to acid red loams 20-60cm depth over silica hardpan support open woodlands to 7m tall dominated by mulga trees. Midlayer shrubs (2-4m) comprise mulga, *Acacia craspedocarpa, A. tetragonophylla* and *A. ramulosa.* Shrub <2m height include acacias and eremophilas eg. *E. forrestii, E. freelingii, E. georgii, E. punicea.* Low shrubs include *Ptilotus obovata, Maireana convexa, Senna helmsii* and *Spartothamnella teucriifolia.* Where a sandy topsoil remains some perennial tufted grasses occur such as *Eragrostis eriopoda* and *Monochather paradoxa.* However, sandy topsoils have been stripped off by erosion over vast areas of the washplains resulting in a bare groundlayer and sparse shrublayers.

At the lower part of the washplains is the sandfan zone of wanderrie banks. These rise to 1m above the hardpan and support a diverse mix of scrub and perennial grasses including those dominant on the laterite sand mantle above the breakaways such as *Acacia ramulosa/linophylla.* The woody cover varies from sparse with a dense grasslayer to the converse. Small trees to 4m height are mostly mulga, with tall shrubs of *Acacia grasbyi, A cuthbertsonii, A tetragonophylla, A. palustris,* and mid to low shrubs (<2m) of *Eremophila forrestii, E. platycalyx, E. pterocarpa, E. macmillaniana, Senna helmsii* and *S. desolata* over wanderrie grasses.

(d) Bottomland systems of outwash and river floodplains exemplified by Beringarra, Evo, Roderick, Cunyu and Mileura land systems. The latter two with calcreted valley flats. Bottomland systems support a large variety of vegetation types and a diverse flora due to the interfingering of many different habitats with higher soil moisture balance status than the washplains and uplands. Along creeklines entering the bottomlands or around claypans are generally dense woodlands and thickets to 8m height of mulga, *Acacia rhodophloia, A. cyperophylla* (northern areas), *A. citrinoviridis, A. distans, A. sibilans, A. burkittii* (southern areas), and taller *Casuarina obesa* and coolibah *Eucalyptus victrix*, with a cassia and eremophila understorey. Also bushclump species such as *Rhagodia eremaea, Enchylaena tomentosa,* *Pimelia microcephala, Scaevola spinescens* and trees of *Eremophila longifolia, Acacia tetragonophylla* and *Pittosporum phylliraeoides*. Claypans are also commonly ringed by low dense woodland of *Melaleuca* spp. with either bare pan surface or wetland grasses typically *Eragrostis setifolia* and *Eriachne flaccida*, and lignum bushes *Muehlenbeckia florulenta*. Where in good condition the saline alluvial plains are dominated by chenopod shrublands composed of *Atriplex amnicola, A. bunburyana, A. vesicaria, Maireana pyramidata, M. platycarpa* with sage *Cratystilis subspinescens*. Degraded floodplains are invaded by scrub of *Acacia victoriae, A. tetragonophylla, Hakea preissii,* and *Senna desolata*.

Calcreted drainage (Cunyu and Mileura l.s.) dominated by acacia scrub of mainly *A, sclerosperma* with *A. ligulata, A. grasbyi, A. sibilans, A. tysonii* and *A. xiphophylla* (northern areas) or *A. eremaea* (southern areas), and chenopod and cassia low shrub components with *Lycium australe*.

(e) Saltlake endpoints (Carnegie l.s). Saltlake margins with saline flats, dunes and sandbanks have low halophytic shrubland and scattered or clumped acacia scrub (Fig. 3a,c,d). The saline flats have mainly samphires such as *Halosarcia auriculata, H. doleiformis, H. halocnemoides* or small shrubs of *Frankenia* sp. and saltbush. On gypsiferous banks and dunes are scattered or clumped *Eucalyptus striaticalyx* trees to 6m height with a shrublet groundlayer of the cactus-like Malvaceous dunna-dunna (*Lawrencia helmsii)*. Sand dunes and lowbanks have a high mosaic diversity of woody species mix including acacias, eremophilas, cassias, saltbush, bluebush, sage and frankenia with wanderrie grasses.

(f) Rocky outcrops of granites (Norie l.s.) and greenstones (Weld l.s.)(Fig. 5). Scrub vegetation sparse or in patches of low trees to 3 or 4m and shrubs up to 2m height. Typically of mulga and *Acacia quadrimarginea*, in parts also with *A. rhodophloia, A. grasbyi, A. tetragonophylla, A. exocarpoides, Dodonaea viscosa* and *Thryptomene decussata* heath. Low shrubs include *Ptilotus obovata, Tribulus platypterus, Eremophila exilifolia, E. glutinosa, E. platycalyx* and *E. latrobei*. On greenstones the scrub cover is more even and taller as seen on Jack Hills Range. Mainly of acacia trees to 4 or 5m height with a scattering of perennial grasses such as *Amphipogon strictus, Cymbopogon* sp., *Eriachne* spp., and spinifex *Triodia* sp. The granite outcrops of this region are typically dome inselbergs, boulder strewn nubbins and block piles of small to medium size (Ollier & Tuddenham 1962, Twidale 1981). Rain runoff supports a narrow discontinuous belt of taller woodland (to 8m) around the base and in the clefts. These alternate with pure grass swards on aprons of shallow soil over rock. On summit areas are two typical ecotopes: gnamma holes, many with ephemeral aquatic communities, and rootmat communities (Bayly 1999). The latter typified by the dwarf grass *Tripogon loliiformis* with sedges, sundews, orchids, mosses, ferns and the pincushion *Borya* sp.

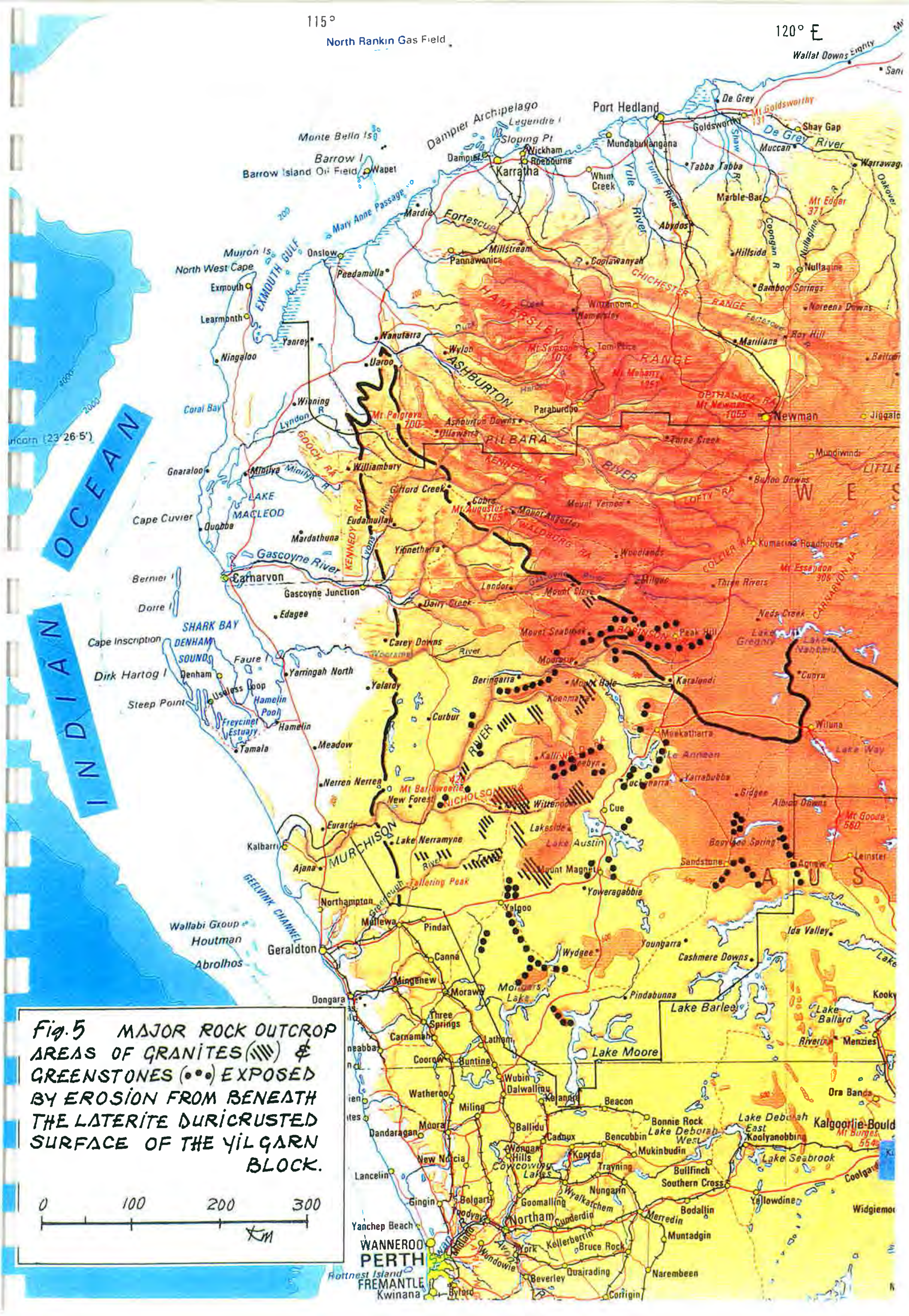


Fig. 5 MAJOR ROCK OUTCROP AREAS OF GRANITES (\\\\) & GREENSTONES (•••) EXPOSED BY EROSION FROM BENEATH THE LATERITE DURICRUSTED SURFACE OF THE YILGARN BLOCK.

0 100 200 300
Km

4.3 Metasedimentary Fold Ranges

(i) Terrain

Between the northern edge of the crystalline region of planation surfaces and the Pilbara ironstone ranges there is a tightly folded belt of WNW-ESE trending strike ranges of mid-Proterozoic sedimentary and metasedimentary rocks. These comprise mainly of arenites (quartzites, sandstones, graywacke), siltstones, conglomerates, shale, chert, banded iron and dolomites with basalt or dolerite intrusions. The main ranges include Mt. Augustus, Collier, Egerton, Kenneth, Godfrey, Teano and Waldberg.

The anti- and synclinal plunging folds have been truncated by erosion which has exposed almost vertically disposed strata of parallel paired razorback ridges. These have outward (synclinal) and inward (anticlinal) facing scarps, and elliptic ridges at the fold plunges. The major belts of the Bangemall Group fold ranges form a trellised drainage divide between the catchment basins of the Ashburton and Gascoyne (Lyons tributary) down to the coastal plain's edge.

The highest ranges in the Bangemall Group are formed by the Barlee, Egerton, Godfrey, and Teano ranges. Mt Augusta, a cuestiform inselberg of 1105m, is the highest massif in the GMSA. Eastwards the mid-Proterozoic Bangemall Group is replaced by Lower Proterozoic folded sediments of the Earaheady Group, and the younger (Upper) Proterozoic of the Savory Group that is mantled by the Little Sandy Desert dune sea. Further eastward, along the interior desert margin, these folded rocks are overlain by a mirror image sequence in parallel with the Coastal plain. The crystalline old land abutts with flat-bedded Permian and Cretaceous sedimentary rocks (Geoecological Region 5)(Figs. 2,12).

Five lesser sedimentary rock groups occur in this fold belt region. The Wyloo Group is interposed between the Bangemall and Hamersley (Pilbara) Groups and drained by the Ashburton River system. On the Peak Hill and Glengarry 1:250 000 geological map sheets are the Bryah, Glengarry, Padbury and Yerrida Groups, all of Lower Proterozoic Age. The Yerrida occupies the largest area of these, almost islanded by Shield granites, south of the Bangemall Belt. Some of these groups have flat-bedded, not folded strata (Elias *et al.* 1982; Gee 1987).

Two isolated sand systems occur in this northern region of fold ranges. The first is a remnant spinifex sandplain which occurs immediately south of Mt. Augustus at the junction of granite country with the fold ranges. This lies over hardpan and is 30km wide by 20km long (Divide landsystem). The nearest extensive dunefields to the above sandplain occur on the plateau summit of the Kennedy Range 155km to the west. The second is a linear dunefield in the headwater catchment of the Ashburton River, next to Tunnel Creek 17km south of Turee Homestead. It is 280 sq km in area, and 140km distant from the nearest major dunefield of the Little Sandy Desert to the east.

(ii) Vegetation (Fig. 9)

Overall the predominant vegetation cover is acacia scrub savanna (2-3m), mainly mulga, in a scattered to clumped spacement with a fieldlayer of cassias and eremophila shrubs. There are some areas of windgrass *Aristida contorta* but generally bare ground surfaces prevale in the ranges and the valley flats. Shorter scrub occurs on stoney convex water-shedding surfaces where the fieldlayer shrubs assume dominance. The greater area has skeletal and shallow stony loam soils. Taller (4-8m) acacia woodland patches occur in mesic sites both on the ranges and the bottomlands. Dense woodland belts occur along watercourses where *Acacia aneura, A. citrinoviridis, A. cyperophylla* are typical. As a major tributary with chains of permanent pools, the Lyons River supports 15m tall river gum, cadjiput and coolibah woodland.

The typical catena sequence across the parallel suites of fold ranges and valleys is: (1) rugged rocky cuestiform range summit crestlines with many scarpfaces, (2) steep talus slopes, (3) footslopes and pediments forming the bottomlands; either narrow and incised valleys within the strike ranges or broad plains underlain by hardpan, (4) drainage lines and flood areas.

Examples of typical plant components include:

(a) On ridges of bare rocky quarzite, chert or ironstone outcrops mulga scrub with some *Acacia grasbyi*, miniritchi wattles and a fieldlayer of poverty bushes, typically *Eremophila eriocalyx, E. exilifolia, E. granitica, E.jacunda, E. peltata*, or *E. macmillaniana* over *Ptilotus obovatus* shrublets. Downslope a sharp change onto shales or mudstones with a dense grass cover of *Aristida contorta* and *Eremophila freelingii* (2-3m) shrubs. On chert ridges tall spindly forms of *E. granitica* (to 3m) can be dominant, and a weeping wattle *A. pyroneura* (3m) on rocky granite terrain. In contrast tall (4-8m) and dense acacia woodlands cover most of the Kenneth and Godfrey fold range suite.

Many other summit areas are covered by spinifex hummock grasses as on Mt. Augustus and the Teano Range. On carbonate rocks, *Triodia wiseana* spinifex is a typical indicator cover. Scarp cliffs are generally bare, but near drainage are the typical habitat of the rock fig *Ficus platypoda*. The Pilbara ironstone cliff plant *Astrotricha hamptonii* was found by the writer on a valleyside breakaway crevice below the Teano Range. This is a southern extension of the known geographical range of the only Araliaceous plant occurring in WA.

(b) Talus slopes have short scrub on convex surfaces, and taller acacia grove patches in drainage heads below scarps. Wattle woodlands cover most of Mt. Augustus for example with 5-6m tall *Acacia eriopoda* dominant on its north-facing scarp slopes, *Acacia linophylla* tall shrubs with an open understorey of cassias, mainly *Senna cuthbertsonii, Calytrix* heath and patches of lemongrass *Cymbopogon ambiguus*. The first acacia is at its southern geographic limit of distribution from the Kimberley, and the cassia an endemic to a district size area between Mt. Augustus and the rocky outcrops of the Ashburton River valley.

Eastwards, as on the Teano Range, both the slopes and summit areas are covered in densely spaced hummock grassland of *Triodia basedowii* spinifex.

Outwash tributaries and fans on the south side of the Teano Range are deeply incised into massive boulder beds, densely wooded with acacias to 7-8m and coolibah emergents. Intervening flats of boulder and cobble gibber with mulga and miniritchi wattle *A. rhodophloia*, bare ground and dense cassias and eremophilas to 2m fieldlayer. Also patches of mallee gums. Most of the talus and footslopes of the strike ranges are surfaced by gibber.

(c) Bottomlands are of two main kinds:

(i) Shallow red neutral to acid loams over hardpan with patches of mulga and gidgee *A. pruinocarpa*, a weeping watte *A. demissa* on sandier surfaces south of Waldburg, and generally bare soil or covered in stony gibber.

(ii) Alkaline red clayey soils, either overlying rubble calcrete or saline clay subsoils. Typical acacias here are *A. cuspidifolia* (to 8m ht.), *A. victoriae* and *A. xiphophylla* with remnant patches of chenopod shrubs typically occurring at long distance from stock watering points. The chenopods recorded on a field traverse in August 2001 were: *Atriplex bunburyana, Maireana georgii, M. triptera, M. pyramidata, M. trichoptera* and *Dissocarpus paradoxus*. Common berry bird bushclump plants beneath bottomland scrub included *Acacia ligulata, Canthium obovatum*, *Enchylaena tomentosa*, *Rhagodia eremaea* and *Scaevola spinescens*. Open treeless gibber surfaces have a scattering of 1-2m eremophilas (mainly *E. cuneifolia, E. fraseri*), cassias (*Senna helmsii, S. luerssenii*) and *Frankenia* shrublets, that form dense shrublands over large areas of overgrazed country.

The remnant sandplain area on the plain immediately south of Mt. Augustus is dominated by a relatively dense wanyu wattle scrub *A. ramulosa* (to 3m) interspersed with *Grevillea stenobotrya* trees (to 6m) over a sparse fieldlayer of *Eremophila forrestii* and *E. margarethae*, and a few patches of wanderrie grasses (Divide l.s.).

(d) Belts of taller and denser woody cover occur along creeklines, typical trees include: *Acacia aneura, A. citrinoviridis, A. coriacea, A. cuthbertsonii, A. cyperophylla*, *A. subtessaragona*, and *Melaleuca* sp. At the foot of the backslope on Mt. Augustus river gum *Eucalyptus camaldulensis* to 12m height occur around permanent springs. Thickets line the overflows, mainly several acacias, *Dodonaea* spp, sandalwood, and *Clerodendrum floribundum* shrubs. Tufted perennial grasses occur along drainage, mainly the inroduced buffel *Cenchrus ciliaris*, also *Themeda triandra, Eulalia fulva*, and *Chrysopogon fallax*.

Tall woodland (to 15m) of river gum, coolibah *Eucalyptus victrix*, cadjiput *Melaeuca leucodendron* and coral trees *Erythrina vespertilio* line the course of the Lyons River and its main tributaries. Run-on cracking–clay soils support coolibah woodland and large bushclumps of lignum *Muelenbeckia florulenta* to 2.5m height, and grasses such as *Eragrostis setifolia, Eriachne benthamii* and *E. flaccida*. A typical shrub associate of this habitat is the swamp bluebush *Chenopodium auricomum* but being highly sought after by stock is now rare in the area, and confined to the large swamp flat on the south of Wanna Station.

4.4 Little Sandy Desert.

(i) Terrain

These are closely spaced, short-limbed dune ridges of linear, chain, braided and net forms. They can be up to 20m in height above the interdune troughs and flats. The dunes trend north westwards in the eastern sector, curving anticlockwise over a distance of 200km, to southwest in the western part. This is due to shifts in the easterly formative winds. Spinifex grass and sparse scrub, or heath stabilized dunefields, mantle the planation surface at the 500m contour of upper Proterozoic Savory Group folded sedimentary rocks. These are mainly sandstones with minor pebbly conglomerates, siltstone, mudstone and dolomitic lenses. They outcrop at irregular intervals as ridge inselbergs, some bordering the outer periphery of Lake Disappointment, a centrally located large playa. The largest ridge inselbergs are the McKay Range (528m) in the north, the Durba Range (525m) on the south side, and the isolated arc of the Essendon-Carnarvon Ranges (913m) on the southwest edge of the Little Sandy Desert (Williams 1995a, 1995b; Williams & Williams 1980; Williams & Tyler 1991).

Lake Disappointment is fed by a single creek system, the Savory, which rises more than 300km to the west in the rocky hill country of the east Pilbara (Fig. 3). Recently it flooded in two successive years: in March 2001 with Cyclone Terri, and in February 2002 with Cyclone Chris. Savory Creek contains several permanent pools on which 20 species of waterbirds have been recorded (van Leeuwen 2002).

The spinifex hummock grasslands that cover the dunefields are highly flammable and fires started by lightning strikes and human agency burn out large swathes of country every year. The resultant fire scars form zig-zag patterns caused by changes in the wind direction. While the terrain is devoid of ground cover, (which can be for nearly a year), surface sand is shifted by the wind and becomes restabilized only with the advent of sufficient rain to stimulate plant regrowth.

(ii) Vegetation

The vegetation of this dune sea consists of dense spinifex hummock grassland cover, predominantly *Triodia basedowii* (also *T. schinzii*, *T.melvillei*) with patches of low dense heath (*Thrypomene maisonneuvii*) on dune flanks (Beard 1975,1990). On dune ridges taller scrub and small trees to 3m height - acacias, eucalypts (bloodwood gum *Eucalyptus chippendalei* and mallees eg. *E. gamophylla* and *E. kingsmillii),* a shrub layer of scattered eremophilas and grevillea, and a few patches of grass-tree *Xanthorrhoea thorntonii*. Groves of 7-12m tall desert sheoak *Allocasuarina decaisneana* occur in some dune hollows and sandy footslopes of isolated rocky outcrops. Though whaleback in profile many inselberges have steep cliffs and ravines (eg. Durba Ra.) that support woodland of coolibah *Eucalyptus victrix*, cypress pine *Callitris glaucophylla*, and rock fig *Ficus platypoda*. Scree slopes have scrub of *Eucalyptus setosa*, *Melaleuca nervosa* and desert willow *Pittosporum*. Inselberg summits are mostly bare rock with short scattered scrub, the lower outcrops mantled by climbing dunes. Mulga scrub of 2-5m height occurs in the south on isolated patches of loam soils and laterite outcrops.

In the SW part of the Little Sandy Desert in the Carnarvon Range area, the main floral groups of vegetation include: acacias (26spp), eremophilas (26spp), Myrtaceae (17 of which 13 are gums and 4 heaths), Papilionoids (16 spp), Proteaceae (9spp), Goodeniaceae (27spp), chenopods (25spp), Asteraceae (41 spp), and grasses (26 spp) (Kenneally et al. 2001; Kenneally & Paton 2002).

The survey by van Leeuwen (2002) records a flora of 552 taxa, a herpetofauna of 87 species, and 116 bird species for the southwest area.

4.5 Interior Desert Margin

(i) Terrain

The far eastern part of the GMSA reaches to 124°30' longitude where the elevation ranges from 440 to 600m above sea level.

There is a north-south margin of transition on either side of the 123° meridian, southwards from the Little Sandy Desert dune sea, through Lake Carnegie and Prenti Downs Station to the de la Poer Range on Lake Wells Station. This margin of transition is from the Crystalline Shield and the cuestiform fold ranges of Proterozoic rocks (region 3), to where they are overlain by Permian and Cretaceous horizontally bedded sedimentary rocks (Fig.12). Refer also to 1:250 000 geological map sheets in Kennewell (1974), Jackson (1978), Bunting (1980), Commander *et al.* (1982).

The Permian geology comprises tillites, sandstone, conglomerates, siltstone and claystone (as exposed in 30m high mesa scarps). They are glacial, fluvial and lacustrine in origin. The Cretaceous sedimentary strata include claystone, siltstone and sandstone. These are of shallow marine origin and have fluvially derived coarse sandstone and conglomerate that cap many mesas and buttes.

These strata have been eroded to form mesaform residuals capped by silcrete or laterite. Some flat-topped ridges extend for up to 100km. They are a marked change in landscape character. These low eminences are surrounded by sheetwash pediments below the 10 to 30m high mesa scarps and laterite breakaways. They have broad footslope valley plains of dunefields and sandsheets abutting saline playas or calcreted relic drainage line bottomlands. These relic drainage line playa courses change direction abruptly from east to south along this margin of landscape transition, as exemplified by the Burnside, Carnegie and Wells saltlakes (Fig. 2, 12). Linear dune ridges 5m to 20m high are mostly stabilized by spinifex grasses.

To the east, the mesa, dune and playa landscape is replaced by the stony undulating laterite plains with sparse vegetation patches of spinifex (*Triodia basedowii*) on the gravel convexities and mulga scrub groves in run-on sites, a mosaic pattern that typifies the Gibson Desert (Beard 1990).

(ii) Vegetation (Fig. 9)

The catena pattern of this rolling plainsland with its tableland residuals includes the following habitats (Mabutt et al. 1963; Beard 1990):

(1) Mesa summits; either bare rock or with sand veneer.

(2) Mesa scarp and laterite breakaways supporting a sparse scrub cover to 3m height of mulga *Acacia aneura, A. grasbyi, A. helmsiana, A. pruinocarpa, Hakea suberea* over *Dodonaea rigida, Eremophila latrobei, E. leucophylla* and *Calythrix carinata* (starflower heath).

(3) Washplains of pediments and laterite convexities with sparse low shrubs of acacia and hakea over hard spinifex *Triodia basedowii* grass hummocks, and mulga woodland groves on loam soils of depressions.

(4) Sandplains and dunes supporting a sparse to clumped scrub cover of mallees (*Eucalyptus gamophylla* and *E. kingsmillii*), acacias (*A. helmsiana, A. linophylla, A. pachyacra*) and *Grevillea stenobotrya* over dense hummock grasslayer of *Triodia schinzii*, and heaths further south (*Thryptomene maisonneuvii*). Bloodwood gums such as *Corymbia chippendalei*, and *C. dichromophloia* are typically the taller trees in the landscape, with a sparse occurrence of coolibah (*E. victrix*) scattered along washes.

(5) Bottomlands of high watertable calcretes support thicket patches of melaleucas (*M. lasiandra* and *M. glomerata*) and saltbush flats of *Atriplex hymenotheca*.

TABLE 3 Major topographic eminences in the GMSA

Geoecological Region & Range	Summit Height a.s.l	c.Height of range between base & crest contours	Summit rock type
Belted Coastal Plain			
Cape Ra.	314m	200-250m	Calcarenitic limestone
Moogooloo (Gooch) Ra.	333m	100-150m	Quartzitic sandstone
Kennedy Ra.	366m	100-150m	Duricrust capped sandstone
*Crystalline Shield (all Archaean greenstone metamorphic fold outcrops)			
Mt. Gould	710m	300	Banded-iron, quartz magnetite
Jack Hills Ra.	697m	200-250m	Banded-iron, jaspilite, chert
Mt. Singleton	678m	200-250m	Basalt, gabbro
Weld Ra.	737m	150-200m	Dolerite, banded-iron
Sedimentary Fold Ranges (all folded Proterozoic sedimentary rocks)			
Mt. Augustus	1105m	500m	Quartzitic sandstone
Mt. Gascoyne	790m	300m	"
Mt. Egerton	994m	300m	"
Mt. Phillips	780m	300m	"
Mt. Samuel	742m	200m	"
Teano Ra.	945m	250m	"
Staten Hill	805m	250m	"
Carnarvon Ra.	913m	200m	"
(edge of LSD) Mt. Methwin.			
Mt. Labouchere	722m	200m	"
Waldburg Ra.	730m	150m	"

*The Shield granites typically outcrop as dome or tor hills only when exhumed by scarp retreat from beneath the overlying old Tertiary planation surface of sand-mantled laterite duricrust.

Table 4 Landscape Gradients across the GMSA

(A) GEOGRAPHIC

(1) Latitudinal (N-S transect across seven degrees of latitude from Pilbara (Ashburton Catchment) southwards to edge of Wheatbelt).

(2) Maritime-Continental Climatic Zonation (coast-inland transect across NW-SE rainfall bands: W. Coast margin and hinterland winter rain/summer dry, central bimodal band, NE Summer rain/winter dry).

(3) Altitudinal/Slope aspect/Regional Catena. (High E-W ranges eg. Bangemall Ranges, Mt. Augustus, Weld Range, Jacks Range; or N-S with E-W ravines eg Kennedy Range. Coastal Plain - Oldland Regional Catena).

(B) BIOGEOGRAPHIC: Junction and overlap of the 3 major Continental Biomes.

(1) Tropical Monsoonal (Savanna Woodlands, Floodplains, Dry Forests, Mangroves).
(2) Central Deserts (arid acacia scrub savanna, spinifex grassland, chenopod shrubland).
(3) SW Warm Temperate Winter Rain (Forests,Mallee,Heaths).

(C) BIOREGIONS

(1) Carnarvon
(2) Gascoyne
(3) Little Sandy Desert
(4) Murchison
(5) Yalgoo
(6) N. Geraldton Sandplain

5 Climate

The GMSA occurs across the central part of WA from north of the tropic at 23°S to the 29°S latitude. The greater part of GMSA has an arid tropical to subtropical continental climate with a narrow zone along the west coast influenced by marine air and advective sea breezes (Australian Bureau of Meteorology – ABM 1998). The climate of the coastal zone is ameliorated by the alongcoast southward meandering Leeuwin gradient current of warm tropical waters. This is in contrast to the perarid west coast deserts of Africa (Namib) and South America (Atacama) at the same latitudes which have north flowing cold currents of upwelled Antarctic bottom-water (Tinley 1986, Gentilli 1991, Pearce 1991).

As with the greater part of the Australian arid zone, the region's climate is controlled largely by the seasonal north and south shift of the midlatitude Trade Wind belt of high pressure, anticyclonic systems. There is a seasonal shift of these main pressure belts towards the equator in winter and polewards in summer. This is in response to the solar control of high sun and low sun thermal conditions. However, trade wind conditions, with their subsiding dry air masses, continue to recur between each cyclonic disturbance.

These systems interact with tropical and temperate rain-generating cyclonic systems that develop on either side of them in different seasons. In summer, the tropical monsoonal and convection systems from the north, and in winter the southerly polar frontal, cyclonic systems (Gentilli 1971).

In winter the belt of westerly circum-polar cyclonic systems moves north reaching over the southern part of the continent while dry easterly winds, off the anticyclone belt, dominate the dry season of the northern tropics. In summer, the reverse occurs with the southward shift of the pressure belts bringing the dry easterly trade winds to prevail across the southern half in the dry season. At the same time, the southward shift of the Inter-tropical Convergence Zone, and the hot season-generated convection heat lows, entrains the advection of moist equatorial air masses into the northern half of the continent resulting in the development of the monsoon system (Gentilli 1971, ABM 1998).

Tropical cyclones are generated mainly between January and March. Many of these cross the NW coast, tracking towards the SE, and bring flood rains to parts of the GMSA at times (Lourensz 1981, ABM 1998). In the late autumn those cyclones reaching the west coast may get caught up by cold fronts resulting in an increase in their velocity and hence damaging effects (Foley & Hanstrum 1994).

The prevalence of a vast, low, and broadly undulating landscape rising gradually over 500km from the coast to the interior continental plateau at 500-600m has permitted a broad overlap of climatic regimes: the south temperate winter rain and north tropical summer rain. The absence of relief barriers - high mountains - means there are no rain shadow desert areas. However, local valley areas may be drier than adjacent ranges as reported from the adjacent Hamersley Range region (van Leeuwen & Bromilow 2002).

Only the sharply defined ranges and inselbergs have contrasting mesocline (shade) and xerocline (sun) slope aspects. This is particularly where their long axes and scarps, or ravines, are orientated east-west. Such ranges are concentrated in the sedimentary fold belt region in the north, the north-south Kennedy-Moogooloo Ranges on the inland margin of the belted coastal plain, and the few major eminences on the crystalline shield - for example, Mt Dalgety, Jack Hills Ra., Weld Ra., Mt. Singleton (Table 3; Fig.15).

A broad central band of bimodal climate exists across the region (Fig. 6). This band receives rain in summer - early autumn (January - March) and/or winter (May – July). There is a long term average pattern of two rain peaks separated by two dry seasons. This is due to the overlap of the two major cyclonic systems (Fig. 1a, 2). One or both these sources of rain can fail in drought conditions.

During winter the movement southeastwards of a cloudband of mid to high level moist equatorial air is an important potential rain producing phenomenon across the region. It originates in the vicinity of the Cocos Islands to the NW and is accordingly named the NW Cloudband. This cloudband is associated with the development of a low pressure system in the Trade Wind Belt and/or the approach of a cold front from the south. Significant rains can result when this cloudband interacts with the polar front. Because of this, rainfall is increased by 50 percent in the Murchison, and by more than 80 percent northwards into the Gascoyne between April and October (ABM 1998).

In midsummer to early autumn, tropical lows and cyclones are the primary causes of heavy rains and flooding. Of the main rivers, the Gascoyne is the most prone to flooding as it lies in the path of the NW Cloudband (Wilcox & McKinnon 1972; ABM 1988). Thunderstorm rains are most frequent in the north and inland parts of the region. For example, the Carnarvon annual average is 7 thunderdays, compared with 21 days at Meekatharra and 38 days at Carnegie. Flash floods produced by intense thunderstorms can deliver from 30 to 160% of the mean annual total in a single event.

Torrential rain is not the only damaging influence from thunderstorms. Severe dustorms associated with the gust front of strong winds can result in considerable deflation of bared terrain and damage to infrastructure. Heavy hail falls can also occcur which leave corridors of smashed woodland in their wake.

Rainfall is the most important climatic factor ecologically, especially because of its highly variable occurrence in space, time, quantity and intensity.

Failure of the whole or part of adequate rains means plant growth can not be maintained. The large variation in summer thunderstorm rain over short distances can lead to prolonged drought conditions at a local or at a regional level (eg. Mundiwindi extreme contrasts in annual rainfall :- 816mm in 1942 and 26mm total for 1944). The driest times are spring and early summer (September – December), when less than 10mm occurs in at least 50 percent of years at most stations, and again, in late autumn (mainly April). The worst droughts recorded in the region occurred from 1935 - 1941 and in 1943 - 1945. The most recent drought period is 1976 - 1979 (ABM 1998). In contrast, between 1995 and 2000, the Mt Augustus, Wiluna and Murgoo Station areas have had five to six consecutive years of average and above average rainfall (ABM rainfall records, accessed 2002).

The long-term climatic seasonal pattern experienced in each geoecological region is depicted by means of Gaussen climographs (Bagnoulds & Gaussen 1957) in Fig. 2. The mean monthly precipitation and temperature figures are plotted in a ratio of 2:1. This index closely correlates with the distribution of vegetation types or formations (eg. Walter 1973, Walter & Breckle 1986, Beard 1990: 37-40). The construction of Gaussen climographs are also valuable for short term monthly and annual correlations with soil moisture and phenological events.

Periods of moisture surplus on the climographs are indicated where the rainfall curve rises above that of temperature. The converse situation, of a moisture deficit or dry season, is where it falls below the thermal curve. The extent of the rainfall line above and below the thermal line indicates the duration and intensity of the seasons. The region illustrates the typical arid zone-desert margin pattern of year round moisture deficit conditions (Fig. 2) (except for the two coastal stations Learmouth, and Boolathana, and the southwest Murchison Yuin Station, where the long term moist period from winter rains is confined to a small part of June and July). Refer to Walter & Lieth (1967) for homoclime equivalent climographs elsewhere in the world.

In summary, the mean annual rainfall across the whole region is around 200mm. This occurs seasonally in a NW-SE band oblique to the coast. There are mainly midwinter rains along the coast and southern Murchison, with bimodal conditions in the central band, and mainly midsummer and early autumn rains in the north and towards the interior in the northeast. Landscape gradients affecting climate characteristics across the GMSA are summarised in Tables 4 & 5.

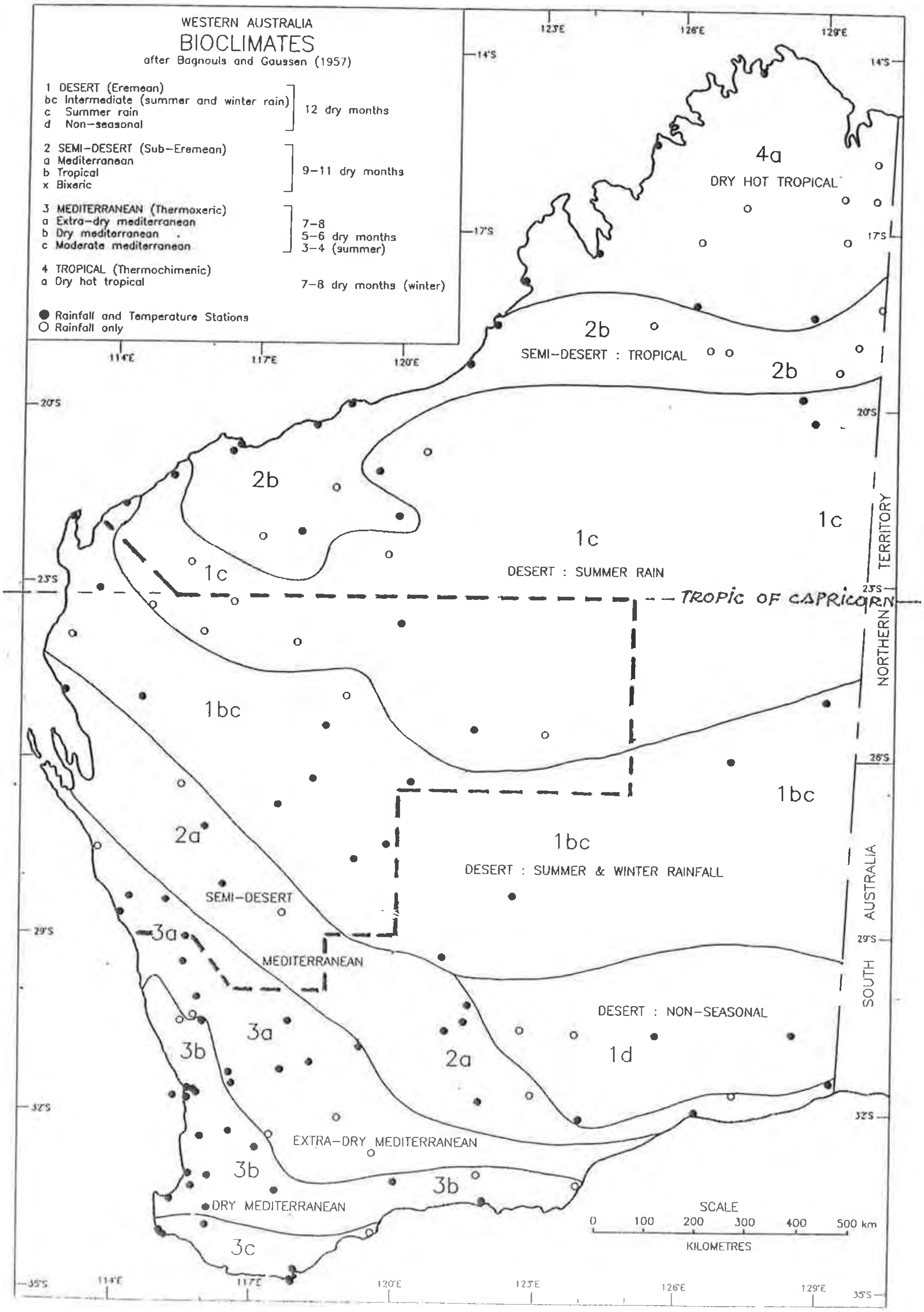


Fig. 6 BioClimatic patterns across the Gascoyne - Murchison Strategy Area in a statewide context (from Beard 1990).

Table 5 Climatic data transect from the Coast inland to the Interior plateau drainage divide.

		Coast: Hamelin	Midland: Errabiddy	Inland: Three Rivers
RAINFALL mm				
Mean Annual Precipitation mm		210mm	203	226
Months with >20mm		May-Aug (winter)	Jan-Mar/May-Jun (bimodal)	(Dec)Jan-May(Jun) (summer autumn)
Anual Rainfall Variation		213%	255%	229%
Evaporation - mean annual/mm		2.608		3.641
TEMPERATURE °C				
Jan.	Highest Daily Max.	47	46	46
	Lowest Daily Max.	10	17	15
	Mean Monthly	29	32	32
July	Highest Daily Max.	29	29	29
	Lowest Daily Max.	2	-0.6	-5.5
	Mean Monthly	25	14	13
RELATIVE HUMIDITY%				
Jan.	09h00	43	29	26
	15h00	33	15	16
July	09h00	71	59	54
	15h00	54	36	31
WINDS - (PREDOMINANTS)		Carnarvon		Meekatharra
Jan.	09h00	S.		E.NE
	15h00	SW.S		E.SE
July	09h00	E.SE		E.NE
	15h00	S.SW		E.NW.W

6 Biogeographic Context

Biomes are major Life Zones (Holridge 1967) or Ecozones (Klijn and Udo de Haes 1994) in which a variety of ecosystems are linked by similar or shared biophysical features and processes. They are large-scale geographical units expressing distinct combinations of landscape, climate, soils, vegetation type, and flora and fauna. Biome Types or Zonal Biomes are ecologically equivalent regions, within the same geographical zones of the world, which have similar physical environments, and analagous biotic components and habitats. At a world scale the vegetation of the GMSA is part of the Arid Savanna Biome Type, typified by acacia/thorn scrub vegetation formations (Fig. 14 inset, after Holdridge 1967, Walter 1973, Walter & Breckle 1986). No steppe climate or vegetation type exists in Australia. True steppes are midlatitude temperate cold grasslands and desertic regions on the poleward margin of the lower latitude tropical-subtropical hot deserts, semideserts and arid savannas (Miller 1931, Stocker 1964, Walter 1973).

As ecotones are interface zones between different systems at all scales, climate and/or landsurface changes can result in the ecotone of today expanding to become tomorrow's ecosystem. In this same process the ecosystem of today would shrink to become an ecotone, islanded or disappear completely.

In the GMSA the coast and the hinterland, together with adjacent Pilbara Region, form the major junction and overlap area for three major biomes in the west of the Australian continent (Fig. 1a). The greater part of the region terminates against the Indian Ocean coastline and forms the western end of arid tropical and subtropical central Australia. The coastal and northern parts of the region are influenced by tropical monsoon elements. The coastal and southern parts by South West temperate elements.

The three biomes are:

(a) Northern – Monsoon or Torresian Biome.

(b) Central – Arid or Eremaean Biome (meets the coast between Shark Bay and 80 Mile Beach).

(c) Southern – SW Temperate or Bassian Biome.

The GMSA coastal zone between Shark Bay and Exmouth Gulf (21°45'S to 26°S) is the main area of overlap between the three biomes on land (Fig. 7), and the tropical and temperate in its shelf seas. The northern limit of the southwest temperate heath and woodland vegetation on the west coast ends at Shark Bay where 145 taxa stop. This includes three Gondwanan related flora of the Restionaceae (*Ecdeiocolea monostachya, Lepidobolus preissianus*, and *Loxocarya flexuosa*)(Keighery 1990). The Gondwanan heritage of Western Australia is reviewed by Hopper et al. (1996). There are also 28 endemic plant taxa recorded and 39 tropical taxa reach their southwest range limits in the Shark Bay area (Keighery 1990; Keighery & Gibson 1993). See also Berry *et al.* (1990) and Humphreys (1993). Examples of endemic flora and fauna distribution patterns across the GMSA are shown in Figs. 8, 9, 10.

The narrow continental shelf is unique on the GMSA Region coastline and indeed on the Australian mainland. It is 10 to 12km wide to the –200m isobath along 100km of the Ningaloo Coast, between Point Cloates and the North West Cape. As the continental slope below the shelf edge is precipitous, this coastal sector has experienced minimal shifts of the shoreline with little land being submerged or exposed during the Pleistocene rise and fall of sea levels (Morse 1993).

The marine angiosperm seagrass species (Walker & Prince 1987) and mangrove species (Semenuik *et al.* 1978, Johnstone 1990) distribution patterns are illustrative for marine shelf waters. The tropical seagrasses occur at their southern geographical limits in Exmouth Gulf (*Thalassodendron ciliatum*) and the outer edges of Shark Bay (*Cymodocea angustata, Thalassia hemprichii*). Temperate coast species reach their northern limits in Shark Bay (*Halodule uninervis, Posidonia australis, P. coriacea*) and Exmouth Gulf (*Amphibolus antarctica*). In total there are 12 taxa from 8 genera of seagrasses in Shark Bay (Walker & Prince 1987, Walker 1991/92).

The coral reef along 375km of the Ningaloo Coast is a unique coastal ecosystem in WA. Over its greater length it is a close-offshore barrier reef system south to Gnaraloo Bay, where it becomes a fringing reef tied to the mainland shoreline. Over 220 species of 54 genera of reef building corals occur here, with a high diversity of associated reef fauna, the majority of which belong to widespread Indo-Pacific tropical coral systems (CALM Publ. 1988).

Six tropical mangrove species reach south into Exmouth Gulf and include *Aegialitis annulata, Aegiceras corniculatum, Avicennia marina, Bruguiera exaristata, Ceriops tagal* and *Rhizophora stylosa*. Of these, only the *Avicennia* extends south of the North West Cape to the South West coast as far as Bunbury (33°20'S).

On land in the south of the region, the biome ecotone between the southwest eucalypt woodlands and the arid acacia scrubland occurs as a broad NW-SW zone between Shark Bay and the Nullarbor plain, traversing the Yalgoo and Coolgardie bioregions (Fig.1c)(Gibson et al. 2000). Different biotic components extend from their core areas to occurrences of suitable edaphic substrates. For example, iron-rich outcrops, such as banded-iron formation, laterite, red sand dunes and orange loamy sands with lateritic gravel and clay at depth, carry south west forest and heath elements into the arid zone (eg. genera such as *Baeckea, Banksia, Calytrix, Darwinia, Micromyrtus, Thryptomene* and *Verticordia*). Examples of arid zone elements that extend into higher rainfall zones of the southwest on saline soils, xeric stony terrain, and deep or calcareous sands include *Acacia tetragonophylla, Eremophila miniata, Swainsona formosa, Triodia scariosa* (Greg Keighery pers. com). Some of the best expressions of overlap between arid and temperate elements in this biome ecotone occurs on the yellow clayey sands of the Joseph landsystem. Here the hard spinifex *Triodia scariosa* and large tufted restio *Ecdeiocolea monostachya* occur side by side as dense, fire prone swards to 80cm in height. Ecotonal species diversity enrichment of this zone is also exhibited by the avifauna (Johnstone et al. 2000).

In contrast, the northern tropical monsoon extension southwestwards along the coast from the Kimberley (behind 80 Mile Beach), is a tenuous biogeographic linkage. This is due to its narrowness on the finger of red Pindan loam soil between Broome to near the De Grey delta (Beard 1990, p268). This narrow, humid corridor between the Great Sandy desert and the sea, links the Kimberley to the Pilbara and GMSA coastal zone. It is typified by the 'hourglass' distribution pattern of many Torresian plants and animals along the humid corridor between the ocean at 80 Mile Beach and the dune sea of the Great Sandy Desert (indicated by arrows in Fig 11).

The Torresian avifauna, for example, show a decrease of species numbers in a SW direction in a corridor along the coast from the Kimberley to the Pilbara (Gentilli 1992: Figs 7, 8). This is contrasted by the very steep drop-off of bird species as one moves SE into the Great Sandy Desert (Gentilli 1992: Figs 6, 8). Because it is narrow, this linkage area, in the path of tropical cyclones, requires close conservation attention as it can be easily degraded by overgrazing, clearing or excessive bushfire.

The tropical monsoon floral elements typically extend into the western arid zone along the humid habitats of the coast. This occurs on alluvia and drainage lines, in gorge and scarp sites, and on rocky outcrops. Examples include: perennial grasses eg. Mitchell grasses (*Astrebla* spp) and associates; woody plants eg. *Capparis spinosa, Clerodendrum floribundum, Erythrina vespertilio, Melaleuca bracteata, Phyllanthus reticulatus*, and *Terminalia canescens* (south to Ashburton River valley). The northern central boundary of the GMSA overlaps into the biogeographically important Hamersley Ironstone Ranges region of the Pilbara (van Leeuwen & Bromilow 2002).

In the GMSA, the 1: 250 000 map sheet areas showed species richness of acacias as the highest known occurrences in the Yalgoo Bioregion interzone (Arid-Temperate Biome Ecotone). The Perenjori sheet area contained 86 species. It forms part of the six NW-SE linked maps with the highest number of wattle species that cover this bioregion (Maslin & Pedley 1988, Hnatiuk & Maslin 1988). The environmental determinants of biogeographic patterns on the continent are analysed by Nix (1982); Keast (ed. 1981), and for the continent's flora by Crisp *et al.* (1999).

For the Eremaean biome mulga *Acacia aneura* amongst many other plants displays a classic trans-arid zone distribution pattern (Fig 7). Central Desert trees such as *Acacia estrophiolata* reach west to near Wiluna, and marble gum *E gongylocarpa* forms tree savanna with mallee and acacia shrubs over spinifex grassland to near Sandstone on the Tyrrell land system.

The GMSA encounters 11 IBRA Regions (Interim Biogeographic Regionalisation for Australia, of Thackway & Cresswell 1995). Five of these have greater than 65% of their total area within the GMSA (Carnarvon, Gascoyne, Murchison, Yalgoo and the Little Sandy Desert). The remainder have a very small area in the Region, with four of these having less than one percent (see Table 2, Figure 1). Four of the IBRA Regions have a high priority for inclusion in the conservation reserve system, these are Carnarvon, Gascoyne, Murchison and Yalgoo (Thackway & Cresswell 1995).

In summary, the patterns of highest landscape diversity occur across ecojunctions at all spatial scales. The four used here are:

(1) The largest where the three major biomes meet and overlap in a half-circle radius of 350km centred on Quobba Point inland to about Mt. Augustus(Fig.17). This covers the highest diversity of topographic relief, geology, climate, soils, geomorphology (landform and processes), soils, vegetation and flora (Fig. 15).

(2) At the next scale down the ecojunction area of five bioregions in the southwest sector which encounters the Carnarvon, Geraldton Sandplain, Yalgoo, Murchison and Avon within a 100km radius. Of four bioregions where the Murchison-Yalgoo-Coolgardie-Avon meet, and the Little Sandy Desert-Gascoyne-Gibson Desert- Great Victoria Desert junction area.

(3) At the district to station scale 34 areas have high landscape diversity values: Belted Coastal Plain 8, Shield 15, Fold Ranges 8, Little Sandy Desert 2, Interior Desert Margin 1 (Fig. 17, Table 11).

(4) At the local paddock size scale the 10x10km grid of landsystem ecojunctions shows highest value concentrated across the southern part of the region (Fig.16). This pattern may however be influenced by the more comprehensive surveys of recent years in the south and south east parts of the rangeland.

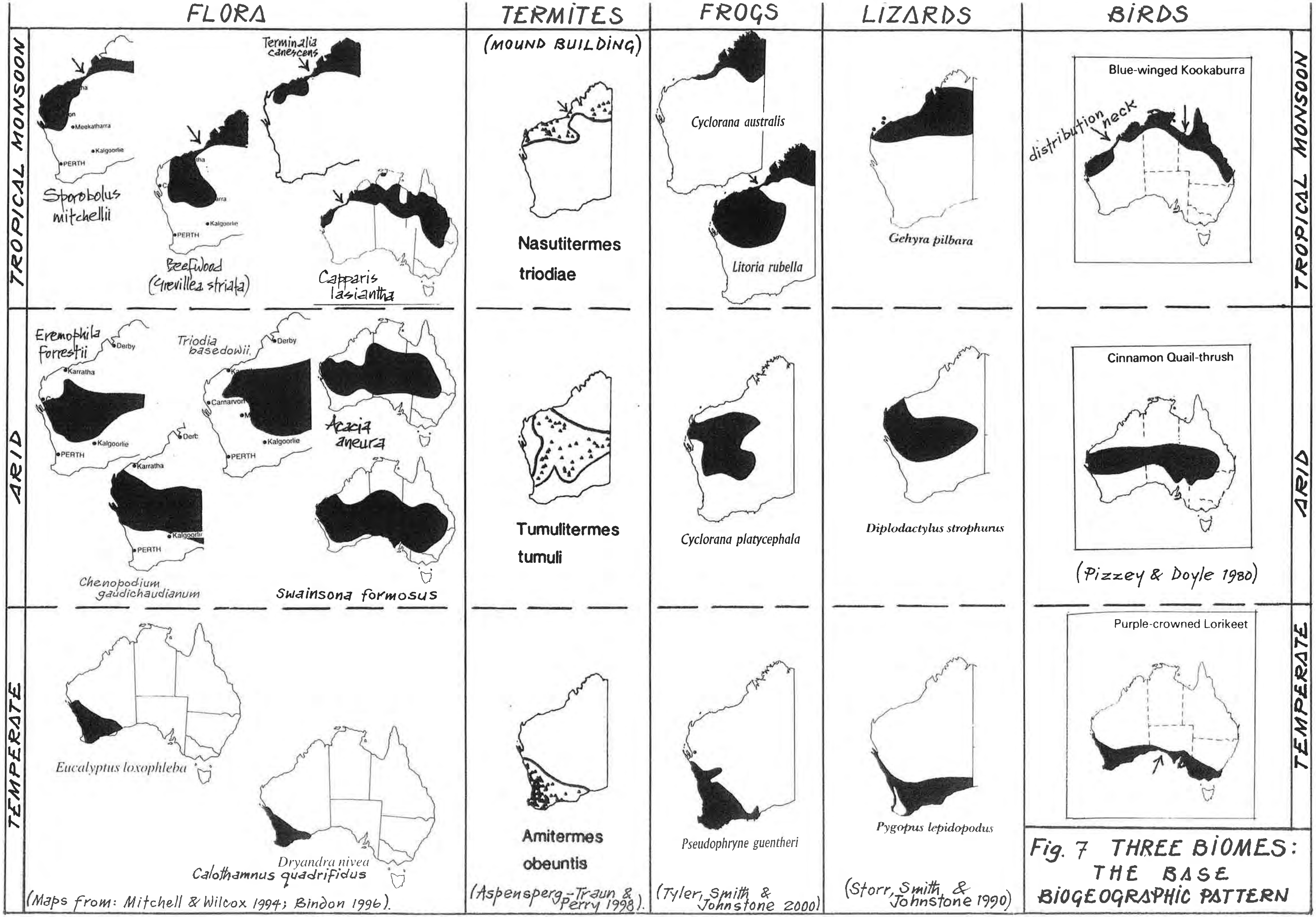
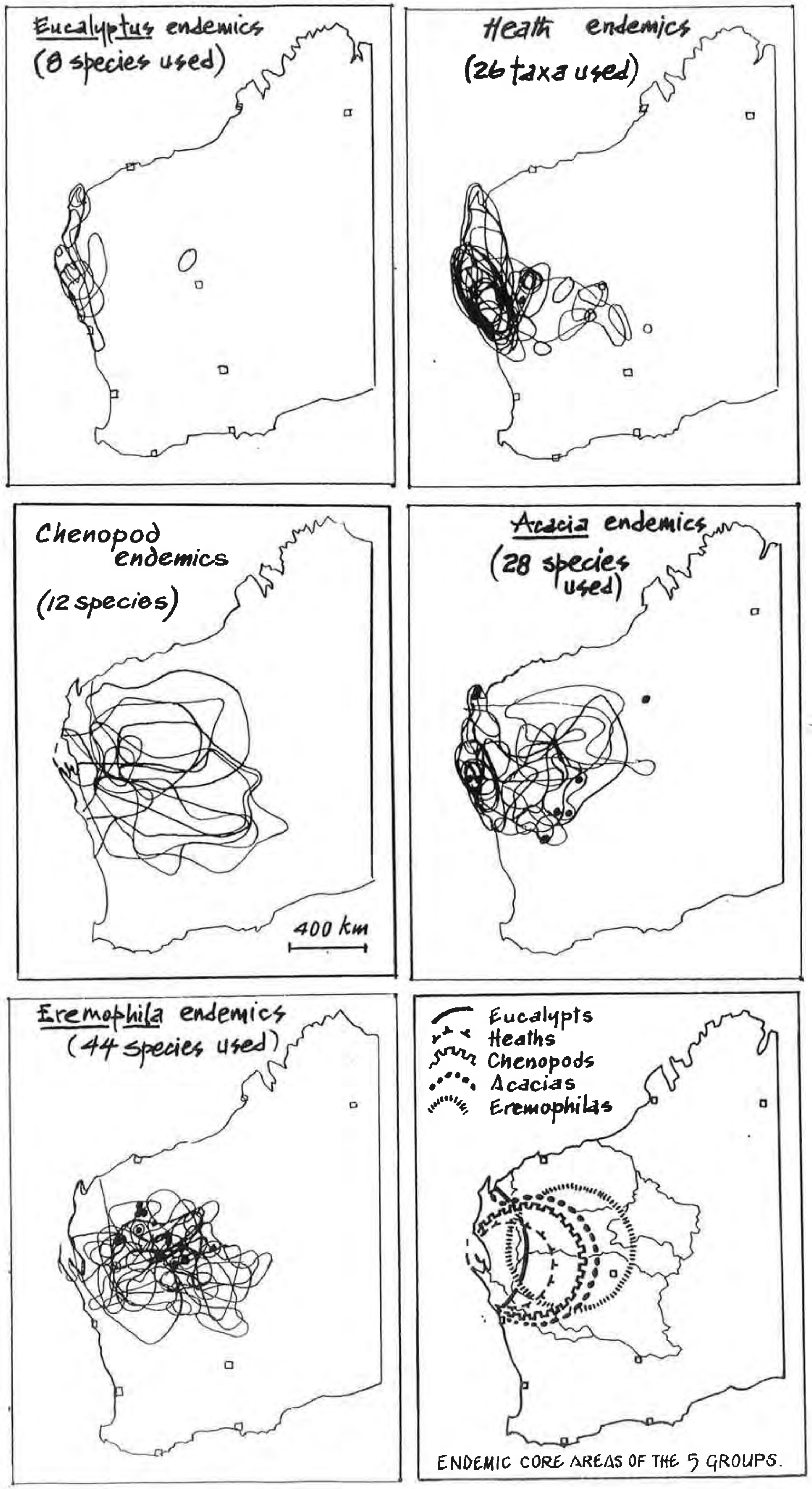


Fig. 7 THREE BIOMES: THE BASE BIOGEOGRAPHIC PATTERN



ACACIA species (Mimosaceae)

alexandri
amblyophylla
anastema
auripila
chartacea
demissa
didyma
drepanophylla
galeata
imitans
intorta
marramamba
microcalyx
oldfieldii
palustris
quadrisulcata
ryaniana
scleroclada
sibilans
speckii
sphenophylla
startii
subsessilis
unguiculata
wilcoxii
"Mt. Magnet (T. McK 5)
"Shark Bay (BRM 3682)
"Wiluna" (BRM 7090).

EREMOPHILA spp. (Myoporaceae)

anomala
arguta
canaliculata
caespitosa
citrina
coacta
conferta
congesta
conglomerata
crenulata
cryptothrix
demissa
enata
fasciata
flabellata
flaccida
gracillima
humilis
incisa
laanii
lanata
macmillaniana
micrantha
muelleriana
ostrina
pendulina
petrophila
physocalyx
prolata
pungens
punicea
recurva
reticulata
retropila
rhegos
rigens
rigida
ringens
setacea
simulans
spathulata
spectabilis
spinescens
warnesii

EUCALYPTUS spp. (Myrtaceae)

fruticosa
giraliensis
oraria
pallida
prominens
selachiana
semota
ultima

CHENOPODS (Chenopodiaceae)

Atriplex cephalantha
A. macropterocarpa
Maireana aphylla
M. atkinsiana
M. convexa
M. glomerifolia
M. melanocoma
M. murrayana
M. polypterygia
M. prosthecochaeta
M. thesioides
Rhagodia latifolia

HEATHS (mostly Myrtaceae)

Balaustion microphyllum
Banksia ashbyi (Proteaceae)
Beaufortia sprengelioides
Calothamnus borealis
Calytrix chrysantherus
C. formosus
C. kalbarriensis
C. truncatifolia
C. verrucolosa
Darwinia masonii
D. virescens
Eremaea dendroidea
E. ebracteata
Euryomyrtus inflata
Lamarchea hakeifolia
Malleostemon minilyaensis
Thryptomene decussata
T. strongylophylla
Verticordia dichroma
V. etheliana
V. jamiesonii
Baeckea blackallii
B. pentagonantha
B. "Barloweerie" (JZW 5079)
Baeckea "London Bridge (Trudgeon 5393)
B. "Melita Station" (H. Pringle 2738).
B. "Sandstone" (Gardner 1963).

Fig. 8
PATTERNS OF ENDEMISM IN THE 4 DOMINANT WOODY PLANT FAMILIES OF THE GMSA.
(outlines drawn by hand around specimen collection sites recorded on FloraBase maps of Western Australia Herbarium.)

(A FIRST APPROXIMATION)

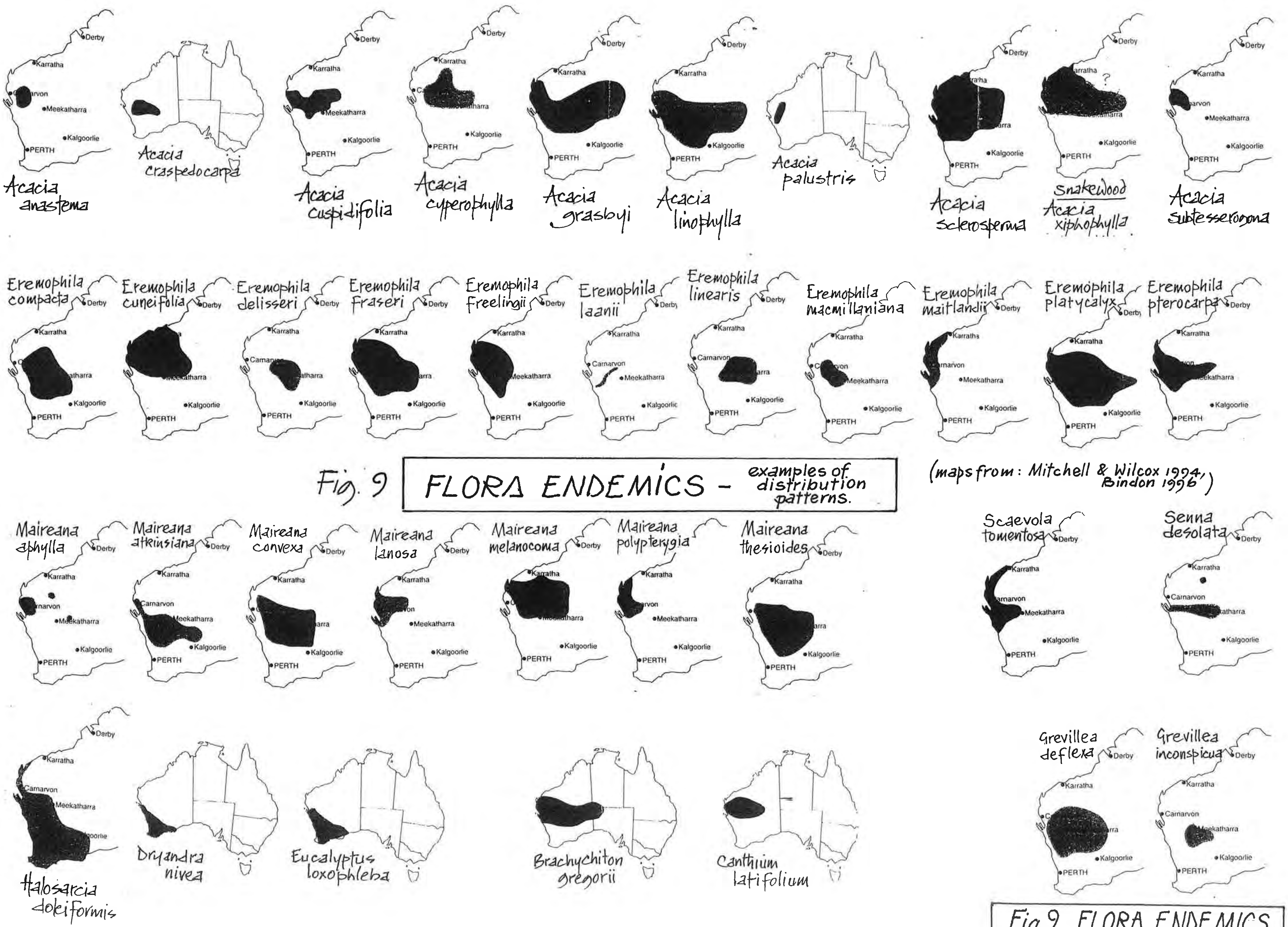


Fig. 9 FLORA ENDEMICS - examples of distribution patterns.

(maps from: Mitchell & Wilcox 1994, Bindon 1996)

Fig. 9 FLORA ENDEMICS.

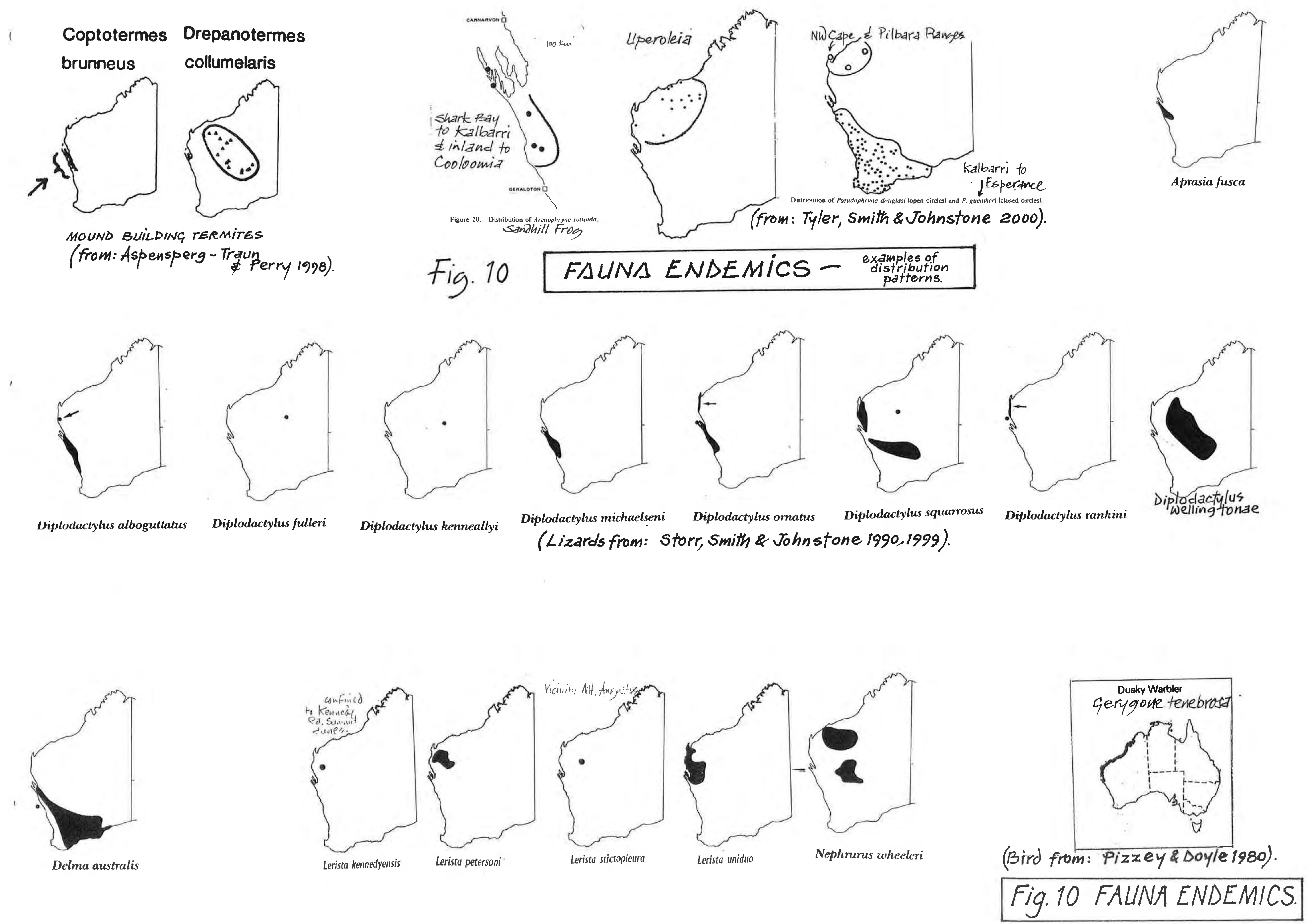


Fig. 10 FAUNA ENDEMICS – examples of distribution patterns.

Fig. 10 FAUNA ENDEMICS.

7. Approach: The Synoptic Ecosystem Method

A synoptic ecosystem method (SEM) was used in this project to discern potentially high biodiversity areas ('hotspots'). This method is based on a map overlay technique used by the earth sciences since the advent of tracing paper, and perfected by Professor Ian McHarg and his school of Landscape Planning & Architecture at the University of Philadelphia, USA. Their approach is enunciated by McHarg (1969) in his landmark book "Design with Nature", particularly the chapter titled "Processes as Values" which remains a classic of its kind.

In the present survey the overlay process involves seven sheets of mapped biological and physical information on tracing film. These can be layered interchangeably over the base map. When all overlays are in place, the areas with coincident occurrence of the largest number of features are the areas of highest landscape diversity and therefore potentially of highest biodiversity.

However, the latter can only be accomplished where the flora and fauna focii of endemism and species richness have been analysed. A task which would complete the final composite map (8^{th} layer) and is yet to be done for the GMSA. Hence the focus in this survey is on landscape or geoecological diversity tempered by some examples of plant and animal endemic patterns of occurrence.

Potential high biodiversity value areas are considered here to occur where there is a combination of two or more of the following:

(a) A wide variation in terrain relief associated with a large variety of landforms and hence terrain processes and soil types (substrate or edaphic diversity),

(b) High geodiversity ie. a high diversity of rock types near-surface or outcropping that contribute to the development of a wide variety of terrain surfaces.

(c) High interspersion of different vegetation types and mapped land systems in relatively small area.

(d) Areas of high species richness and locations of endemic plant or animal species, or significant outlier populations, where known.

(e) Unique features such as drought buffering habitats (wetlands, riparian zones, surface water occurrences) and including water-remote ungrazed or least-grazed areas (Biograze 2000).

Like the term 'environment' biodiversity is all embracing, and the emphasis on 'bio' in practice can mask the fundamental geomorphic and ecological processes responsible for ecosystem form, function and composition. This emphasises the need to assess the interactions of local, district or regional systems within the larger landscape arena (as exemplifed by drainage basin units) of which they are a part (Noss

1983, 1984, 1996; Lotspeich 1980; Swanson *et al.* 1988, Holland *et al.* 1991; Franklin 1993, Smith et al. 1993; Ferguson 1994; Noss and Murphy1995; Burnett *et al.* 1998; Nichols et al. 1998; Tinley 1986, 1991b; Pringle & Tinley 2003).

The term landscape ecology or geoecology as discussed by Rowe & Barnes (1994) is the basis for the ecosystem approach used here. Geoecology was apparently first conceived in America by Adams (1901) and Cowles (1901) as physiographic ecology and developed further in the 1930's by the German geographer Carl Troll (Vink 1983).

Geoecology is defined here as:

> Top-down cognition of terrestrial physical and biotic processes and their interactive relationships in geographically definable natural system units of all kinds and at all spatial scales. In particular those interactions that affect ecosystem patterns, structure and function including composition and succession.

In short, " Life and Earth functioning together" (Odum 1993).

Of these natural system units, the drainage basin system dynamics are primary determinants of pattern, process and change. 'Pattern indicates the diversity of phenomena in space, and process indicates the diversity in time' (Vink 1983).

(7.1) Approach Premise

The methodology of the synoptic ecosystem approach is based on the following premises:

(i) *A relatively small area of different ecosystems* or habitats (vegetation types/landsystems) potentially contains a greater diversity of landforms, soils, vegetation, flora and fauna, and diversity of geoecolgical processes than a large homogenous area.

(ii) *Vegetation type reflects climate through the edaphic medium*. Vegetation formations (or communities) are a biotic expression of landscape diversity and succession. Vegetation type is an expression of a particular ecosystem at all spatial scales, from a biome to a habitat. Vegetation type reflects climate through its translation by the edaphic medium (the climo-edaphic determinant).

(iii) *Ecojunctions are areas of potentially highest biodiversity.* Ecojunctions are nodal areas of confluence between a number of different ecosystems. They occur where different systems meet and at all spatial scales, from biomes to the local habitat mosaic. Ecojunctions are significant because a relatively small area with several different ecosystems contains a greater diversity of landforms, soils, vegetation, flora and fauna. It also contains a greater diversity of geoecological processes than a large homogenous area.

Thus ecojunctions are nodal areas of potentially highest biodiversity. Juxtaposition of six or more landsystem catena units in the GMSA at ecojunction nodes are used in this survey as indicators of potential high landscape diversity (Fig. 16). The importance of 'biogeographic crossroads' in biodiversity conservation is also stressed by Spector (2002).

(iv) *Ecotones can develop new habitat features.* Ecotones are zones of transition or overlap between ecosystems at all spatial scales. In addition to a mix of different species from the abutting systems,

ecotones may be subject to different processes and support biotic elements unique to them. The interactions at these edges can be drivers of ecosystem change where they involve geomorphic surface replacement successional sequences as exemplified in Chapter 8, (6th Layer). Hence ecotones are an important focus in research and management for discerning landscape function and trend (eg. Gosz & Sharpe 1989; Holland et al. 1991; Risser 1993; Cadenasso et al. 2003; Strayer et al. 2003). Ecotone expansion can replace and develop new system features not expressed by those abutting, ie. the ecotone of today can become the ecosystem or biome of tomorrow.

(v) *A hydrologic ecosystem is the fundamental unit of terrain processes.*

A hydrologic ecosystem contains all landscape components. It is a single arena of multidirectional changes; a result of water moving sediment downslope and erosion cutting back upslope. Hydrologic ecosystem units are easily identifiable on the ground and on maps where drainage catchments are separated by divides (watersheds), or by terrain type in the case of sandplains and karst systems that lack surface drainage (Tinley 1991b).

(vi) *Ecosystem physiognomic features integrate flora and fauna into community.* Ecosystem or habitat physiognomic features, as expressed by geomorphic diversity, are the common integrating features linking flora and fauna into community, association or habitat types. Geomorphic diversity includes terrain form, slope, substrate and drainage type (eg. sandy, clayey, gravelly, rocky or wetland, and whether base saturated or acidic).

(vii) *The geomorphic landscape is the base for biogeoclimatic processes.*

Of the 7 levels (Table 6), the geomorphic landscape (Layer 3) is the fundamental base and most important evolutionary arena for biogeoclimatic interactions and processes.

7.2 Background to the Synoptic Ecosystem Method

The synoptic ecosystem method was used in Mozambique with success in the 1960s and 70s by the author. The task then was to identify high diversity coastal and inland areas for protection status as national parks and nature reserves (Tinley 1969, 1971, 1977).

In 1988 the same approach was used at the station scale for a habitat survey of the Abydos-Woodstock Reserve in the Pilbara Region of Western Australia (Tinley 1991a). The subsequent fauna survey discovered one of the richest herpetofaunal assemblages recorded in Australia. This was due to the close juxtaposition of high geomorphic and vegetation diversity along a 20km transect (How *et al.* 1991).

Various applications of the synoptic ecosystem approach are illustrated by McHarg 1969; Wiens et al. 1985; Purdie et al. 1986; Gosz and Sharp 1989; Gosz 1991, 1993; Holland et al. 1991; Bedward et al. 1992; Burnett *et al.* 1998; Schwartz 1999; Pressey *et al.* 2000; Groves *et al.* 2002.

The importance of using the larger-scale geoecosystem or landscape approach for practical and effective conservation is reiterated by Lotspeich 1980; Delcourt & Delcourt 1988; Swanson *et al.* 1988; Franklin 1993; Smith *et al.* 1993; Klijn & Udo de Haes 1994; Forman 1996; Noss 1996; Wondzell *et al.* 1996.

7.3 The Overlay Method: 'Whole of System' Approach

The 'whole of system' approach for landscape identification here involves superimposing 7 layers of mapped information that comprise the biophysical makeup of a landscape (Table 6). The layers are added in order of importance with the base map at the bottom. The third (Geomorphic) and fifth (Ecosystems) layers are the most important and form the basis to which all others are cross-referenced. The identification of ecojunctions in each layer is central to the map overlay technique.

In the field ecosystems are interfaced at all scales by ecotones of various width and definition (mapped on 5th layer). Together these are embedded in the geomorphic landscape (3rd layer) where drainage processes are primary drivers and connectives within and between landscapes.

The disparity in map scales used affects the level of detail resolution possible. Hence the distributional correlations derived from the overlay process vary between coarse and finer filtered according to the map detail. It is vital to range and integrate between all scale levels in the process to comprehend the eco-geographic context. This enables one to discern the different pattern relationships of systems, ecotones and key linkages that may be missed if only one scale is used.

7.4 From Macro to Micro Scale: The 'Top-down' Perspective

The 'top-down' perspective starts with the whole drainage basin or natural region as the base reference template for identifying, inter-relating, and integrating the biophysical component parts down to the micro-level of individual species in a nested heirarchy of salience (eg. Mc Harg 1969; Tinley 1977, 1987 Table 2; Rowe & Barnes 1994; Klijn & Udo de Haes 1994). At each scale the particular composites of terrain and cover pattern, gradients, ecotonal relationships, processes and linkages are considered.

To begin with, the five major geoecological regions are considered together at the biome and whole GSMA scale (Fig. 17). Then the individual regions are considered, then applied to the district level, and finally the local station size scale.

Different nodal patterns emerge as each change of scale alters the level of detail. This is exemplified by comparing the junction of three biomes at the whole region dimension (Fig.17) with those junctions between and within each geoecological region, or bioregion junction (Figs. 2, 1c); at the district scale (one 1:250 000 map sheet), and again, at the individual station scale using landsystem or vegetation type maps (Fig. 16).

The four spatial scales (biome, region, district and local) are considered, each nested within the other and containing its own unique properties. Each may appear homogenous at one scale and diverse at another (Delcourt & Delcourt 1988; Klijn & Udo de Haes 1994). At all four scales, potential high biodiversity areas are identified through overlay of data layers (manual and part GIS) including geology, physiography, soils, vegetation and land systems (Table 6).

7.5 Other Approaches

For examples of other approaches and quantitative methods to identify areas of conservation value for reserve selection refer to: Purdie 1986; Margules et al. 1988; Margules & Pressey 2000; Bedward et al. 1992; Belbin 1993; Lockwood et al. 1997; Pressey et al. 1993, 2000; Schwartz 1999; Poiani et al. 2000; Scott & Sullivan 2000; Environmental Management 2000.

Table 6

Top-Down Ecosystem Approach used for identifying potential high biodiversity areas in the GMSA.

[1] GEOLOGY
Tectonic structure. Rock types mapped at 1:250 000 scale.

[2] CLIMATE
Patterns and gradients eg. wet-dry regimes (summer-bimodal-winter); maritime-continental climates ie. gradient; terrain aspect (xerocline and mesocline slopes).

[3] THE GEOMORPHIC LANDSCAPE
Land surface form and configuration (shape, relief, elevation, slope, arrangement, surface composition, source rock: 50m contour interval @ 1:250 000 map scale; 20m @1:100 000 scale).

[4] SOIL
Dominant Groups in WA @ 1:3 million scale.
(a) rocky/stony, (b) sandy, (c) loams/earths, (d) clays (e) duplex (f) wet.

[5] ECOSYSTEMS & ECOTOPES
As indicated by biome, geoecological region/bioregion, drainage basin units, vegetation types, catena complexes.

[6] LANDSCAPE PATTERNS
Faultlines, dykes, ranges, scarps, sea & lake shorelines, drainage, linear dunes, vegetation stripes & patches.

[7] UNIQUE FEATURES OR COMPONENTS
(a) Physical: eg. Aquifer recharge areas; fossil occurrences; markers of previous strandlines; unusual or rare rock types; limestone cave systems; landforms; wetlands (incl. springs, floodplains, marshes, billabongs, claypans and playas).
(b) Biophysical: eg. plant community, ecotope, habitat or ecosystem; biogeographic and ecosystem outliers or endpoints. Karst stygofauna. Nationally listed wetlands. Water-remote least grazed habitats.
(c) Biotic; eg. flora and fauna endemics, species rich areas. Rare and endangered species.

8. Identifying Potential High Biodiversity Locations

In addition to the map overlays a stereo-airphoto scrutiny of the entire GMSA identified the locations of highest terrain diversity. Such areas in country of low relief are indicated on the black and white airphotos by changes in the density, texture, tone and pattern of the plant cover (Premise 2 above). See Fig. 17.

1st Layer: Geology/Rock Type Diversity

The occurrence of highest rock type diversity in a local area is by far the outstanding geological characteristic of the greenstone metamorphic outcrop areas in the crystalline Shield geoecogolical region. Here as many as 18 different rock types are closely juxtaposed within 20 x 20km areas, as exemplified by Paynes Find, Mt. Magnet, Cue and other gold mining centres (Fig. 15b).

Superficially, the excellent detailed geological maps in colour at 1:250 000 scale would seem to be the ideal basis on which to look for correlations between flora and fauna and the physical environment. Field evidence to the contrary, however, shows vegetation physiognomy, floristic associations and endemic flora are most closely correlated with the occurrence of the secondary regolith formations which mask country rock over vast areas. This is well exemplified by comparing the Glenburgh 1:250 000 geological sheet (SG50-6) showing extremely high rock diversity with the Glenburgh topographic map which is geomorphically homogenous over the greater part due to the predominance of pediplanation surfaces and hardpan. These masking land surfaces are noted in the 3rd Layer (Geomorphology).

Only where different kinds of geology cleanly outcrop are particular kinds of vegetation or plants found to be associated with them. Reptiles too are highly correlated with land surface or substrate type (eg. How *et al.* 1991).

At the broad whole-region scale on the 1:2.5 million geological map (Myers & Hocking 1998) the areas of highest rock type diversity within a 100km radius are centred on:

(1) Winning Station (N. Carnarvon Coastal Plain),

(2) Doolgunna Station (source area of Gascoyne and Murchison rivers and the Nabberu saltlake chain),

(3) Callytharra Springs Station (on the central Wooramel River),

(4) Coolcalalaya Station (on the Lower Murchison River at the head of the gorge tract).

At the larger 1:250 000 whole sheet (147.5 x 110km) map scale highest rock type diversity is in two areas, (1) the Robinson Range Sheet (SG 50-7) between the upper Murchison and Gascoyne catchments, and (2) the Winning Pool - Minilya sheet (SG 50-13/SF 49-16) that traverses a cross section of the northern Carnarvon Belted Coastal Plain and its inland junction with Mesozoic and Proterozoic sedimentary rocks and the crystalline oldland rocks of Early Proterozoic Age.

Again at the 1:250 000 scale, but at the local level within a radius of 5km, highest rock type diversity occurs where folded greenstone metamorphic lenses outcrop through the crystalline rocks. For example in the upper Murchison 11 rock types occur around Trillbar Outcamp, in the lower Murchison 12 types at Twin Peaks (Murgoo Sheet SG 50-14), and on the inland drainage divide 12 rock types in the Mt. Magnet area (Kirkalocka sheet SH 50-3).

Refer to Fig. 9b.

2nd Layer: Climatic Diversity

Topographic features, altitude, distance from the sea and sea surface temperatures are determinants of the climate experienced in a particular area as these influence the expression of each climatic component (eg. Gentilli 1971). The GMSA has a narrow humid maritime zone and a vast continental arid climate with hot summers and mild winters (Fig. 2 climographs). The predominantly low broadly undulating relief of the region has allowed for a wide overlap of the area affected by summer and winter rain-forming systems. This results in a banded NW-SE rainfall pattern oblique to the coast with a central bimodal band merging southwestwards to mainly winter rains and midsummer to early autumn rains northeastwards (Fig. 6). Average rainfall across the region is 200mm and is highly variable in space and time, hence as is the occurrence of long dry periods and drought. A large percentage of rainfall is brought by a few major synoptic events such as a tropical low or cyclone, thunderstorms, or the interaction of a strong polar front with NW Cloudband. Gale force winds and storm surges occur on the coast with the advent of strong cyclonic events. Evaporation exceeds average annual rainfall by 13x on the coast and 16x inland (Table 4).

The region is also subject to summer heat waves (consecutive days >40^{0}c) or cold spells. Minimum ground temperatures less than 0ºC are rare on the coastal plain averaging five days between May and September, inland to 12 days between June and August in the southern part (Paynes Find) and to 28 days in the NE (Three Rivers) between May and October (ABM 1998).

The isolated massifs and ranges have modifying influences on local climates particularly where there are steep slope aspect differences and ravines. Such topography is confined to the larger inselberg massifs of the Shield (eg. Mt. Singleton, Weld Ra., Jack Hills Ra.) and the Sedimentary Fold Ranges of the Gascoyne-Ashburton catchment (Table 3).

The degree of cloudcover and its occurrence daily and seasonally directly affects radiation and insolation values and thus the ranges of diurnal temperature variations, as well as air and ground moisture content. Generally average daily cloudcover across the region is sparse at less than 2/8ths, with number of cloudy days per month averaging between 0.5 and 3 (ABM 1998). Mean daily global radiation totals are highest between November and January (29-32 Megajoules/sq.m), and lowest in July (11-13MJ/sq m).

There are three superimposed climatic gradient patterns that operate across the region:

(1) the NW-SE banded precipitation pattern, composed of three rainfall regimes:

(a) winter frontal rains dominant in the W and SW towards the coast,

(b) central bimodal overlap zone,

(c) NE to eastern interior with summer thunderstorm rains dominant.

(2) a latitudinal gradient across nine degrees (21° to 30°S),

(3) maritime–continental gradient on a gradually ascending and faintly undulating regional relief profile from sealevel to the 500m contour 500km inland.

3rd Layer: The Geomorphic Landscape: Terrain Surface Diversity

Geomorphic or land surface diversity here includes landscape forms (Table 7), processes (Table 9), nature of the materials, relief (elevation and slope) and configuration in plan and profile. This is the base template that exerts far reaching fundamental influences on climate expression and landscape development affecting drainage, edaphic and vegetation patterns and thus biodiversity and land use.

There are four great landsurface recurrences across the region that mask the geological (rock type) diversity:

(1) Dunefields and sandsheets: coastal plain, Victoria and Kennedy plateaux, and inland the Tertiary planation surface and Little Sandy Desert.

(2) Salinity of breakaway footslopes (eg. Sherwood landsystem), and of bottomlands (mainly on the Shield).

(3) Stony gibber surfaces (mainly in the Sedimentary Fold Belt, the Shield, and the Interior Desert margin).

(4) Duricrusts of laterite and silica hardpan - the most widespread; calcrete (bottomlands) and locally gypcretes mostly marginal to saltlakes (kopi lunette dunes).

Geomorphic diversity is of two kinds in the region, those with

(i) pronounced relief contrasts and/or having varied rock types at the surface (topo-catenas), and

(ii) subdued relief with laterally contrasting soils in various patterns and degrees of differentiation from planation "cut and fill" processes eg. alluvial fans, deltas, washplains and near-surface occurrences of differentially weathered rock types in gently undulating terrain (plano-catenas). Hence the influence of different kinds of rock on plant species composition and distribution is typically confined to where they outcrop aerially, unaffected by regolith or salinity; eg. heaths on exposed edges of laterite duricrust along breakaway scarps

In the GMSA Region, there are successional land surface replacement sequences at all spatial scales in a fractal series from local through to regional dimension involving whole drainage catchments. Highest landsurface diversity thus occurs where different systems abut, interfinger or overlap; referred to here as ecojunction nodes. At the whole GMSA scale such nodal areas occur across the junction of geoecological regions, well exemplified in the north west where three regions meet; the belted coastal plain with the sedimentary fold belt and crystalline units (see Winning Pool-Minilya 1:250 000 geological map sheet SF 49-6/SF50-13). In the southwest of the GMSA five bioregions adjoin (Carnarvon, Murchison, Yalgoo, Geraldton Sandplain and Avon).

Enlarged colour satellite images best depict the complex of high land surface diversity that occurs around certain playa saltlakes and their surrounding pediment catchments where seasonal alternations of wind and water erosion and deposition occur (eg. west Lake Nabberu area on Ned's Creek Station). Ecojunction areas at district and local scales are easily identified on the rangeland landsystem map series where numbers of systems meet in circumscribed areas (eg. map in Payne *et al.* 1998).

The geomorphic and edaphic underpinning of process and pattern translates and orchestrates climatic influences through drainage, soil moisture balance and vegetation cover (eg. Wondzell *et al.* 1996, Tinley 2001).

4' Layer: Soil Type Diversity

Distribution of dominant soil groups mapped at the 1:3 million scale (Natural Resources Assessment Group 1995) derived mostly from land system mapping by the Rangeland Surveys shows three areas of highest diversity within a 100km radius (Fig. 15c):

(a) northern Carnarvon BioRegion centred on Winning Station with 11 groups,

(b) junction area of three BioRegions (Carnarvon-Yalgoo-Geraldton Sandplain) centred on the Toolonga Nature Reserve - 11 groups, and

(c in the Yalgoo BioRegion 9 groups centred on Pinyalling Hill (Thundelarra Station).

In summary, these station-by-station rangeland surveys recorded 62 soil types in eight soil groups of the Carnarvon Bioregion, 57 types in 12 soil groups in the Murchison, and 84 types in 12 groups of the Yalgoo-Paynes Find-Sandstone area (Payne et al. 1978; Curry et al. 1994; Payne et al. 1998).

The predominant soil groups over the remainder of the region covering vast areas are the red loams over hardpan (Litchfield & Mabbutt 1962), deep red sands, rocky and stoney soils and red duplex (sand over clay).

Table 7 Landform Genera and Types

(1) TERRAIN EMINENCES(ranges, ridges,inselbergs,escarpments including gorge scarp faces):
- (a) Peaks, Domes and Tors (eg. igneous rocks).
- (b) Fold Ranges (eg. Bangemall Sedimentary Series, Greenstone metamorphic suites),
- (c) Plateaux, breakaways, cuestas, mesas and buttes.

(2) PLANATION SURFACES:
- (a) Undulating Tertiary surface of red sand mantled laterite duricrust.
- (b) Hardpan Pediments (incl: footslopes, etch and wash plains).
- (c) Dunefields (ridges and troughs)
  - i. Coastline - pallid greyish-white to beige calcareous sands (Holocene Age).
  - ii. Desert - ferruginized red sands. (Late Pleistocene - last glacial hyperarid period).

(3) DRAINAGE, WETLANDS & WATER TYPES
- (a) Riparian Creeklines
- (b) Floodplains, deltas and fans.
- (c) Basins: saltlakes, claypans, billabongs, rockpools, river pools.
- (d) Springs, seeps/soaks.
- (e) Karst waters (calcrete, limestone and dolomite)
- (f) Artesian outflow (incl. moundsprings).
- (g) Mangrove and saltflat tidal wetlands.
- (h) Water types (limpid, turbid, blackwater/fresh, brack,saline, brine.

(4) COASTFORMS
- 4.1 Coastline in Plan
  - (a) Linear (Zuytdorp, delta coast)
  - (b) Curvi-linear with N-facing zetaform bays and spits (Ningaloo coast).
  - (c) Ria-type peninsula and embayed coast (Shark Bay)
  - (d) Gulf (Exmouth)
- 4.2 Soft Coasts
  - (a) Beach and Dune types
  - (b) Tidal mud/sand flats
  - (c) Estuarine/tidal lagoons and marshes
- 4.3 Hard Coasts
  - (a) Rocky shore
  - (b) Cliffed coast
  - (c) Nearshore Islands
  - (d) Coral Reefs (fringing and barrier types)

5' Layer: Ecosystems

Ecosystems are definable geographic unit areas in a nested heirarchy of scales composed of characteristic physical features and biotic components. In an ecosystem there are interactive influences between the physical and living parts as well as between organisms themselves. The terrestrial expression results from interactions between geomorphic, climatic, and edaphic processes and biotic activities that form landscapes of varying structure and composition. These range from the biome or ecozone level down through geoecological regions and drainage basin units to local ecotopes (Klijn & Udo de Haes 1994).

(1) Biomes/Ecozones

Biomes are the largest terrestrial ecosystem units occurring in latitudinal belts between the equator and the poles, and are arranged in altitudinal zonation sequences on high mountains (eg. Stocker 1964; Walter 1973; Olson et al. 2001).

The GMSA together with the adjacent Pilbara Region form the junction and overlap area of three major Australian biomes in the west of the continent. These are northern tropical monsoon (Torresian), central arid tropical to subtropical (Eremaean) and southern winter rain temperate (SW Bassian)(see Chapter 6 above).

(2) Geoecological Units: regions to local ecotopes

Terrain unit areas identified by their natural features, configuration and topographic position, are characterised by particular composites of geologic, geomorphic, climatic and vegetation features (see introduction to Ch. 4 above).

(3) Drainage Catchment Units and Wetlands

[A] Hydrologic Ecosystem Units

On land, the ecological unit area that identifies the minimum arena encompassing all process and response relationships between physical, biotic and human activities is the hydrolgic ecosystem ie. the drainage basin or catchment unit (Odum 1971; Lotspeich 1980; Tinley 1986, 1991b). The drainage basin and its tributary sub-units that are practically identifiable in the field, on maps and air photographs by their watershed boundaries are the intrinsic process arenas. In areic areas without surface drainage the process unit boundaries are identified by surface features such as sands, gravels, limestones and/or by distinct changes in the natural vegetation cover.

The five major external draining river systems in the region are the Ashburton, the Gascoyne, Wooramel, Murchison, and Greenough. The longest extant inland river system is Savory Creek at 270km straight line length to its Lake Disappointment endpoint in the Little Sandy Desert (Fig. 3). Exceptional floods and erosion are caused at irregular intervals by the passage of a tropical cyclone as recorded for the Ashburton River for example (Mitchell & Leighton 1997).

Large areic areas of sand sheets and dunefields occur between drainage tracts on the coastal plain, and inland on the sand mantled laterite duricrust remnants of the Tertiary planation surface that is broadest east of the central divide and in the dune sea of the Little Sandy Desert (Fig.3).

Stream capture and beheading of source tributaries by abutting steeper sloped catchments is actively occurring in many parts. Refer to 1:250.000 topographic and geological map sheets of Mt. Egerton, Glenburgh and Robinson Range sheets as examples.

Of the playa systems the largest are the MacLeod barrier lake (130 x 40km) on the Ningaloo Coast, Lake Disappointment (40 x 40km) in the Little Sandy Desert, and some of the linear playas that occupy palaeo-drainage valleys east and south of the main regional watershed, such as the Carnegie-Wells lakes, Barlee, Moore, Nabberu, Way, Annean, Austin, Noondie and Monger lake systems (Fig. 2). See also van de Graaff et al. 1980; Beard 1998, 2000; Commander 1989.

Geomorphic, hydrologic and ecological change is multidirectional with reciprocal effects transmitted upslope and downslope to the confines of the basin. Some changes are transferred across system boundaries along watershed divides as in stream capture or source truncation that shift the divide, and at drainage disharge areas in deltas, estuaries or endoreic endpoints. Landscape and ecosystem evolution in the region is mainly in response to the action of rainwater and changes in soil moisture balance resulting from interactive geomorphic, edaphic and vegetation successional processes adjusting to shifts in base levels at all scales between mouth and source (Fig. 11). See also Pringle & Tinley 2003.

[B] Arid Zone Wetlands:

Three major categories of wetlands occur in the region:

i) Saltwater (a) coastal tidal mudflats, estuaries or lagoons,
(b) terrestrial playas and saltpans,

ii) Terrestrial aquatic habitats - freshwater to brackish,

iii) Man-made eg. windmill tank overflows or leakage, artesian bores, dams and wells.

Except for perennial springs or soaks most of the surface waters in the region are of seasonal or episodic occurrence related to the advent of rain. Of the three water types (limpid, black and turbid) only the first and third occur. The tea-coloured blackwater type found in the southwest forest–heath country as well as in the Kimberley are apparently absent from the region except temporarily after first summer rains as in the Gascoyne River headwaters for example (John Forsyth, Three Rivers Station pers. com.). Limpid waters are typical of river and rock pools after flood sediments have settled, and turbid waters are typical of many claypans.

In the arid zone the longer lasting aquatic habitats are often the deeper rock pools of otherwise sediment filled creeks flooded at irregular intervals. Though surface waters remaining after flood ebb may initially be fresh, they can become increasingly saline as they are shallowed by evaporation and they may dry out completely. Many of these pools have little aquatic vegetation particularly in overgrazed areas.

The changes from flowing to still, or fresh to saline, or from flooded to dry, with poor or depeleted aquatic vegetation, makes a clear-cut or meaningful classification difficult if based on changeable properties of the wetland. In terms of the dynamic land surface processes and of habitat relationships the more permanent wetland defining features are its geomorphic features and topographic position in the drainage's longitudinal profile. This relates the aquatic habitat to a particular terrain setting, or container, and its geology and thus to different kinds of ponding or drainage environments.

(i) Saltwater Systems

On the coast, mangrove tidal flats and samphire marshes occur primarily in Shark Bay, mainly along the delta coast sector between the Gascoyne and Wooramel River mouths, and again along the southern and eastern margin of Exmouth Gulf (Semenuik et al. 1978; Johnstone 1990). A unique inland grove of mangroves occurs in the middle of the MacLeod barrier salt lake connected to the sea by a subterranean passage through limestone (Ellison & Simmonds 2003).

Estuarine or lagoonal conditions, including birrida pans, develop where shallow inlets on the Shark Bay peninsulas are in the process of being separated from bay waters by the growth and linkages of swashbanks and sandspits. Small lagoon environments are formed along the Ningaloo coast by sandbars across creek mouths, many of which are calcretized.

Depending on their size saline wetland systems on land (playas, saltpans and birridas or gypsic pans) are flooded episodically by exceptional rainfall events. In the flooded state many of the salt lakes that contain islands become important foci for bird breeding concentrations that include black swans, gull-billed terns, marsh terns, dotterels, banded stilts, black-wing stilts, red-necked avocets and hoary-headed grebes (Ron Johnstone, WA Museum pers. com. 2002). Salt lake vegetation that is typically zoned around lake margins in a haloclinal successional series is a rich and varied flora containing a number of endemic species that are confined to different parts of the region. There are two major saline land systems, the Warroora on the coastal plain (Payne *et al.* 1987) and the Carnegie inland (Curry *et al.* 1994, Pringle *et al.* 1994, Payne *et al.* 1998).

(ii) Fresh to Brackish Aquatic Habitats.

Apart from perennial springs and certain river pools most terrestrial aquatic habitats are only temporarily wet though they can last for several months or more depending on the incidence of rain. Natural thermal springs or mound springs as occur in South Australia (Harris 1992) are not reported from the region.

(a) *River and Creek pools:* Rock pools, scour pools, rock bars (riffle-pool alternation), outer curve pool (undercut bank position) delta wetlands (eg. Gascoyne marshes).

(b) *Basins and Drainage flats:* Billabongs of floodplains, claypans (eg. coast plain drainage of the lower Ashburton, Gascoyne and Wooramel Rivers), vertisol pans (cracking-clay or crabhole) characterised by the Roderick landsystem in the Murchison Catchment. An isolated area of panfields also occurs on the plains west of the Middle Murchison River divide across Curbur, Mt Narryer and Muggon Stations. Two unique wetland examples are the confluence-lake at Wooleen in the Roderick tributary near its junction with the Murchison River, and the Muggon chain of lakes along the palaeo-valley once occupied by the Upper Wooramel River. Seasonal wetlands of drainage flats and vertisol pans are also found in several other topographic positions, for example: (a) the source areas of the Gascoyne River and its Lyndon tributary, (b) along the hill footslope-pediment keyline contour, (c) in the outwash and fans between distributaries, (d) along the junction of pediment plains with bottomlands (Pringle & Tinley 2003).

(c) *Rocky outcrops:* karst including bottomland calcretes, gnamma holes, cave pools, waterfall plunge-pools, springs (eg. dipslope base of Mt Augustus, western cliff base of the Kennedy Range).

(iii) Man-made Waterpoints:

Despite an arid climate there are generally readily available supplies of stock-quality water within 30m of the surface across the GMSA (Payne *et al.* 1987, Curry *et al.* 1994, Payne *et al.* 1998). This has allowed for the proliferation of artificial waterpoints at high density, averaging approximately 5km apart (Fig 18).

In addition to water being available to fauna in troughs, leakage and overflow from windmills and tanks has provided perennial wet soil patches on which sedges and other plants have become established. Many animal species have become dependent on artificial waterpoints and these have become crucial to the survival of wildlife during heat waves and droughts. There have been first hand reports of "thousands" of birds dead around congested water points during severe drought and heat waves (Allan Humphreys, formerly leaseholder of Lake Mason Station and John Woods, formerly leaseholder of Waldburg Station pers. com. 2002).

Run-on pan habitats, and other ponding surfaces, which are replenished after even light rains, are lost where overgrazing has caused siltation and/or they are breached by headward erosion of gullies and then invaded by scrub. This is a major and critical landscape change in arid lands and has been verified in the GMSA from the low-level air surveys and ground traverses of the EMU Program (Plate 2b; and 6^{th} Layer 1b).

On the Carnarvon coastal plain, between 1880 and 1920 about 100 uncapped artesian bores were put in, accessing the Birdrong artesian aquifer. This has brought 100 years free-flow of hot (30^0 - 60^0C) brackish to saline water to the surface, outpouring some 9 to 14 million litres per day (Water & Rivers

Commission, Carnarvon 2002). These have formed local perennial aquatic habitats generally less than half to one hectare in size in sandy terrain, or 1km long creeks on harder terrain bared from heavy use by stock and feral goats.

(4) Vegetation Types (See Table 10 and Fig. 14)

Vegetation types are identified primarily by their physiognomic and floristic characteristics and related to terrain features (Beard 1975, 1976a, 1990; Hopkins 2000).

The highest diversity of vegetation types within 100km radii occus in four areas Fig. 10d (based on 1:1 million vegmap series of Beard loc. cit.).

(i) 26 types on the northern Carnarvon coastal plain bioregion centred on Winning Station.

(ii) 23 types centred on Meedo Station encountering the juncion area of four bioregions (Carnarvon-Geraldton Sandplain – Yalgoo – Murchison). Fig. 1c.

(iii) 16 types in the biome ecotone of the Yalgoo bioregion centred on Pinyalling Hill (Thundelarra Station).

(iv) 10 types inland centred on the Frere Range-east Naberu saltlake chain on Cunyu Station. Includes the area between Ned's Creek – Mt. Essendon (SW Little Sandy Desert) – Earaheady – Wiluna.

In contrast at the larger 1:250 000 scale on the Ajana map sheet, 27 floristic plant associations are recorded by Beard (1976) in the junction area of three bioregions (Geraldton Sandplain – Carnarvon – Murchison - Yalgoo). The vegetation types and their patterns of occurrence in a state-wide context is synthesized by Beard (1990).

(5) Catena Complexes: Land Types, Landsystems and Land Facets

These are geoecological catena units characterised by particular combinations of landform, geology, soils, vegetation and drainage in a recurring pattern (Christian & Stewart 1953). Each land type is made up of one or more land system variants in which terrain surface, source rock and/or vegetation is different, within the same generic terrain-form and topographic position in the landscape. In turn landsystems are composed of lesser land units or facets. Together these form catena complexes. The hierarchy of component parts are identifiable on aerial photographs. This terrain catena approach is the method used primarily to map the pastoral lands of Australia, including the GMSA by means of airphoto interpretation and station-by-station survey on the ground (Mabbutt *et al.* 1963; Wilcox and McKinnon 1972; Payne *et al.* 1987,1988; Curry *et al.* 1994; Pringle et al. 1998; Payne *et al.* 1998).

To identify where the highest diversity of land systems occur in the GMSA a 10x10km grid was GIS superimposed over the colour coded land system maps produced by the above surveys. In each 100 sq km cell those with ecojunctions of 6+ landsystems were recorded (Fig. 16). This shows the highest diversity areas to be concentrated in the south central part of the Murchison and adjoining

Yalgoo bioregions. This is a broadly undulating varied terrain of internal drainage south and east of the main regional watershed. Here catena mosaics are densely interspersed due to the close juxtaposition of rocky hills, breakaway scarps, pediment washplains and alluvial tracts abutting zoned shoreline vegetation around saltlake bottomlands.

Elsewhere in the region local high diversity of land systems occurs where lines of rocky hills and their outwash valley plains are traversed by major creeks (eg. 10 landsystems centred on (a) Errabiddy Homestead; (b) Mt. Egerton; (c) Williambury Homestead; and (d) Mia Mia Station. The use of landsystems as surrogates for biodiversity conservation planning has recently been validated by Oliver et al. (2004) from their Sturt National Park research in the arid northwest of New South Wales.

6th Layer: Landscape Processes and Patterns (See Table 9)

[A] Key Ecosystem Processes

Three fundamental succcessional processes in the GMSA result from the dynamic interaction between particular physical and biotic components. These are rainwater, erosion, fire, plants and the animal components. The latter include both introduced ungulates and the native berry birds. Each affect changes in the others directly or via feedback loops resulting in ecosystem or habitat transformation and hence cascading effects in structure and function. Landscape processes as orchestrating determinants of biodiversity (Smith et al. 1993), and as values in planning (Mc Harg 1969) and management (eg. Ludwig et al. 1997) are generally omitted from conservation assessments for reserve selection.

The first is progressive succession where simpler habitats become more complex in structure, function and composition. This might be merely an advance in plant life-form dominance from herbaceous to woody. The second, regressive succession, is where mature complex habitats are degraded and simplified back towards a weed or bare ground stage. Third, 'to and fro' or return succession is typified by the fire-induced shifting sequences in wooded grasslands and the repeat process in the spinifex hummock grasslands. Examples of each are noted below.

(1) Progressive Succession

In the GMSA the advance sequence is mediated by four main geoecological processes:

(a) berry-bird formed bushclumps and thickets

(b) unplugging and desiccation

(c) fire

(d) overgrazing.

(a) Berry bird formed bushclumps and thickets.

A characteristic feature across GMSA landscapes is the dot pattern of the vegetation cover (Plate 1c) which also extends into, or is superimposed onto, riparian and other patterns (eg. Plate 1d). This is a primary advance succession that results in the development of bushclumps or thickets beneath individual trees or shrubs. The bush clumps are classically bird-formed and are an apparently unrecognised keystone habitat component of the Australian arid zone. Soon after my arrival in Australia in 1984, I encountered bush clump habitats when on a traverse across the Central Desert between Leonora and Uluru. The bush clumps are composed predominantly of plants that produce berries or arillate seeds that are eaten by birds. In the GMSA the bush clumps are widespread and abundant beneath perch trees which are typically established trees or large shrubs whose seeds were originally dispersed by other means (Plate 1 a,b).

Berries or seeds with conspicuous coloured arils that are typically displayed whilst still attached to the parent plant are identified as adaptations for primary dispersal by birds (Ridley 1930, van de Pijl 1969). Seeds with small pale yellowish or white elaiosomes that drop to the ground are typical of those dispersed by ants. However both are also subject to transport by wind, water or other ground-foraging animals.

Though generally small in size and absent in unwooded habitats, the berry-bird formed bushclumps are the major archipelago habitat pervasive across both arid and monsoonal Australia (pers. rec.). In size bushclumps are highly variable, from several small plants beneath the perch through to dense tall thickets composed of up to seven or more baccate species.

Of the 63 woody plant species preferentially browsed by ungulates in the GMSA (as determined from Mitchell & Wilcox 1994), 25 (40%) are typically bird dispersed to perch-based sites (mainly live trees). Five (8%) of the clump components have wind dispersed seeds (that can also be carried by water) that lodge against the clump obstruction and mature within the perch tree's protection as do the others ('nurse effect').

A total of 65 berry plant species (excluding arillate acacias) from 26 Families have been recorded by the author from across the GMSA. There are also 135 acacias (Mimosacae) whose seed have arillate or elaiosome funicles (Bruce Maslin, WA Herbarium pers. com. 2002). The berry or berry-like (baccate) fruit forms vary in size from 20 to 30mm diameter (eg *Santalum acuminatum*, *S. spicatum*), down to 2 or 3mm in certain chenopods (eg. *Rhagodia* spp.).

In addition to those bird dispersed plants noted for Plate 1 other examples include: *Acacia coriaceae, A. ligulata, Alectryon oleifolius, Brachychiton gregorii, Canthium spp., Capparis spinosa, Clerodendrum floribundum, Ficus platypoda, Jasminium lineare, Loranthaceae, Lycium australe, Myoporum montanum, Pittosporum phylliraeoides,* and *Stylobasium spathulatum.*

Perching berry-birds are directed dispersal agents; taking seeds directly to perch-sites (eg. Ridley 1930, Tinley 1977, 1985). Likewise, ants carry elaiosome seeds to the nest (Davidson & Morton 1984). Emu are important dispersal agents of seeds, however these are usually excreted between clump areas and often near water (Davies 1978). Elsewhere in the arid zone, a large number of birds are recorded taking berries and arillate seeds (Forde 1986).

In the GMSA, two wide-spread omnivorous birds, spiny-cheeked honeyeater (*Acanthagenys rufogularis*) and singing honeyeater (*Lichenostomus virescens*), are important seed dispersers that are found in, or move through, virtually all habitats. As they both pollinate and disperse the seeds of berry trees such as *Eremophila longifolia* their role is referred to as doubly-ornithochorous (Forde 1986). Berry-bird bush clumps are formed beneath tree and tall shrub canopies in the majority of vegetation types including chenopod shrubland, sandpine, and in the fire-prone spinifex grasslands with desert sheoak (*Allocasuarina decaisneana*) overstorey, and eucalypt trees or mallees. In the GMSA bushclump archipelagoes are common on calcareous coast sands and dunes, on alkaline duplex soils as exemplified by snakewood (*Acacia xiphophylla*) scrub savanna, and in eucalypt woodland on textured base-rich soils (Plate 1a,b,c).

Many perch-trees are the nitrogen-fixing acacias, the majority of which are re-seeders; the bush clump components are resprouters and thus have a contrasting response to damaging effects. The former are particularly prone to death from water starvation where sheetwash recharge of soil mosisture is interrupted by roads or fencelines.

In summary, this progressive bird-mediated succession results in changes of cover, pattern and structure, function, composition, productivity and resilience. Their presence and intact condition in pastoral country is used by the EMU Process as one of the indicators of habitat health and integrity. It is an enrichment process in archipelagoes of fertile patches that enhance favourable conditions for the dispersers and other bushclump dependents as well as the carrying capacity for ungulates.. These archipelagoes may remain separate or, under favourable conditions, expand and coalesce into larger patches as they do on the Shark Bay peninsulas.

(b) <u>Unplugging and desiccation</u>:
An insiduous process widespread across the GMSA, with far reaching implications in ecosystem health and integrity, is the loss of run-on ponding surfaces due to breaching of their sills by the headward erosion of gullyhead nickpoints (Plate 2b), or are filled-in by sediment. Both processes cause soil desiccation resulting in what was a rain water holding habitat with green grassy growth (Plate 2a) being replaced by dry land scrub thickets, typically of karara (*Acacia tetragonophylla*). Similarly nickpoint incision and guttering of alluvial grass flats and of chenopod shrublands entrains their eventual replacement by scrub. The former by unplugging and hence reducing effective flooding and waterlogging responsible for their pure grassland form. The latter by fragmentation and stripping of topsoils, all of which change the soil moisture balance towards the xeric (Tinley 2001; Pringle & Tinley 2003).

Table 8. Ground and Near-Ground Foraging and/or Nesting Birds in the GMS Area.

Non-aquatic birds that forage and/or nest mostly within 2m of the ground (as determined from Pizzey & Doyle 1983, Johnstone & Storr 1998, Ron Johnstone pers.com. WA Museum) ie within the shrub and groundlayers, the habitat most susceptible to modification by stock, feral goats, fire, erosion and within reach of fox predation. (Nomenclature after Johnstone 2001).

Casuariidae
- Emu

Megapodiidae
- Malleefowl

Phasianidae
- Stubble Quail
- Brown Quail

Otidae
- Australian Bustard

Rallidae
- Black-tailed Native Hen

Turnicidae
- Painted Button Quail
- Little Button Quail

Burhinidae
- Bush stone-curlew

Charadriidae
- Banded Plover
- Inland Dotterel

Glareolidae
- Australian Pratincole

Columbidae
- Peaceful Dove
- Diamond Dove
- Bar-shouldered Dove
- Common Bronzewing
- Crested Pigeon
- Spinifex Pigeon

Psittacidae
- Pink Cockatoo
- Red-tailed Black Cockatoo
- Bourke's Parrot
- Budgerigar
- Cockatiel
- Elegant Parrot
- Galah
- Little Corella
- Mulga Parrot
- *Night Parrot
- Port Lincoln Parrot
- Princess Parrot
- Scarlet-chested Parrot

Cuculidae
- Black-eared Cuckoo

Centropodidae
- **Pheasant Coucal

Caprimulgidae
- Spotted Nightjar

Halcyonidae
- Red-backed Kingfisher

Meropidae
- Rainbow Bee-eater

Climacteridae
- Rufous Tree-creeper
- White-browed Tree-creeper

Maluridae
- Splendid Wren
- Variegated Wren
- Blue and White Wren
- Rufous-crowned Emu-wren
- Striated Grass-wren
- Thick-billed Grass-wren

Pardalotidae
- Redbrowed Pardalote

Acanthizidae
- White-browed Scrubwren
- Redthroat
- Fieldwren
- Broadtailed Thornbill
- Chestnut-rumped Thornbill
- Slate-backed Thornbill
- Yellow-rumped Thornbill
- Samphire Thornbill
- Banded Whiteface
- Southern Whiteface

Meliphagidae
- Black Honeyeater
- Grey-headed Honeyeater
- Yellow-fronted Honeyeater
- White-fronted honeyeater
- Crimson Chat
- Orange Chat
- White-fronted Chat

Petroicidae
- Hooded Robin
- Red-capped Robin
- Southern Scrub-robin

Pomatostomadae
- Grey-crowned Babbler
- White-browed Babbler

Cinclosomatidae
- Chiming Wedgebill
- Chestnut Quail-thrush
- Cinnamon Quail-thrush

Pachycephalidae
- Crested Bellbird

Dicruridae
- Magpie Lark

Campephagidae
- Ground Cuckoo-shrike

Cracticidae
- Australian Magpie

Sylviidae
- Little Grassbird
- Spinifex Bird
- Rufous Songlark
- Brown Songlark

Alaudidae
- Singing Bushlark

Passeridae
- Painted Firefinch
- Starfinch
- Zebra Finch

Motacillidae
- Australian Pipit

*Now considered extinct in pastoral areas at least.

**Moist tropical species with western south range limit coastal to Minilya River in recent past. Range now contracted back northwards to Ashburton River.

Whilst most such depressions only hold potable water for several months after rains and may dry out completely during droughts, nevertheless together with the more permanent springs, deep rock pools and billabongs they are arid zone keystone habitats. These indispensable, moister, more dependable, fertile habitat patches ('sweet spots') also function as drought refugia. But with the introduction of foreign herbivores, native animals have had unequal competition for this key arid-land resource (Morton 1990,; Morton et al. 1995; Stafford Smith & Morton 1990). Ponding surfaces are typically isolated from one another even within the same floodplain system. However, as these 'sweet spots' are a focus for all grazing mammals they become connected to each other by stock pads, particularly the deeper more incised pads of cattle which habitually walk in single file. When heavy rains occur these erode linking up the depressions, breaching their sills thus causing their demise.

In a similar way pervasive landscape desiccation across the GMSA is caused by the artificial 'rivers' of vehicle tracks, roads, and graded fencelines that act as channels for excessive run-off loss of rainfall and are a major cause of fragmentation-coalescence erosional processes.

(2) Regressive Succession

(a) <u>Reverse succession</u>:

Best exemplified by the fragmentation and coalescence process of ecosystem or habitat transformation and replacement (Plates 2 to 4; Fig. 11). This involves two related phenomena: (I) overgrazing causing baring of the field and groundlayers with topsoil stripping, and (ii) landscape desiccation from breaching of ponding surfaces by erosion incision, and excessive run-off loss of rain water along track/road, fenceline and stock pad "creeks".

Fragmentation starts with opening up and depletion of plant cover in patches resulting in the baring and erosion of topsoils by sheet and rill erosion (also wind). This is either due to (i) gully incision which lowers the local base level causing excessive and rapid runoff that results in erosion and water starvation of the area upslope of the gullyhead nickpoint (ie. system becomes unplugged); and /or (ii) groundcover and fieldlayer depletion due to overgrazing and the break-up of topsoil by hoof action. Either or both of these result in the stripping of friable topsoils exposing the subsoil as the new land surface. As the bare patches enlarge and coalesce, they leave decreasing sized fragments of the original soil-plant system (Fig. 11; Plates 2 to 4).

The bare patches of textured subsoil exposed at the surface are typically hard and water-shedding. They may become salt-scalded as well with soft saltpuff patches. Both conditions are inimical to the continued survival of perennial plants, including the chenopod shrubs, which die from water starvation, excess salinity, or both.

Continued expansion of the topsoil stripping process becomes self-perpetuating as the area of bare-patch catchments enlarge. Enlargement increases runoff volume and multiplies its erosive power. Eventually, a critical threshold is reached such that erosion continues even with greatly reduced stock numbers. Unless it is arrested naturally, or by intervention, this process sequence continues until the greater part of the affected area is denuded (Plates 2c, 3d, 3e). A downward spiral of biopauperization leads to the demise of the original ecosystem. Denuded scalded flats can remain bare for many decades, even without the presence of stock (Curry et al. 1994, photos 2-6, pp. 351-352).

However, even when eroded down to the hardpan, the bare condition is a geoecological process stage in landscape development, not an end point. When these denuded planar surfaces are incised or guttered by rill and gully erosion, the soil moisture conditions and excess salinity are ameliorated by the channeling of rain runoff along the incisions.

Following this ameliorisation, scrub encroachment and colonization of the denuded area takes place along the erosion gutters, resulting in a stage of progressive succession towards re-diversification but of a different scrub dominated system (Fig.11; Plate 4d). Expansion of gullies headwards and laterally entrains the spread of scrub cover resulting in a scrub dominated ecosystem replacing the original chenopod ecosystem. (Plate 3a ; Fig.11).

The major habitats affected are those supported by duplex soils of various kinds. They include floodplains, the chenopod shrublands, bottomland alkaline textured soils, as well as the mulga loams and wanderrie sand fans over hardpan of the pediplains (Plates 2 to 4). With their thin friable topsoils chenopod shrubland habitats, in even the slightest perched situation above the surrounding terrain, are most susceptible to dissolution and replacement.

It is the sandy topsoil that is the critical rain-absorbing surface. Once stripped off, the soil moisture balance is changed to the xeric. This results in the demise of the perennial grasses. Water starvation causes dieback in the mulga, as well as the perch-trees of bird-formed bushclumps that have been left on remnant mounds of topsoil protected beneath them when the surrounding inter-patch areas are lowered by sheet erosion.

(b) <u>Over-grazing induced habitat degradation:</u>

The breakdown of habitat form, structure, and plant species composition is in the main caused by the interaction between heavy selective grazing pressure and erosional and edaphic processes. This results in the opening up and depletion of the ground and field layers below 2m, and hence depletion of recruitment (except of unpalatable species). A self-reinforcing cascade effect is entrained whereby bare areas spread and coalesce causing biopauperization and loss of pastoral integrity.

The preferred woody plant browse species that at present exhibit little to no recruitment across most of the GMSA include: *Santalum* (4spp.) *Brachychiton gregorii, Alectryon oleifolius, Acacia sibilans, Eremophila longifolia, E. oldfieldii, Canthium* (3spp.), *Erythrina vespertilio, Pittosporum phylliraeoides* and *Acacia grasbyi* and *Scaevola spinescens* in some areas (pers. rec. from EMU traverses).

Grazing pressure is hugely exacerbated where the grazing zones (piospheres) of 5km radius around permanent water points are close to 5km apart and hence overlap (Fig.18). As this figure shows, a major cause of landscape degradation in the GMSA is that the permanent artificial waterpoints are too close together (eg. Plate 3 d, e)(Landsberg et al. 1997; James et al. 1999).

The typical habitat simplification process caused by a legacy of overgrazing by sheep in the GMSA is the selective depletion of the palatable lower shrub (<2m) and groundlayer plants. Increasing conversion to cattle on many stations has further compounded the problem as has the widespread depredations of large feral goat populations (Woolnough & Martin 2003), the far reaching impacts of which are generally underestimated, as is their quite different physiology (MacKenzie 1957) compared to sheep and cattle. Vast areas of the middle Gascoyne catchment, for example, that once supported chenopods, grasses and snakewood (*Acacia xiphophylla*) now support dense low shrublands of secondary growth unpalatable eremophilas *(E. cuneifolia, E. fraseri*) and cassias (*Senna helmsii, S. luersseni*) in even aged/size stands.

Over large areas then all that is left is the out-of-reach top layer scrub. A 'standing dead' predicament due to the absence of younger replacement sequences, and the elimination or supression of any recruitment except for unpalatable 'woody weeds'. Congruent with this opening up of vegetation and baring of the ground is the loss of water absorbent sandy surfaces, the litter layer and also of the important cryptogamic crust (Eldridge & Greene 1994, Belnap 2003).

'Canary in the mine' indicators of scrubland habitat change are birds that forage and/or nest on or near the ground of which 83 species occur in the GMSA (Table 10). Assessment of the conservation status of arid zone birds across Australia by Reid & Fleming (1992) show those groups most adversely affected by habitat disintergration include: (a) the three small passerine familes of wrens, thornbills and their allies, and the quail-thrushes, (b) cockatoos, parrots, doves and pigeons amongst the non-passerines, and (c) those associated with chenopod shrubland habitats (eg. redthroat, white-winged fairy wren and rufous fieldwren). In the GMSA spotted nightjar and bush stone-curlew (both ground nesting) are rare to extremely rare in my experience.

Reid & Fleming (1992) make the point that in the absence of widespread regeneration of ground cover and field layer "the next major drought could cause accelerated declines and extinctions". See also Recher (1999).

On the other hand species such as the plover, dotterel, pratincole and pipit, which show preference for bared, sparsely vegetated terrain, have a hugely expanded habitat area.

The cascading effects of the habitat impoverishment process reaches through changes in structure, composition, productivity, and hence carrying capacity, to impact on economic and sociocultural viability and wellbeing (see Ch. 10 below).

The fragmentation-coalesence process is insiduous and can easily escape notice because the full extent and severity of the damage can only be judged from the air. From a ground view perspective the eye is easily tricked by the remnant strips and patches of vegetation as this gives a benign, covered appearance to the landscape. By means of secondary scrub encroachment the reverse succession is turned around progressively to dominance by scrub.

(3) Fire-induced 'To and Fro' or Return Succession:
A 'to and fro' fire induced selective succession is imposed over time on wooded grass savannas enchancing either the grass layer or the woody strata at the expense of the other depending on the coincidental timing of a number of factors. These factors include height and density of the grasslayer, seasonal timing and weather (RH%, wind), fire intensity, soil moisture status in regard to the moisture competition between grasses and woody plants (Walter 1964), post fire conditions whether followed by drought or rain, impact or absence of grazing pressure, whether the woody plants are mainly resprouters or reseeders, and whether long enough absence of fire has allowed recovery of the woody components.

Longterm burning experiments in the moist to mesic ecologically equivalent savanna woodlands of Africa (Trapnell 1959) and the Top End of Australia (Rose 1995, Dyer et al 2001) show an increase of woody plants from no burning and cool early dry season burns, and the converse of grass sward expansion and dominance from hot late dry season burns that damage or kill woody plants in the peak of pre-rain spring flush and select for fire tolerant and coarser grasses.

Like overgrazing, fire can, under certain conditions, entrain a progressive succession from predominantly grassland to woodland or thicket. Conversely when hot burns are frequent, transformation can be from wooded savanna to predominantly grassland with woody coppice survivors at or below the grass canopy. Over time this leads to changing habitat structure, composition and diversity between extremes of a grassland or dense woodland or thicket whose plant components may comprise one or a few dominants.

The highly flammable spinifex hummock grasslands exhibit a return succession in which annuals and short-lived perennials flourish during the several seasons following the advent of fire before the spinifex reasserts a near total dominance of cover (Burbidge 1943, Suijdendorp 1967). Depending when rains occur, the post-fire succession is mainly of *Asteraceae* and other herbs with winter rains, and of grasses with summer rains. In wooded terrain a shifting threshold of dominance between spinifex (or wanderrie grass swards) and wattles for example occurs depending on the timing of fire and rains, and of shade effects from the development of a dense scrub canopy from maturation of coppice regrowth or mass germination of wattle seedlings that typically exhibit an even aged/size structure and single species dominance.

The introduced tufted buffelgrass is invading many habitats such as riparian woodland, chenopod shrubland, bottomland bushclump habitats that naturally would rarely if ever experience fire. When ungrazed, buffelgrass poses a major fire threat to the above habitats but is revitalized itself and thus becomes the predominant cover as has occurred on a calcareous sand plateau south of the Cape Range, where the woody plants have been mostly eliminated. The negative influence of buffelgrass on native flora and fauna is recorded from Western Australia (Piggott 1995) and Queensland (Hannah &Thurgate 2001; Franks 2002).

Process Summary Points:
These natural and imposed landscape processes are of direct significance to developing effective biodiversity management action guidelines for the CALM acquired stations and the ecojunctions of high landscape diversity areas (Fig 17, Table 11). A recommendation here is also for each station to establish ecojunction exclosure paddocks as a conservation strategy (Ch. 10.3).

Except for saltlake margins, fire-prone ungrazed buffelgrass and spinifex areas, longterm succession is towards eventual dominance by scrub. This means the demise of wetlands, alluvial grasslands, and chenopod shrublands (in perched terrain positions) accelerated by the legacy of overgrazing erosion and the ongoing excessive runoff of rainfall from eroded and scalded terrain and the plethora of tracks, roads and fenceline "creeks".

As these eroded areas enlarge they become self-generating hence merely destocking and fencing-off may be quite inadequate. A first management action therefore is to apply on-ground measures to slow down rain runoff, and turn it back into the natural drainage lines. As a habitat protection measure against uncontrolled fires in conservation areas the occasional agistment of cattle herds to graze down buffelgrass may be required.

PLATES

1. Bird & Sheetwash formed habitat patterns.

2. Rainwater movement across the landscape.

3. Fragmentation & coalescence geoecological successional processes.

4. Breakaway fragmentation & coalescence sequence (clockwise).

PLATE 1: Bird and sheetwash formed habitat patterns.

(a) Berry-bird formed bushclumps beneath perch trees of southern snakewood *Acacia eremaea* over baccate or arillate fruited shrubs of *Acacia tetragonophylla, Chenopodium gaudichaudianum, Dianella revoluta, Enchylaena tomentosa, Rhagodia eremaea* and the grass *Stipa elegantissima* (wind/water dispersed).

(b) Bushclumps or thickets beneath coolibah *Eucalyptus victrix* trees on floodplain alluvia. Bird fruit components include *Acacia sclerosperma, A tetragonophylla, Enchylaena tomentosa, Exocarpos aphylla, Pimelia microcephala, Rhagodia eremaea, Santalum murrayanum, S. spicatum, Scaevola spinescens, Spartothamnella teucriiflora* and *Eremophila laanii* (water dispersed).

(c) Berry-bird formed dot pattern of *Acacia sclerosperma* bushclumps on red sand over calcrete soils, around a claypan with flood-ebb concentric zonation of chenopod shrubs.

(d) Sheetwash formed stripe pattern of mulga woodland contour litter trains on pediplains. Sheetwash direction is normal to the stripes. Functionally positive conditions are indicated by accretion of sediment (pale deposit fringe) along the upslope margin of the wooded band, and sharp-edged along the eroding downslope side. This photo is an example of the negative or downgrading condition showing the reverse deposition pattern due to change from run-in to erosive run-through of wash across the wooded strips.



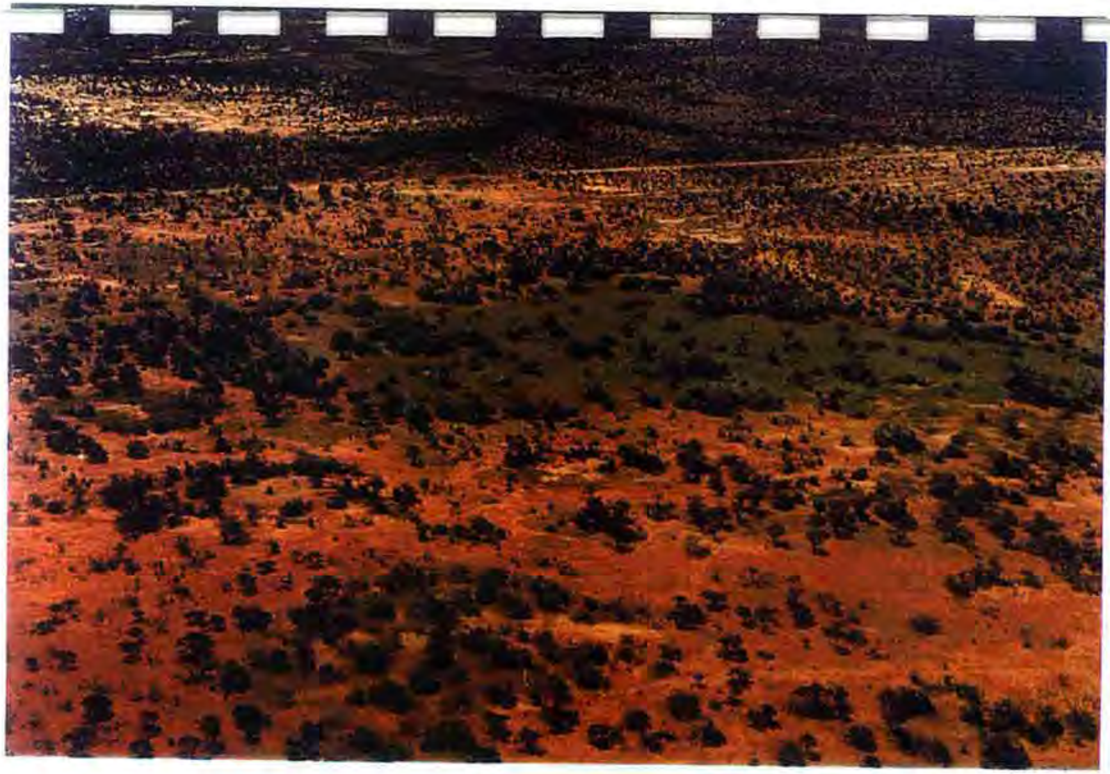

PLATE 2: Rainwater movement across the landscape.

(a) The indispensable habitat in arid lands – ponding surfaces of all kinds that hold rainwater and remain greeener longer than the surrounding country. A dot bushclump landscape both on the claypan and its surrounds. This claypan is in good condition, neither breached nor silted up.

(b) Gullyhead nickpoint eroding upstream poised to breach the pool rim and convert the freshwater container and its green herbage into the hardpan surface of the foreground. The erosion process desiccating landscapes that is rife across the whole GMSA. On the left behind the acacias, chenopod shrubland perched above the watercourse level hence susceptible to being eroded and fragmented as the stream incision continues upslope and laterally.

(c) Air view upstream of a valley plain with fragmented acacia woodland cover, and enlarging and coalescing bare areas. The 'staring stage' Scrub increasingly confined to the immediate watercourse, and faint depressions, with scalded patches (centre of photo on eitherside of the creekline).

(d) Ground view of the same area showing mulga woodland without middle or lower layers ie. 'standing dead' – no recruitment or replacement growth, stripped topsoils exposing gravel lag on the subsoil surface.



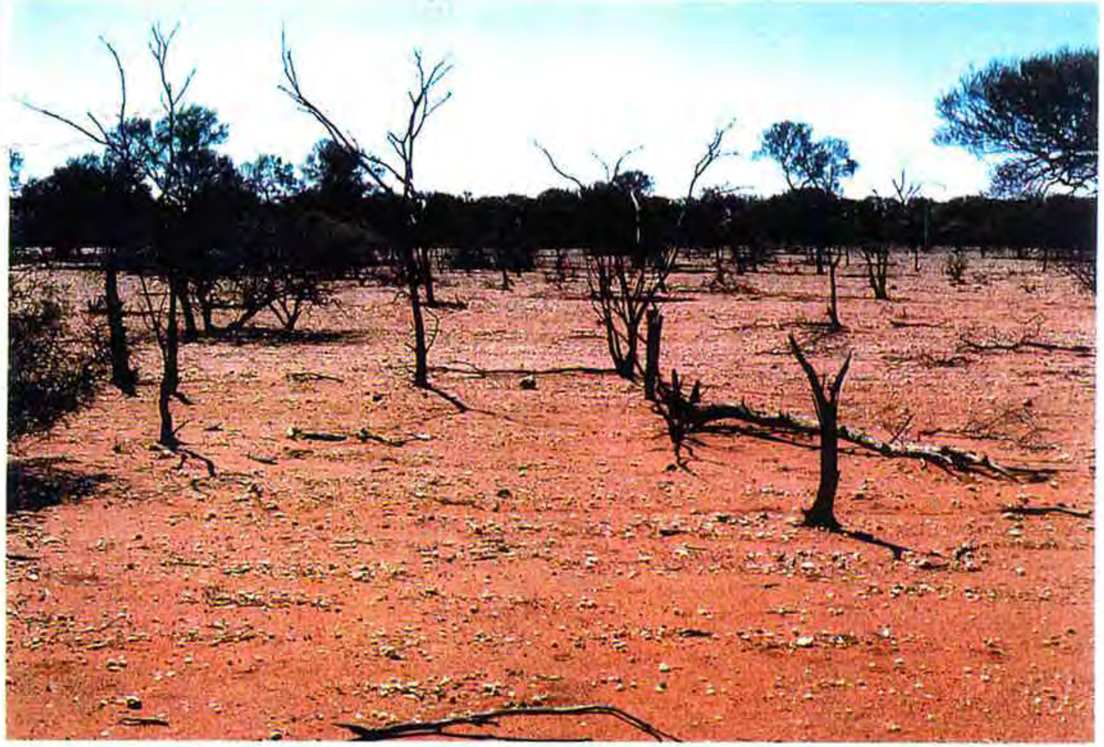
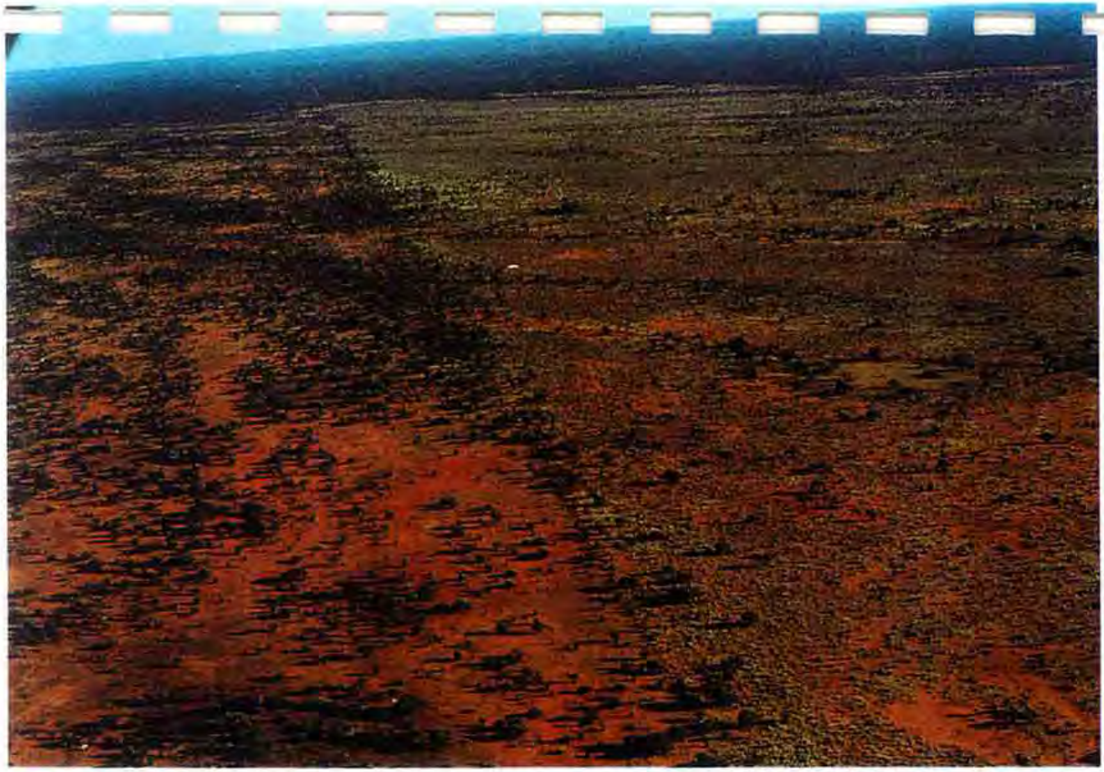



PLATE 3:Examples of the fragmentation and coalescence geoecological successional process:

(a) Fenceline effect: sheetwash plains draining from left to right with local claypan endpoints. Chenopod shrubland at right originally covered all the faintly rising terrain to the left. Historical overgrazing in the left paddock resulted in stripping of topsoils, exposing the compact subsoil over hardpan leading to the demise of chenopod shrubland and its replacement by acacia scrub woodlands.
(b) Lower pediment washplains sandfan zone (wanderrie banks): Grey areas are perennial tufted grasslands on a sand mantle of up to 1.5m depth over shallow compact loam subsoil on hardpan (red areas) exposed at the surface by erosion of the sand cover. Grassland in process of being eliminated and replaced by scrubland. A typical first colonizer of exposed subsoil areas is the unpalatable turpentine bush *Eremophila fraseri*,. Acacia trees occur on the intermediate thinning sand areas.
(c) Floodplain chenopod shrubland in good to excellent condition with mostly intact topsoils and claypan islands of bushclump thickets. Note bare patch initials of lost topsoil and chenopods in upper part of photograph.
(d) Mosaic of wooded and chenopod shrubland at the 'staring stage' of fragmentation affecting first the most sought after chenopod pasture areas, their demise and replacement by bare scalded surfaces that enlarge and coalesce. The proliferation of saltpans and claypans by water and wind erosion is also a consequence of this surface replacement sequence, which in time may be colonized by scrub.
(e) Airview of the next stage of the fragmentation – coalescence process on floodplains. Topsoils mostly stripped, leaving small fragments within a large area of scalded subsoils now forming the new surface. Virtual total loss of the chenopod habitat. In time rill and guttering erosion will enable scrub colonization by species such as *Acacia victoriae, Eremophila fraseri, E. pterocarpa, Hakea preissii* and *Senna desolata*.



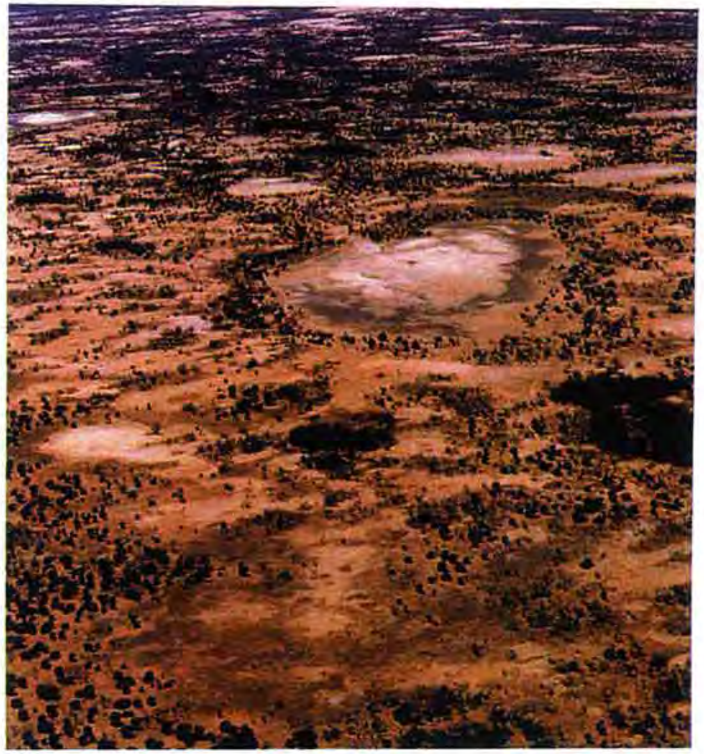
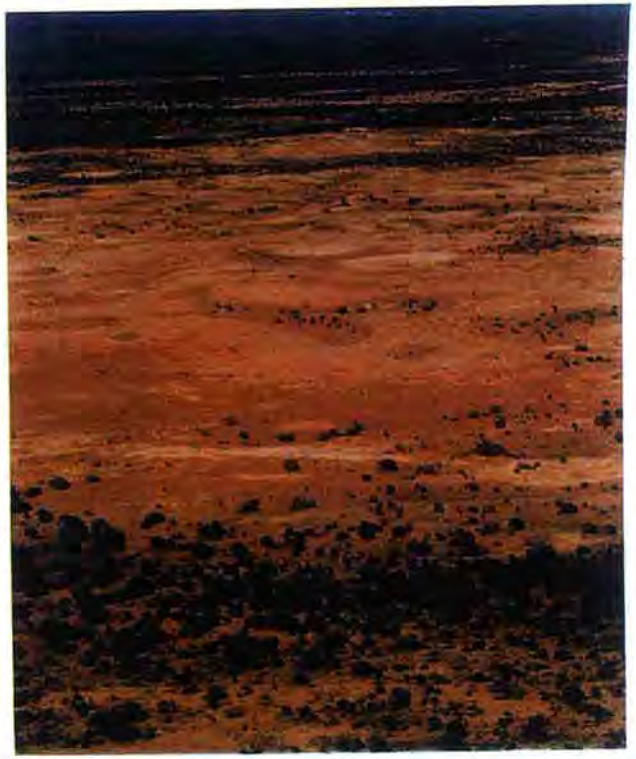
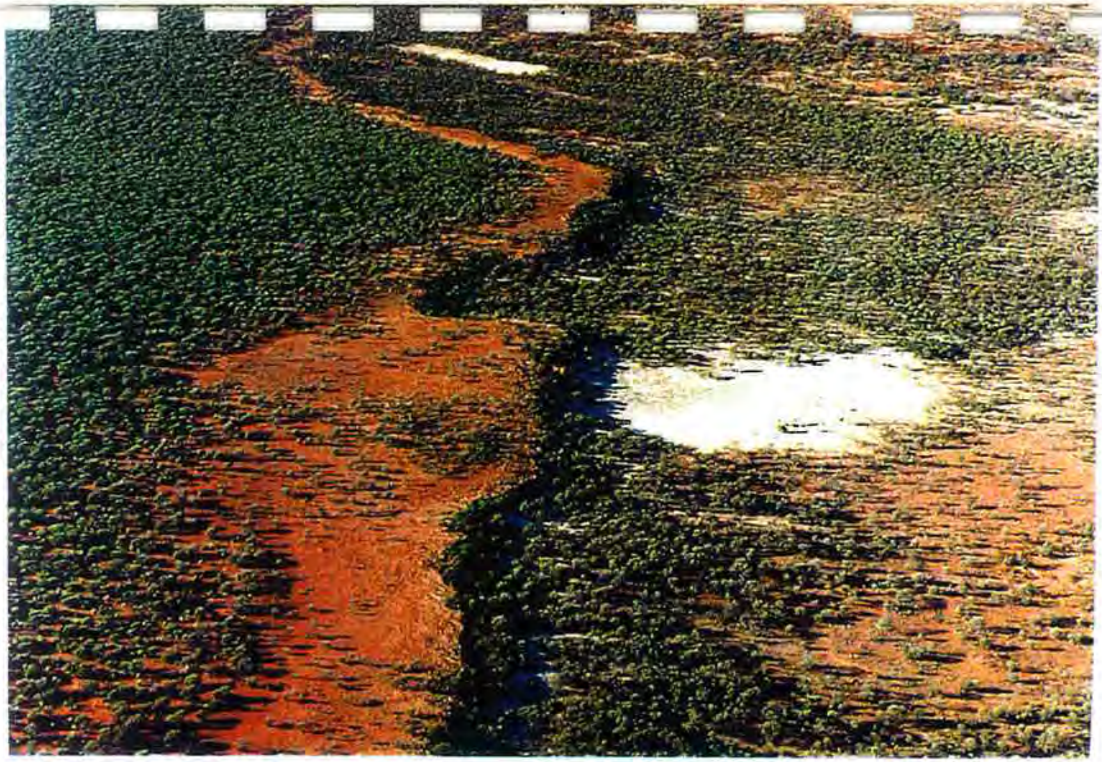




PLATE 4: Breakaway fragmentation and coalescence sequence (clockwise).

(a) Breakaway with two bare saline kaolin initial patches that likely once supported chenopod shrubland. The wooded footslope below the scarp is typical where the red sand mantle over the laterite is naturally eroded off the top of the scarp and deposited below over the saline duplex of the footslope.
(b) Expansion of the initial topsoil stripped patches on scarp footslopes involves the whole tributary unit of dendritic drainage off the breakaway. Sandplain woodland above the breakaway predominantly bogoda/wanyu *Acacia ramulosa/linopylla* with mulga, sandpine and mallees (2 - 8m height).
(c) Lateral coalescence of drainage heads below the scarp. Surface stripped areas white leaving 'grey' remnants of topsoil held by the low grass *Eragrostis dielsii*. Note widened sand stripped margin above the escarpment exposing laterite at the surface. An important habitat for heaths, but highly impacted by feral goats.
(d) Almost total elimination of the pediment topsoils, scalded gritty subsoils at the surface with remnants of grass (grey patches). Scrub remaining on red sand veneered footslope (bottom right) and in the gully incisions which they also colonizing. Note laterite remnant of old Tertiary planation surface stripped of its red sand mantle and eroding scarp..



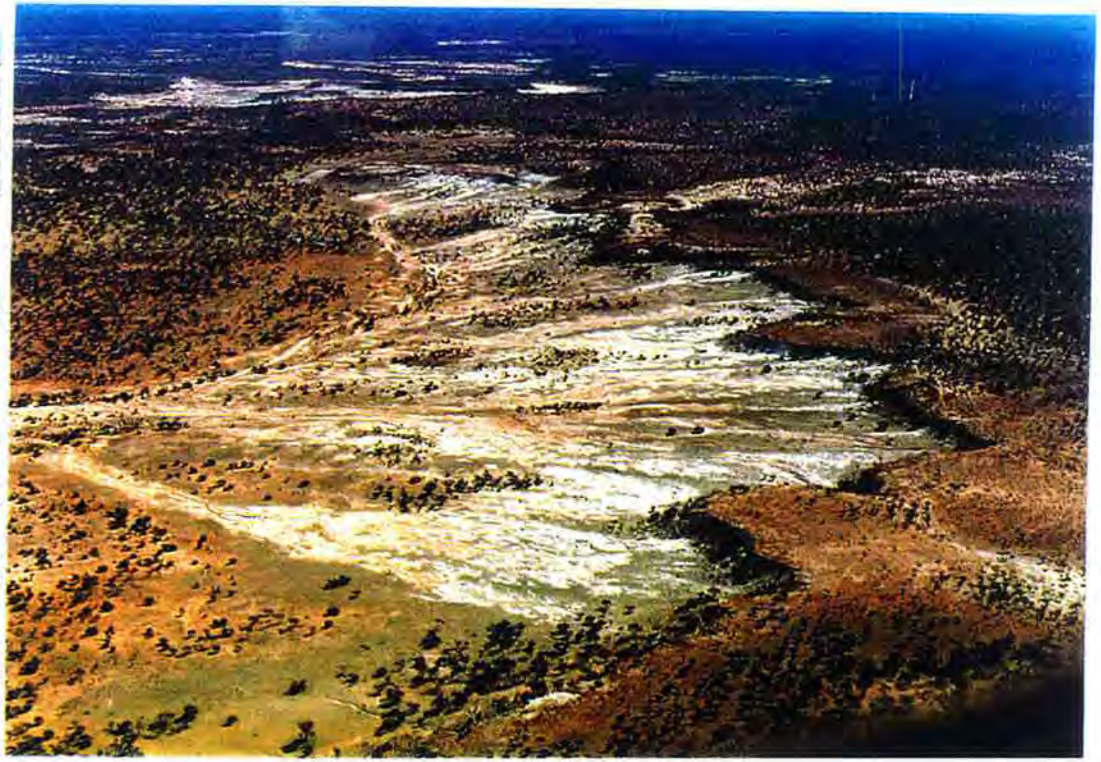



Fig. 11 The fragmentation-coalescence ecosystem replacement sequence, here involving three soil horizons: (i) friable topsoil 4 to 8cm (marked in black) of intact chenopod-grass habitat on duplex soil, (ii) saline clay subsoil (white horizon) over (iii) silica hardpan (dashed lines).

The process is graphically self-explanatory, however note: (4) & (5) at the predominant scalded bare ground stage when the subsoil becomes the new land surface; (5) initial rill, gutter or gully incision of the new surface, (6) colonization of incisions by scrub; (7) to (8) headward and lateral spread of scrub predominance as the scalded clay surface is cut into. Infill of sediment along the incisions, or (9) incision down through the clay horizon onto the hardpan which forces erosion laterally exposing widening areas of a second new surface. In time this is also incised by erosion enabling the establishment of plant growth along the incision.

Fig.11 THE FRAGMENTATION - COALESCENCE ECOSYSTEM REPLACEMENT SEQUENCE ...

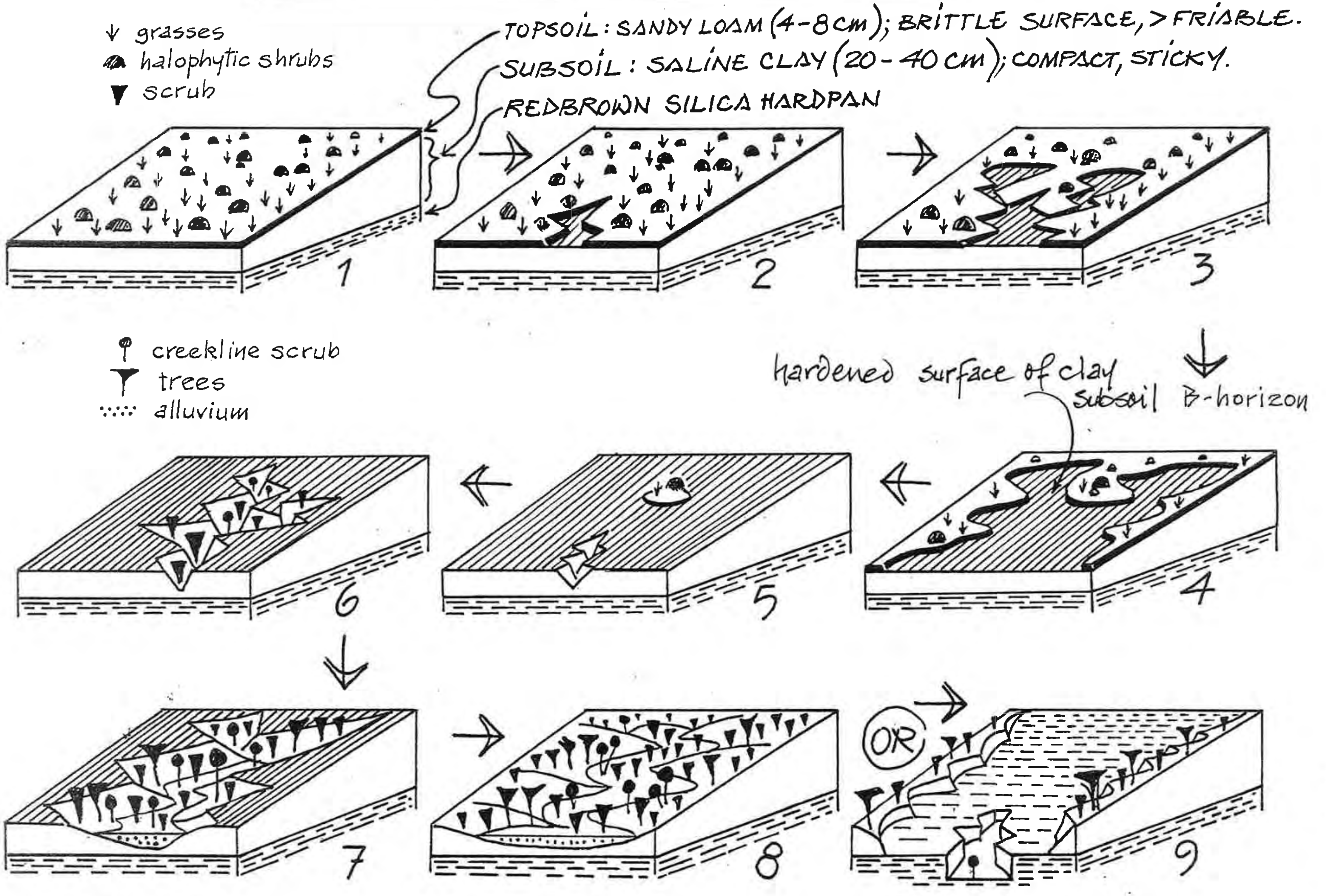


Fig. 11

[B] Patterns and Landscape Connectives

The regional landscape linkages form a net pattern that is dominated by the normal to oblique east-west axes of:

(1) the major river systems draining from the interior to the Indian Ocean coastline;

(2) the sedimentary fold ranges; and

(3) the linear dunefields of the interior.

The palaeo-river systems of linear salt lakes are also east-west but with south to south east axes as well. Three structurally controlled straight drainage sections trending NNE-SSW occur in the Lyons (150km), Gascoyne (100km) and Murchison (200km) imparting a zig-zag pattern within the overall East-West axes of these rivers.

The major north-south axes are the sea coast (with ria and gulf embayments), the series of coast-parallel ranges and linear dunes and troughs of the coastal plain, and inland the greenstone ridges of the crystalline shield.

Linear Linkages (apart from the coastline and main rivers are discontinuous dashed lines):

1. Seacoast and playa shorelines.
2. Drainage lines:rivers, creeks, tributaries,distributaries.
3. Ranges, ridges, breakaways and other scarplines.
4. Linear dune ridges and troughs.

Archipelago 'stepping-stone' Linkages:

1. Rocky isolates eg. inselbergs, domes and tors.
2. Seasonal wetlands eg. claypans, cracking-clay pans, billabongs, floodplain, delta marshes and saltpans.
3. Rock pools (incl. gnamma holes), seeps and springs, artesian bores, and windmill waterpoints.
4. Patch-interpatch Vegetation Patterns.

   (a) Contour-parallel bands of 'tiger/zebra stripe' pediment sheetwash-mediated litter-line pattern of woodland groves (Mabbutt & Fanning 1987). Plate 1d.

   (b) Perch-base bushclumps and thickets; 'Aboriginal dot-art' or 'leopard-dot' berry-bird mediated pattern. Plate 1c.

The highest linkage pattern interspersion is again at ecojunction nodes at all spatial scales. This is exemplified by the confluence of bioregions, drainage systems, dune ridges and troughs, and hill ranges on the 1:25.000 geological map sheets of Winning Pool - Minilya (Hocking et.al.1985a), Nabberu (Bunting et.al.1982), and Kennedy Range (Hocking et.al.1985b).

At the whole region level, two major landscape ecotone patterns are expressed by the predominance of three vegetation cover formations.:

1. *a N-NE acacia-spinifex line (Beard 1975)*
2. a NW-SE acacia-eucalypt biome ecotone between Shark Bay and the Nullarbor.

7' Layer: Unique Features and Components

Of the phenomena noted in Table 5, only passing mention will be made of the physical and biophysical aspects with slightly more emphasis on biotic endemism using examples from four woody flora families dominant in the region. A total of 432 endemic plant species are recorded from the Western Australian part of the Arid Biome (Beard et al. 2000; Pacskowska & Chapman 2000).

(1) **Physical features** include the Birdrong artesian aquifer and the Cape Range karst features and habitats.

(i) The Birdrong formation is a Cretaceous sandstone component of the Carnarvon Basin stratigraphy (eg. Hocking *et al.* 1985b) that outcrops on the inland margin of the coastal plain in a coast-parallel series of cuesta or mesaform ridges or ranges. Exposures of the Birdrong sandstone form a discontinuous line of small outcrops (Fig 12). Presumably main aquifer recharge sites are through leakage from overlying sediments and drainage may also contribute.

(ii) Limestone karst formations occur mainly in the Cape Range (van der Graaf *et al.* 1980; Humphreys 1993), and bottomland drainage line calcretes are widespread throughout the region (Commander 1989),

(2) **Biophysical features** include the biome or ecosystem distribution endpoints or outlier areas (Figs.7 - 10), and two land systems that occur nowhere else in the region.

(i) The Marloo landsystem on the lower Lyndon floodplain on Mia Mia Station has the southern limit of the tropical cracking clay Mitchell grassland association typical of the Top End (including *Astrebla elymoides, A. pectinata, A. squarrosa, Chrysopogon fallax, Eulalia fulva,*and *Dicanthium fecundum*)(Payne et al. 1987).

(ii) East of Mt. Magnet is the Merbla landsystem of highly productive grass-chenopod shrub habitat on red clay plains derived from weathered gabbro (Payne et al. 1998).

Other examples include the Cape Range cave habitats and the unique stygofauna (Humphreys 1993), and the hypersaline Hamelin Pool at Shark Bay that contains a unique assemblage of stromatolites of world conservation importance (Burne 1992; Playford 1990).

(3) **Biotic Features and Components:**

(a) Flora. Endemic flora distribution patterns at the broad scale for the four woody plant families dominant in the region are used as an example of biotic uniqueness (Fig.8). These are the *Chenopodiaceae, Mimosaceae*

(Maslin & Pedley 1988; Hnatiuk & Maslin 1988), *Myoporaceae* and *Myrtaceae* (heaths and eucalypts are mapped separately). For the chenopods the main overlap of range outlines is some 150-200km inland of Shark Bay coincident with the terrain developed on Permian carbonate rocks. The patterns of heaths, gums, and acacias show high concentrations of superimposed lines in the Carnarvon, northern Geraldton Sandplain and Yalgoo Bioregions, and for eremophilas more centrally in the Gascoyne and upper Murchison catchments on crystalline and sedimentary fold range geomorphic surfaces (dark patches on the maps are concentrations of occurrences within a small area).

(b)Inland Fish Fauna. In the terrestrial aquatic systems a similar biome pattern is exhibited by the fish fauna. The Murchison River forms the southern limit of three tropical genera: *Craterocephalus* (hardyheads), *Leiopotherapon* (grunters) and *Hypseleotris* (gudgeons), and the Moore River the northern limit for most of the SW Temperate fish fauna (Allen 1982).

One tropical inland species, the spangled perch (*L. unicolor*) that occurs across the northern three-fourths of Australia, has its Western southmost limit in the Greenough River (Allen 1982). Another inland species, the Murchison hardyhead (*C. cuneiceps*), occurs in the NW exoreic drainage to the Indian Ocean between the De Grey and Murchison Rivers, then recurrs in the Finke River of the Central Desert (Allen 1982).

Four endemic fish occur in the region. Two blind fish in the karst system of the Cape Range; a blind gudgeon (*Milyeringa veritas*) and blind eel (*Ophisternon candidum*)(Allen 1982). Confined to the Gascoyne and Murchison Rivers is the golden gudgeon (*Hypseleotris aurea*) and the Fortesque grunter (*Leiopotherapon aheneus*) to the upper Ashburton River that occurs within the G-MS Region (Allen 1982).

(c) Dugong and turtles. Shark Bay is a major world concentration area and refugia for the dugong (*Dugong dugon*)(Anderson 1991/92, Preen *et al.* 1994) in a 13,000 sq km area of embayments containing close on 4,000 sq km of seagrass meadows (Walker & Prince 1987; Walker 1992). On Dirk Hartog Island are important nesting beaches for loggerhead turtles (Burbidge 2002).

(d) Terrestrial vertebrates. Amongst terrestrial vertebrates the most abundant endemic species in the region are the lizard fauna (see maps in Storr *et al.* 1983, 1990, 1999). In the bird fauna, geographically isolated races of the spinifex pigeon occur on Cape Range, Pilbara Ranges, the Carnarvon Range on the southwest margin of the Little Sandy Desert, and the Rawlinson Range on the Northern Territory border (Johnstone & Storr

1998). Only one endemic bird, the Dusky Warbler (*Gerygone tenebrosa*) occurs in the region confined to mangrove woods from south of Carnarvon, at its southern limit, and shared northwards with the Pilbara and SW Kimberley coast to its northern limit in the mangroves of King Sound (Pizzey & Doyle 1983; Johnstone 1990, Fig 43).

The larger islands of Shark Bay are critical refugia for 8 native mammals extinct or seriously endangered on the mainland (Morris *et al.* 1992). These include the Shark Bay Mouse (*Pseudomys praeconis*) confined to Bernier Island. On both Bernier and Dorre Islands are boodie or burrowing bettong (*Bettongia lesueur*), banded hare-wallaby (*Lagostrophus fasciatus*) and western barred bandicoot (*Perameles bouganville*). The greater stick-rat (*Leporillus conditor*) was re-introduced to WA and established on Salutation Island in Freycinet Inlet (Burbidge 2000, 2001; Burbidge & Friend 1990, Morris *et al.* 1992).

9. Results

To identify potential biodiversity 'hotspots', this report has focused primarily on the findings of the stereo-airphoto scrutiny of the region, combined with map overlays of the first six layers of information to identify the areas of highest landscape or ecosystem diversity. (The synthesis of species distribution patterns for both endemics and species-rich areas is a task yet to be done.) The biodiversity can only be verified by a combination of the species mapping analyses and from ground truthing involving biological surveys to realize the overlay composite (8th layer).

The layered map overlay approach, using ecojunction nodes as the centring areas for correlations, is considered to be the most rapid and practically effective method for identifying areas of high landscape or ecosystem diversity. This is based on the author's ecological experience on three continents .

This high landscape or ecosystem diversity is the result of different systems meeting at ecojunction nodal areas at all scales. 'Between-system' heterogeneity is concentrated at landscape nodes, whereas 'within-system' diversity involves variation in proportions and patterns of different habitats and communities quite apart from their species content. The area-diversity relationship is used as an indicator of diversity in the region. The greater the number of landsystems meeting in a given area indicates greater system diversity.

In the GMSA Region at the 1:250.000 map scale, six or more land systems meeting in a 5km radius area represent a concentration of highest system diversity in relatively least area ie. area-diversity relationship.

This project has identified 34 areas of highest landscape diversity across the region (Table 11, Fig. 17). In summary these are:

8 areas on the belted coastal plain,

15 on the Shield, 8 in the foldrange region,

2 large areas in the Little Sandy Desert

2 on the desert margin south of Lake Carnegie.

The red shaded areas on Fig. 17 are intensive (high ecojunction interspersion), and red hatched extensive areas of widely dispersed ecojunctions, or of slightly less importance as judged solely from the airphoto and map overlay process.

Station boundaries are used as a convenience for map shading and do not imply an all or nothing conservation protection strategy. One of the crucial requirements is for the pastoral land matrix to take part in conservation of biodiversity at the whole catchment and regional scales whilst ensuring their own means of managing land in an ecologically sustainable manner.

The patterns of highest landscape diversity occur across ecojunctions of all spatial scales. The four used here are:

(1) the largest - where the three major biomes meet and overlap in a half-circle radius of about 350km centred on Quobba Point, between

Exmouth Gulf and Shark Bay, and inland to Mt. Ausgustus (Fig.17). This covers the highest diversity of geology, climate, soils, geomophology (landforms and processes), soils, vegetation and flora (Figs. 7-10,15).

(2) At the next scale down, there is the ecojunction area of five bioregions in the southwest sector. These include (a) Carnarvon, Geraldton Sandplain, Yalgoo, Murchison and Avon within a 100km radius (Fig.1b). (b) Four ecojunctions where the Murchison-Yalgoo-Coolgardie-Avon meet, and (c) another four at the Little Sandy Desert-Gascoyne-Gibson Desert-Great Victoria Desert junction area.

(3) At the district to station scale, 34 areas have high landscape diversity values (Fig. 17, Table 11).

(4) At the local paddock size scale, a 10 x 10km grid of landsystem ecojunctions shows highest value concentrated across the southern part of the region (Fig.16).

10. Overview and Management Options

(1) Parallel aims of Ecologically Sustainable Pastoralism (ESP) and Biodiversity Conservation.

The present predicament of pastoralists in the arid rangelands is a legacy from previous generations of mismanagement. They are trying today to make a living from stock production using the same animals as their predecessors, in landscapes altered by previous overstocking, windmills closely spaced at an average of 5km apart (Fig.18), and tracks and fenced paddocks largely positioned without cogniscance of the landscape processes. Highest pasture potential is confined mostly to the run-on bottomlands of floodplains, deltas, and margins to saltlakes (Fig. 19); all of which has taken the brunt of heavy continuous grazing to the present day.

The enormous overstocking in the past (Curry et al. 1994) has caused much of the thin and brittle topsoils to be eroded away exposing the underlying saline clays. Large areas have remained bare and scalded for decades. The changing land surfaces and hence vegetation types follows the spread of the erosive processes. These changes together with a hundred and fifty years of selective grazing by sheep, with the help of feral rabbits and goats, has altered the vegetation structurally and floristically to becoming more woody and composed mainly of less palatable acacias, cassias and eremophilas. The recent favourable pasture assessment from WARMS sites (Watson & Thomas 2002) not withstanding as these were sited away from proximity to waterpoints and erosion. Saltbush and bluebush, so important to the sheep industry, are still to be found but over large areas these have been reduced to a single species,such as sago bush and even these are threatened by surface stripping of topsoils. Over vast areas the groundlayer has been fragmented, species variety reduced and recruitment of all layers drastically diminished.

In the bimodal and winter rainbelts of the GMSA many pastoralists are converting to cattle production. However, in the absence of adequate falls of rain, the cattle are subsisting on woody plants for most of the time. So even before considering the natural arid ecosystem drivers of erratic rains and long dry periods with severe droughts, the recruitment of many preferred plants is rare to non-existent (see Section 8: 6th Layer)(Stafford Smith & Morton 1990).

How can viable healthy ecosystems be restored in the arid lands such that they simultaneously support ecologically and economically sustainable pastoralism and the recovery of biodiversity and viable ecosystem functioning? (Curry & Hacker 1990; Ludwig 1990; Werner 1990; Friedel et al. 1990; Walker 1993; Tongway 1990, 1994; Bennett 1995; Morton et al. 1995; Pringle 1995; Curtis & De Lacy 1996; Stafford Smith et al. 2000; Australian Collaborative Rangeland Info System 2001).

At present the practices toward both ideals are diametrically opposed, or at best at right angles to each other. As hooved herd animals graze/browse and trample it is unlikely that sufficient changes to pastoral landuse can be made for the aims of the two ideals to coincide. Next best is for them to be parallel, pointing in the same direction of habitat health, recovery and maintenance.

In an evolutionary sense successful living in arid lands demands two related attributes:

1. The ability to move freely and explore over a large area to find the necessary life requirements and
2. Versatility, to be able to do a number of things depending on the opportunity provided by changing circumstances.

To this end the following examples are potential strategies for pastoralists in the quest for sustainable environment-economic-sociocultural viability:-

(i) Diversify useage of a station's many natural resources.

(ii) Animal production diversification. Introduce stock that are arid-adapted, browsing animals. Harvest kangaroos and emus sustainably as a station owned product. Value add the products where possible, eg. biltong, emu oil (Lunney & Dickman 2002).

(iii) Close or relocate artificial waterpoints to least fragile landsurfaces and away from areas containing seasonal wetlands.

(iv) Rest paddocks using rotational grazing methods (Bartle 2002). Seasonal up and downslope grazing useage (catena grazing strategy).

(v) Use trapyards around waterpoints for stock management. Minimize fencing and shift stock by opening and closing waterpoints.

(vi) Push for changes to obsolete pastoral legislation that limits pastoral enterprise diversification and adaptability.

(vii) An enabling environment is required which both helps and encourages more people with diverse abilities to live and work in the arid lands. Further emptying of the outback will see the increased explosion of feral pests, especially goats (Woolnough & Martin 2003), exacerbation of erosion, and increase of fire damage in buffelgrass infested areas.

To set these improvements in action the Gascoyne-Murchison Strategy facilitated the development of an off-reserve conservation and management program with pastoralists on their stations. Out of this the EMU Process was born (Ecosystem Management Understanding)

(2) The EMU Process.

The primary purpose of EMU is to introduce pastoralists to the ecological management of landscape processes, habitat condition and trend to help recover the foundation to their pastoral enterprises. This hands-on tool for ecosystem management addresses diversity and connectedness in a drainage unit context and the compatibility of good habitat for both stock and native plants and animals (Pringle & Tinley 2001, 2002). The EMU process helps pastoralists to change their approaches to landscape management (Curtis & de Lacy 1996)..

In this process pastoralists are guided in recording their station knowledge in a baseline mapping exercise, followed by ground and air traverses of the key areas identified. A qualitative landscape and habitat monitoring technique is demonstrated during ground traverses augmented by ground and aerial photographs. The synopsis of this monitoring, performed annually by the pastoralist, is transferred to clear overlays on the station landsystem map as a permanent record for tracking change over time and identifying and refining strategic management responses. Other valuable features of a station can also be targeted by this management system, including key areas for grazing, conservation of special habitats such as wetlands, cultural heritage, harvesting craft woods and essential oils, aquaculture, ecotourism and so forth.
The fact that landscapes are dynamic and ever-changing in terms of interrelationships both within and between systems is basic to the EMU approach. Amongst several natural and human-induced drivers of change, the movement of water through the landscape, and the management of it, is pivotal (Le Houerou 1984). In certain landscapes, such as coast dunefields, wind is equally important as is fire in the spinifex for example (Davies 1973; Stafford Smith & Morton 1990).

Recognising patterns, processes and drivers of change, mapping them and synthesizing the visiual information has generally had a profound effect on EMU participants. The distillation of their knowledge allows them to see their station land as a whole system of interconnections. This holistic perspective of the Outback allows pastoralists to identify and design 'best fit' ecological management; a key outcome of this project. They learn to become land literate, to read the signs of the land (Burnside et al. 1995; Ludwig et al. 1997;), their significance, and how to obtain maximum response with least effort by getting nature to do the recovery work.

The main aim of the EMU process is thus to set in motion a synergy of motivation and capability amongst pastoralists in the attainment of successful self-reliance, mutual support and learning approaches towards a viable Triple Bottom Line by working with natural processes and not against them.

(3) Benchmark Paddocks
As the rangeland stock production country forms the matrix to formally proclaimed nature conservation reserves and parks, the establishment of a 10 x 10km benchmark paddock exclosure on each station, containing its ecojunction node of highest diversity would help realize two fundamental requirements simultaneously (a) as a management yardstick for the station, and (b) off-reserve conservation. The establishment of an archipelago of stepping-stone natural systems interlinked by drainage, ridges or scarplines would go a long way toward realizing an effective conservation network.

Ecojunctions are areas where a number of different ecosystems meet and hence of potentially greatest diversity representative of the particular station. Using the overlay technique the core areas of highest diversity on each station are identified by finding where the largest number of landsystems abut in a 5km radius or 10 x 10km paddock size area (5 x5 km on small stations).

A benchmark paddock would function as a station's core reference area, generally containing viable representative examples of most landsystems occurring on the station, as well as most quickly enabling restoration or enhancement of biodiversity. It would also provide a visual record (Campbell & Hacker 2000) of change with which to compare the condition and trend of the grazed paddocks.

"Health is a concept requiring a reference point or baseline against which a relative assessment is made" (Genthin Morgan for Environment Australia, 2001; Rapport et al. 1998; Whitehead et al. 2000).

The benchmark paddock approach combined with that of Biograze (2000), which recommends fencing off least-grazed corners of paddocks out of general stock reach from waterpoints, will provide a practical basis for realizing biodiversity conservation effectiveness across the rangelands. How quickly this could be achieved of course would depend on funding support for fencing able to exclude all herbivores.

Areas of potentially highest biodiversity need to be protected from grazing and trampling by stock, including goats and camels, so that they are valuable control areas for comparing natural landscape processes and ecological interactions. They can also be used for gauging successful and effective ESP management, and for tracking change imposed by seasonal events eg. flood, drought, fire.

Thus benchmark paddock ecojunction exclosures will be focus areas for monitoring and comparing with the ecological health status of the production terrain areas. Indicating where, when and how to intervene minimally for maximal effectiveness to rehabilitate degraded terrain. Where and how to apply rainwater harvesting, spreading and retention to minimize loss, heal erosion and recover or enhance productivity (ie. reversing run-off to run-in). Exclosed areas can serve as refugia for wildlife, particularly birds dependent on ground cover (see Table 10), for plants selectively eaten-out by stock and for flora that is endemic, Priority or Declared Rare. These areas can also be resource areas and seed banks for valuable plants, oils, timbers and attractive wilderness areas for ecotourism.

Ecojunction exclosures would be the most immediate way of establishing off-reserve protected areas within the rangeland matrix. Should finance be found for exclosure fencing, at least several to half-a-dozen should be established that can also act as demonstration examples.

(11) Conclusions:

Out of 253 pastoral stations in the region:16 whole stations and parts of 18 others have been acquired for the national conservation estate amounting to only 7.5% of the 573.000sq km GMS area. This obviously still samples only a fraction of the biodiversity in this region of junction and overlap between three major biomes of the continent. The greater area of the GMSA is under pastoralism which forms the matrix in which the parks, nature reserves and acquired stations are embedded, all linked together by drainage.

Due to the continental dimensions of the State and tight agency budget constraints (Pringle 2002), it is unlikely that each of the acquired stations in the region will be able to have a resident ranger/land manager let alone an ecologist. The majority of regional CALM and AGWA personnel at present are town-based and only able to make a few visits annually to any one place due to the vastness of the region.

This means (as most everywhere else in the world) the present and future survival of biodiversity – ecosystem health and integrity of parks and reserves, lies in the hands of the rural people who are in everyday contact with them. In the rangelands it is the pastoral station families who live in the outback and interact with the land and its seasonal vicissitudes who are the actual or potential frontline stewards of biodiversity.

The major ongoing environmental degradation across the GMSA is sheet and gully erosion in which overgrazing, tracks, roads, fencelines and stock pads are all implicated, exacerbated by torrential rain events. The major threat to biodiversity is also from the depradations of feral goats and the invasive spread of buffelgrass. The latter when ungrazed is a fire hazard to riverine and bottomland habitats that don't naturally experience fire.

The overall vegetation trend in the GMSA is towards dominance by scrub ('woody weeds') and the contraction of chenopod shrublands on perched terrain surfaces. A critical factor is the loss by gully incision of the indspensable temporary wetlands of ponding surfaces, and landscape desiccation due to excessive rainwater runoff.

Any pastoralist attempting to realize effective pastoral management (ESP) that rewards all three components of the Triple Bottomline (environment-economy-sociocultural) are thwarted by a complex of confounding factors:- an arid environment of erratic rainfall, market vagaries, government legislation that confines them to grazing useage only, legacy of historically overstocked country with outdated infrastructure, very large stations run by one or two people since the 1970s, maintenance of family well being and all that that entails.

Through the EMU (Ecosystem Management Understanding) process pastoral landcare groups in the Gascoyne-Murchison rangelands are developing a clear understanding of how self-reliance through mutual help can assist the recovery of health and productivity of their stationlife-support systems. To date (three and a half years since the start of EMU) seven landcare groups comprising 50 stations (20% of the 253 total) have undergone the EMU process.

EMU is working toward off-reserve conservation in partnership with pastoralists across the region to develop ecologically sustainable pastoralism (ESP/ESD). This process is changing the focus from pasture management to landscape management, hence protecting and restoring natural habitats that support both biodiversity and enterprise. The change in objective enables pastoralists to ask not 'what can I get out of this land" but "what does this land have to give if I cooperate with it" (Mollison 1988).

A key recommendation from this survey is for the pastoral industry to establish a Benchmark Paddock exclosure over the area where the largest number of landsystems adjoin, on each station of the Western Australian rangelands. This will simultaneously provide a yardstick or control against which grazing and landscape management can be judged, and an off-reserve biodiversity protection area.

There are four fundamental management requirements needed across the GMSA for turning ecosystem and habitat recovery towards health and integrity.
(a) Sieve barriers at key sites in drainage for slowing runoff and retaining rainwater on the land can result in far reaching and rapid landscape recovery as it entrains successional sequences.
(b) Restoring the 'sweet spot' depressions as focal keystone habitats during the dry spells.
(d) Closing or re-positioning windmills away from sensitive habitats susceptible to erosion. Rotational useage of paddocks that gives habitats sufficient rest for regrowth to set seed, and allow recruitment to occur.

To be effective, both on- and off-reserve biodiversity conservation in the rangelands will require participatory cooperation between the station families who live on the land and the overseeing land agencies. Examples already exist in the form of Aboriginal station groups, the pastoral landcare groups, and private Conservancies who are helping each other and on their own initiatives have combined to start healing drainage catchments (eg. the Murchison River group). Strategies offering incentives to communities need to be used in tandem with the cooperative approaches.

CALM has already started to develop cooperative land management programs with traditional groups in certain national parks. A parallel requirement is fundamental in the rangelands so that pastoral landcare groups together with government scientific expertise manage for conservation across the whole of the GMSA.

Cooperative approaches in the field are urgently required between the government agencies responsible for the wise use of natural resources so that a unified approach is adopted across the Outback where the specialities and requirements of each complement and reinforce each other (a whole-of-Government approach to the regional ecosystem as a whole).

Biodiversity has become 'one-eyed' and keeps overlooking the essential other 'eye' for it's realization; and that is human-diversity. An Enabling Environment needs to be developed in the rangelands that addresses how livelihood and sociocultural issues can begin to express the diversity of human skills, talents, creativity, interests and innovation in relation to the arid environment's many natural resources.

With guidance and time, station families and people who love to live on the land can produce a generational entrainment of ecological understanding and biodiversity management in the Outback.

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TABLE 9 Landscape Processes

(1) BELTED COASTAL PLAIN

1. Sea coast processes:- wind, wave & tidal action, storm surges, longshore currents - beach, spit, dune formation & erosion. Predominant winds S-SW resulting in net northward longshore currents & development of N facing zetaform bays. Delta & river mouth - marine and riverflooding interaction - sandbanks and bars, mangrove silts and muds, (sediment sorting, transport, deposition and remobilization by exceptional events such as the advent of a tropical cyclone - large scale erosion of both hard and soft coasts and shallow seabeds - mangroves destroyed. Calcareous rocky shores subject to solution and erosion by waves, basal sapping and collapse of cliffed areas. Buffel grass invaded coastland fire prone where not grazed down.

2. Coastal plain linear dunefields and sandsheets stabilized by dense plant cover; rain absorbing, but interdune flats subject to flooding with exceptional rains when claypans can link up. Fires in spinifex and heath cover, and buffel grass areas. Unlike inland desert dunes after fire there is only a short bared stage hence wind action is minimal.

3. Floodplains subject to episodic exceptional flooding, and to gullying where main river bed is incised leaving floodplains increasingly perched. Hence floodplain grasslands/chenopod shrublands drying and being replaced by acacia scrub encroachment. Sheet and rill erosion of topsoils, scalding of exposed base saturated subsoils (geomorphic landsurface succession sequences) Riverbanks and levees now increasingly stabilized by invasive perennial buffel grass grazed by cattle.

4. Rocky eminences mostly of calcarious rocks subject to karst erosion, scarp retreat (block falls and basal sapping of softer strata).

5. Apart from the major rivers traversing the coastal plain from east to west, the greater part is sand mantled with no surface drainage. Recharge of Birdrong artesian aquifer at small Cretaceous sandstone outcrops along inland margin of plain. Artesian outflow at uncapped bores form secondary wetlands.

6. Saltlakes including berrida series on Shark Bay Peninsulas subject to segmentation from spit and swashbank formation and their colonization by plants. Sediments also derived by rain wash from the sides, and from creeks in the case of MacLeod Saltlake. Lacustrine processes.

2 CRYSTALLINE SHIELD PLANATION SURFACES

1. Gently undulating plainsland of very broad sheetwash pediments extending from below low laterite duricrust scarps on convexities down at faint gradient to creek or saltlake bottomlands. Isolated rocky eminences are of granite or folded greenstones. Actively eroding western seaward drainage with wide and expanding upper saline stripped pediment zones below breakaways and shrinking wanderrie fan sands of their lower pediment zones. Contrasting the eastern internal drainage region of lower gradients typically with the reverse pediment conditions - mostly accreting mid to lower pediment sand fans and narrow upper stripped pediment zone below the breakaways.

2. Playa drainage endpoints - when shallowly flooded subject to wind wavelets with swashbank and island formation. When dry, winds remove loose sediments deposited in lake shore hummock and lunette dunes (mostly gypsic clayey sediments). Together these processes result in segmentation and/or rounding-off of shorelines connecting lateral outgrowths of spits, sandbars and splay deposits.

3. Flooding by major rivers - breaching of rock bars and other base levels; erosion incision of main channels resulting in progressive perched condition and hence drying of their floodplains. Overbank floodout and re-entry sites incised and cutting back into the adjacent floodplains - resulting in far-reaching cascading effect of drying - loss of perennial grasses and chenopod bushes being replaced by invasion of acacia scrub - changes in landsurface, plant cover and composition, productivity vis-a-vis carrying capacity for stock/sustainability), changes in biodiversity (form, structure and content). Sanding or silting up of river pools and billabongs; or, the converse, loss of drought buffering depressions from breaching by headward eroding gullies. Pool and riffle or rapids sequences -scouring and/or sanding up.

4. Plainsland surface replacement sequences (geomorphic succession). Layerite scarp retreat by basal sapping and mass wasting resulting in (a) contraction of Early Tertiary planation surface, (b) expansion of silica hardpan pediplains & (c) exhumation of granite cores as rocky isolates. Red sand mantle washed off the top of laterite breakaways with scarp retreat - expanding exposure of underlying saline kaolin and granite saprolite surfaces - stripping of thin brittle topsoils. Scalding of exposed subsoils - loss of high carrying-capacity saltbush-bluebush habitat to bare ground, colonized by scrub only when guttered by erosion.

5. *Granites:* hydration (physico-chemical tafoni weathering). Formation of gnamma holes, overhangs (basal sapping), spheroidal weathering. Gibber surfaces of quartz lag. Rainwater held in gnamma basins.
Greenstones: mostly near vertical disposition of strata - gravity falls and coarse talus accumulation, gibber surfaces. Typically waterless habitats at the surface.

(3) SEDIMENTARY FOLD BELT

1. Rocky ranges with upturned strata alternating with valley flats of base rich soils subject to sheet flooding and gullying on sloped terrain. Coarse boulder and block talus below cliffed scarps from rock falls, slides and basal sapping of softer argillaceous strata. Cave and overhang formation. Dolomitic formations subject to surface karst weathering; argillaceous formations to 'badlands' type weathering and erosion (eg N.Wanna Station). Spinifex grass covered hills and sandplains prone to fire. Stream capture processes in headwater areas, resulting in truncation and downsizing of slow draining low gradient catchments and enlargement of those with more active headward erosion on faintly steeper slopes.

(4) LITTLE SANDY DESERT

1. Predominantly dunefields fixed by spinifex hummock grasses and sparse scrub. Prone to lightning and human induced fires. During dry periods when

bared by fire, for up to a year, subject to wind action (crestline modification) until rains permit regrowth of plant cover.
2. Lake Disappointment and its Savoury Creek catchment subject to irregular flooding by passage of tropical cyclones. Otherwise all drainage areic, apart from local runoff from the inselberg ranges. Saltlake wet and dry alternation of processes from swashbanks from wind wave action, to wind deflation and dune (silt, clay, sand) formation when dry. Lunette and hummock dunes.

(5) INTERIOR DESERT MARGIN

1. Mesa and plainsland terrain catena with dunefields, gravel pediments or flats and saline or calcrete bottomlands. Lower pediments either dunes or sand sheets ending in small playas or calcreted valley floors. Plains areas become increasingly stony surfaced with laterite gravels eastwards into the Gibson Desert . Mesas subject to scarp retreat, basal sapping, mass wasting.

2. Linear saltlakes of palaeodrainage systems segmented and narrowed by shoreline deposition and saltbush colonization (swashbanks, spits) and from outgrowths of alluvial fans from the valley sides. Subject to deflation and dune formation when dry.

3. Spinifex covered areas prone to fire. When burnt bare sand subject to wind action until restabilized by plant regrowth.

Table 10 Vegetation Types in the GMS Area

HERBACEOUS FORMATIONS & COMMUNITIES

1. **Suffrutex and Forb Communities**

(a) Rock outcrops, (b) drainage lines, (c) disturbed ground, (d) soft herb communities of caves and overhangs, (e) winter rain annuals (mainly spp. of *Asteraceae* eg. *Angianthus, Brachycome, Cephalipterum, Helipterim, Podolepis, Rhodanthe, Schoenia, Waitzia,* and a geranium (*Eradium crinitum*).

2. **Grassland Formations**

Annual Grasses: eg. *Aristida contorta, Eragrostis dielsii* (to 30cm ht).

Perennial Tufted Types:

1. Alluvium: (a) *Astrebla* 3spp, *Dicanthium fecundum, Eriachne benthamii, Chrysopogon fallax, Eulalia fulva, Sporobolus mitchellii* (to 100cm ht) - confined mostly to northern Carnarvon & Gascoyne Bioregions (eg. Marloo landsystem). (b) *Eriachne flaccida, Sporobolus setifolia* (50cm), (c) *Eragrostis australasica* on claypans (to 1.5m).

2. Various Habitats: *Cenchrus ciliaris* (introduced buffel grass) on delta alluvia, creek levees, duplex sands and compact sands (60cm).

3. Wanderrie sand mantled terrain: *Eragrostis eriopoda, E. lanipes, Eriachne helmsii, Monochather paradoxa* (to 60cm)

4. Calcareous substrates: *Enneapogon caerulescens* (to 30cm).

5. Spinifex post-fire regeneration succession: eg. *Amphipogon caricinus* (50cm).

Perennial Hummock-forming types:

Spinifex on sandy or duplex plainsland soils, dunes and rocky terrain (eg. *Triodia basedowii, T. brizoides, T. lanigera, T. pungens, T. wiseana* (on calcareous substrates).

Coastal foredunes (*Spinifex longifolius*).

SHRUB COMMUNITIES (mostly <1.5m)

1, Chenopod shrubland mostly on saline soils eg. species of *Atriplex, Halosarcia, Maireana.* Also *Frankenia* spp.

2. *Eremophila-cassia* (67 *Eremophila* spp. in Murchison).

3. Lignum (*Muehlenbeckia florulenta*) on claypans.

4. Heaths (eg. *Baeckia, Calytrix, Eriostemon, Grevillia, Micromyrtus, Thryptomene, Verticordia*). On rocky outcrops of granite, banded iron, laterite duricrust, sandstone and dune sands.

5. Coastal foredune shrub Zone (eg. *Atriplex isatidea, Olearia axillaris, Scaevola* spp).

SCRUB COMMUNITIES (generally 2-6m with emergents to 8-10m of low trees and tall shrubs).

1. *Acacia* scrub savanna, widely scattered to clumped over shrub midstratum and grass groundlayer, eg. species: *aneura, burkittii, coriacea, cuspidifolia, eremaea, ligulata, linophylla/ramulosa, pruinocarpa, quadrimarginea, sclerosperma, tetragonophylla, victoriae, xiphophylla.*

2. Mallee savanna: eg. *Eucalyptus kingsmillii, E. eudesmioides, E. giraliensis, E. oldfieldii over spinifex hummock grasses.*

3. Sandpine - *Callitris glaucophylla.*
4. Clayflats - *Eucalyptus victrix* (coolabah) trees over perennial grasses and bluebush (*Chenopodium auricomum*).

WOODLANDS (two crowns apart to overlapping).

1. Low (2-8m): mangroves, mulga, bowgada, melaleuca, sand gidgee (*Acacia anastema*), black mulga (*A. citrinoviridis*), *Casuarina obesa* (saline drainage and calcrete banks).

2. Tall (8-18m): (a) Riparian (*Eucalyptus camaldulensis, E. furruginea* (NE), *E. victrix, Erythrina vespertilio,* (b) Base-rich duplex soils (*Eucalyptus loxophleba, E. striaticalyx*), (c) Desert dune depressions and sandy pediments (*Allocasuarina decaisneana* (NE only).

THICKETS (2-5m, occurring as linear, patchy or clumped cover. Usually stratified dense tree or scrub community.)

1. Along (a) drainage lines: (eg. black mulga, melaleuca);
(b) coastal dunes - *Acacia coriacea, A. scleroperma, A. ligulata.*

2. Ravines and Scarps: Cypress pine, *dodonaea*, mulga.

3. Sandplains: *Acacia linophylla/ramulosa.*

4. Tree-base bush clumps: eg. *Canthium spp. Enchylaena tomentosa, Alectryon oleifolius, Acacia ligulata, A. coriacea, A. sclerosperma, A tetragonophylla, Eremophila longifolia, Exocarpos aphyllus, Jasminum lineare, Rhagodia spp, Santalum spp, Scaevola spp.*

TABLE 11 **HIGH LANDSCAPE DIVERSITY AREAS IN THE GMS REGION**

	Landscape Features of High Diversity										
Station Areas	Landform: Steep Relief Catena	Landform: Gentle Relief Mosaics	Climate - Winter, Bimodal, Summer, maritime, continental	Rock Types	Soil Groups	Ecojunctions & Ecotones	Wetlands incl tidal, mangr., springs,claypans, saltlakes	Dunes Sandplain	Karst/Calrete Dolomite	Breakaways Scarps Cliffs	Terrain Processes
Belted Coastal Plain											
1. Hamelin		1	Wm	1	1	1					1
2.Koodarrie		1	Bm		1	2	1	1	1		1
3. SE Mia Mia -W Lyndon-N Middalya	1	1	Bc	2	2	3	1	1		1	3
4. Nanutarra	1	1	Bm-c	2	1	2	1	1	1	1	2
5. Uaroo	1	1	Bm-c	3	2	2				1	2
6. Williambury	1	1	Bm-c	3	2	3				1	2
7. Gnaraloo	1	2	Wm	1		2	2	3	1	1	3
8. Meedo		1	Wm	1	3	3	3	2			2
Crystalline Shield											
9. New Forest-Yallalong	1	1	WBc	2	2	2	1	1		2	3
10.Jack Hills Ra.	2		Bc	1	1	2				1	2
11. Weld Ra. (Madoonga-Beebyn-Glen)	2	1	Bc	2	2	3	1			1	3
12. Mt. Wittenoom	1	1	WBc	1	2	2				2	2
13. Karara		1	Wc	2	2	2				1	2
14. Tallering Peak area (Wandina Stn)	1	1	Wc	2	2	2				2	2
15. Kirkalocha-Narndee	1	1	Wc	1	2	2		1		3	2
16. Edah	1	1	Wc	2	2	2				1	2
17. Dalgaranga-Lakeside-Mt Farmer	1	1	Bc	2	2	2	2			1	2
18. Ninghan	2	2	Wc	2	2	2				1	2
19. Barambie	1	1	Bc	2	2	2				1	2
20. Cogla Downs			Bc	2	3	3		1		3	3
21. Windimurra	2	2	Bc	2	2	2	1			1	2
22. Dandaraga	1	1	Bc	2	2	2				1	2
23. VCL betw. Karroun Nat Res.& Diemals Stn.		3	Wc		3	3					2
Fold Ranges											
24. Edmum	2	1	Bc	1	1	2	2		3	1	2
25. Wanna	2	1	Bc	3	3	3	2			3	3
26. Milgun	2	1	Bc	2	2	2				1	2
27. Dooley Downs	2	1	Bc	1	1	2					
28. Mt. Vernon	2	1	Bc	2	2	3					
29. Teano Ra. VCL	2	1	Bc	1	1	3				2	3
30. S of Turree Cr. VCL		1	Bc		1	1	1	2			2
31. Ned's Creek		2	Bc	1	3	3	2	1	1	1	3
Little Sandy Desert											
32. Lake Disappointment & Savoury catchment plus surrounding dune and inselberg ra.	1	1	Sc	1	2	2	2	2	2	1	3
33. Essington-Carnarvon Ra.	2	1	Sc	2	2	2	2	2		2	2
Interior Desert Margin											
34. Prenti Downs-Windidda	1	1	Sc	1	2	2	1	1	1	1	3

Relative Values:
1 = High
2 = Very High
3 = Exceptional

GEOLOGY

SEDIMENTARY ROCK FORMATIONS

- CAINOZOIC: Qm.Czc.Czp.Czv coastal plain, drainage, saltlakes (yellows & palest brown).
- CRETACEOUS: Kl.Km.Ku western & eastern margins (light greens).
- PERMIAN: Pl.Plg.Pu western & eastern margins (blues).
- CARBONIFEROUS: C (grey); DEVONIAN: D (purple) narrowly confined to coastal plain - oldland junction betweenYannarie & Gascoyne Rivers.
- SILURIAN: O-D. Ow confined to extreme SW corner (magenta).
- PROTEROZOIC: B1. B2. Bh. Br1. Br2. Cm. Cn1. Cn3. Cn4. E1. E2. Pa. W1. W2. W3 Y1. Y2. Y3 broad WNW-ESE brown band between crystalline shield and Hamersley ironstone formations.

CRYSTALLINE AND INTRUSIVE ROCK FORMATIONS

- ARCHAEAN to PROTEROZOIC
  Granites = g (pinks & reds); Gneiss = n (cerese);
  Greenstone metamorphics = b (emerald green);
  Other metamorphics = s (khaki);
  Basic intrusives = d (blue-green) & Br1.

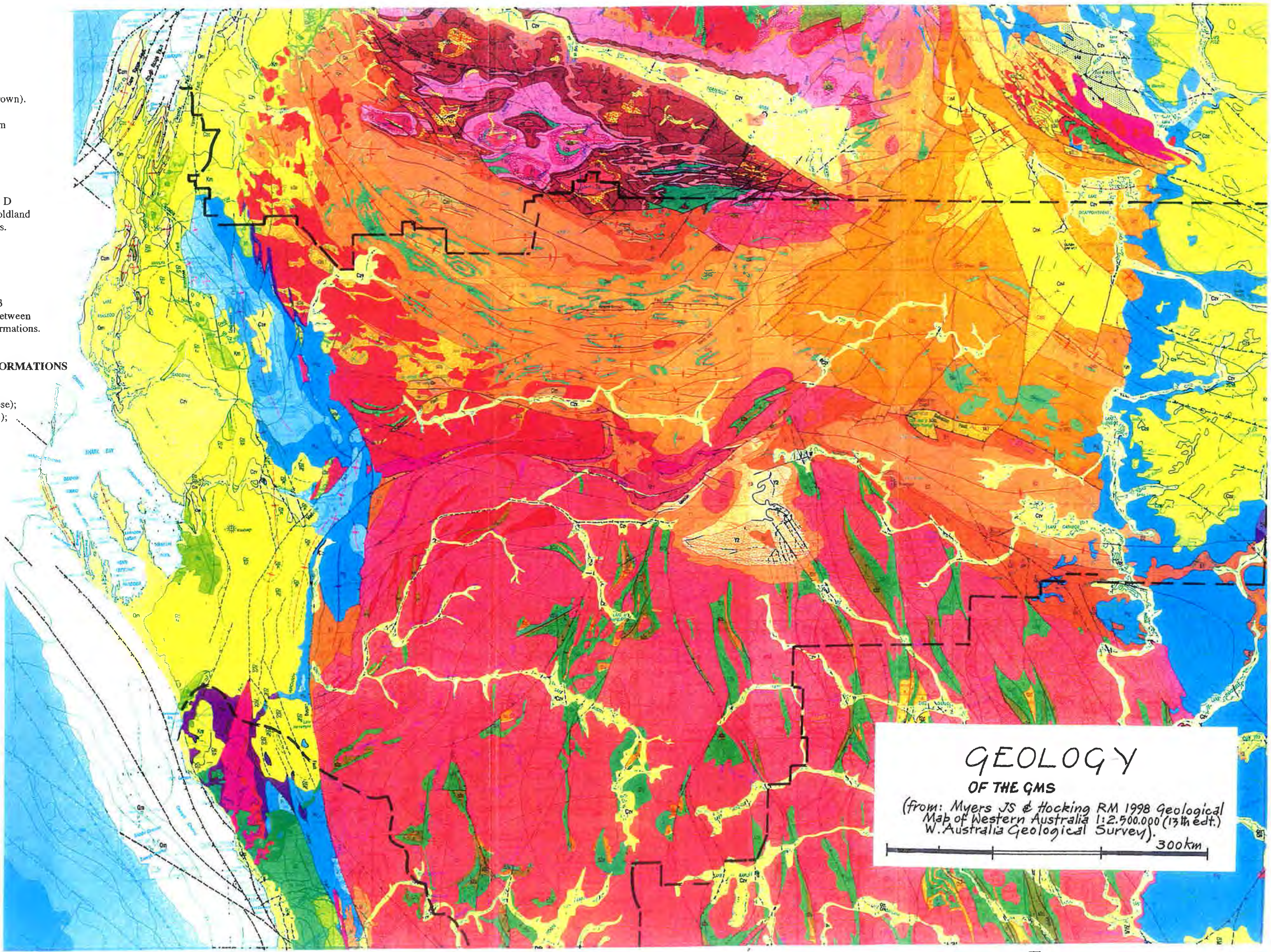


Fig. 12

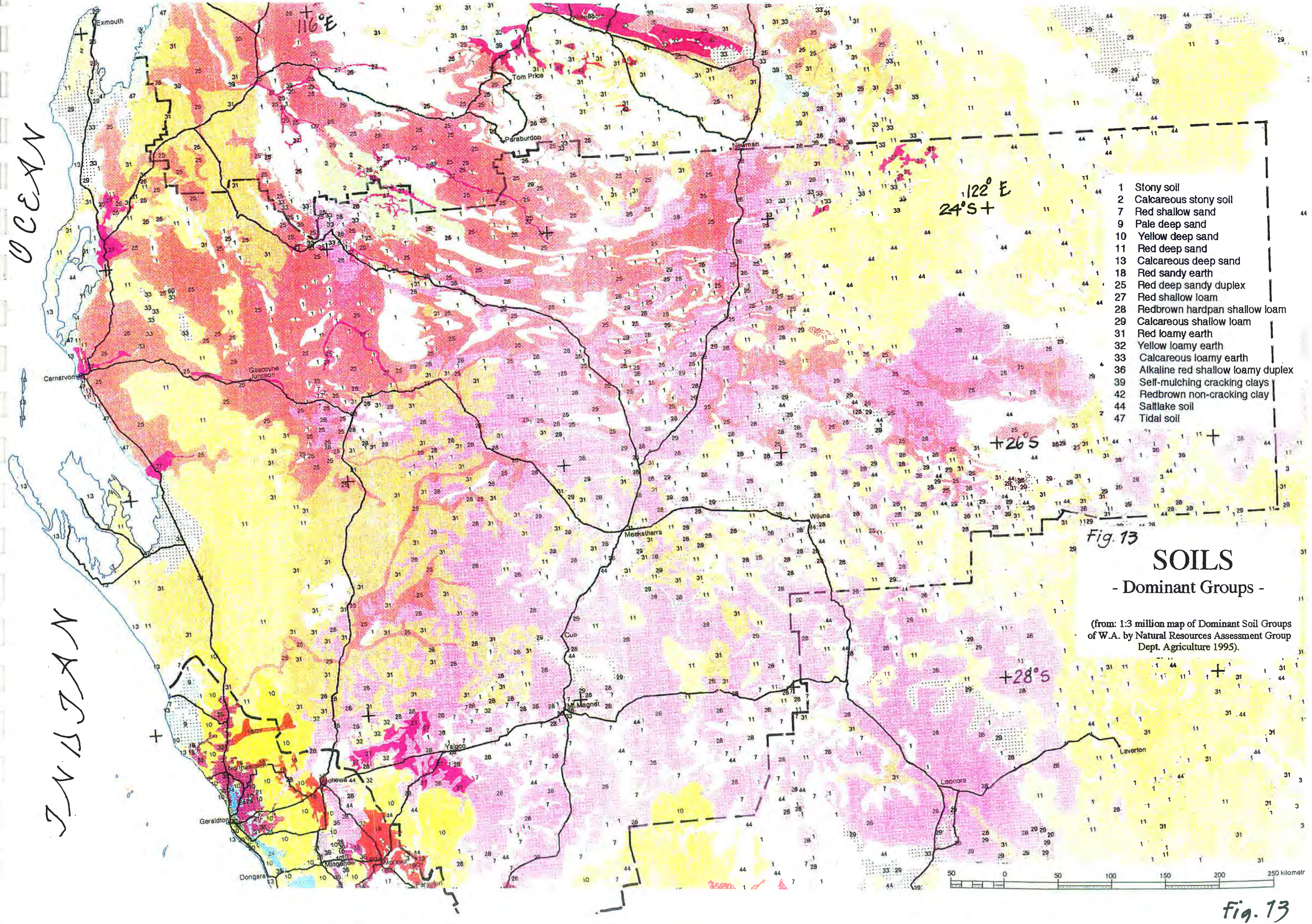
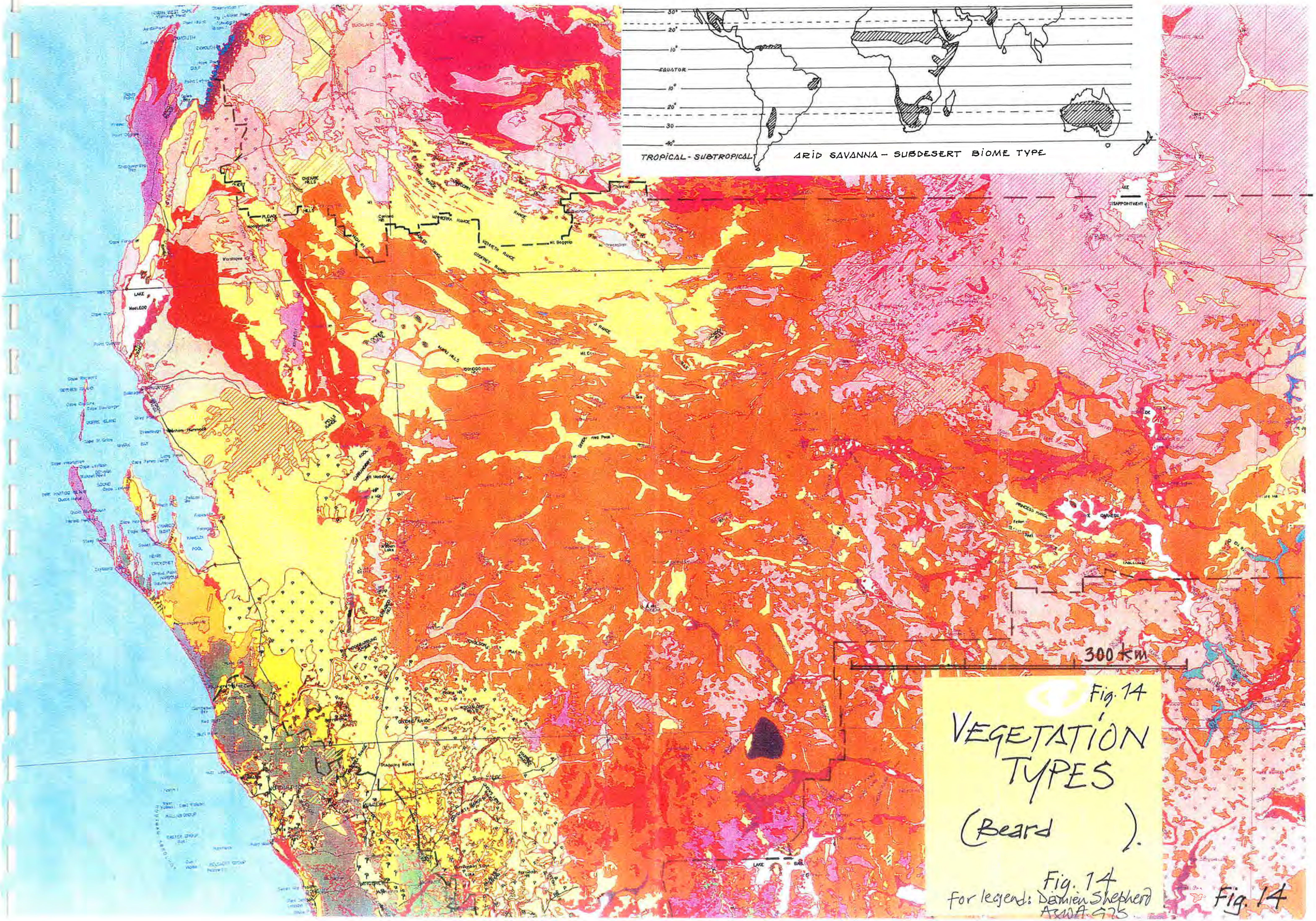
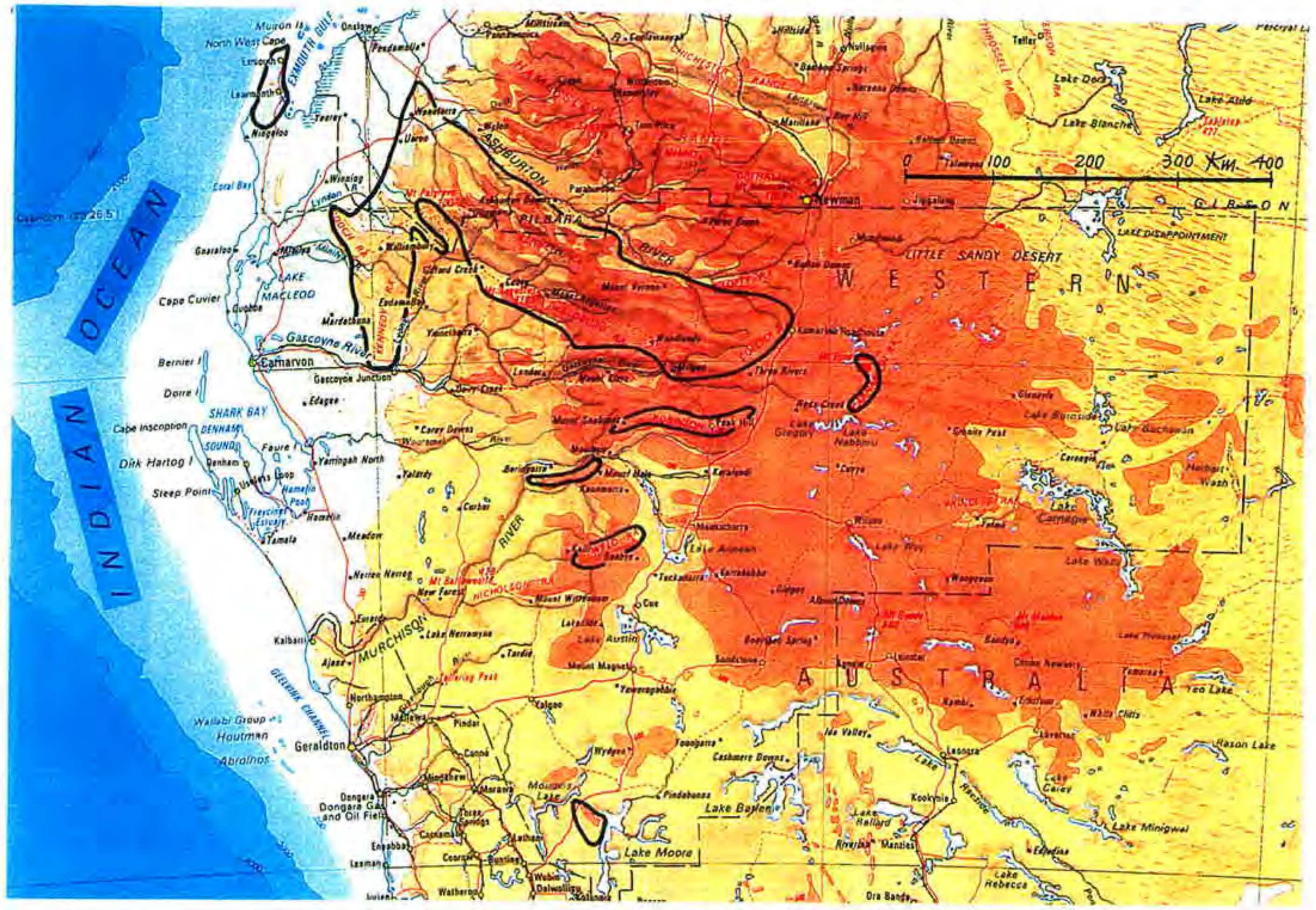
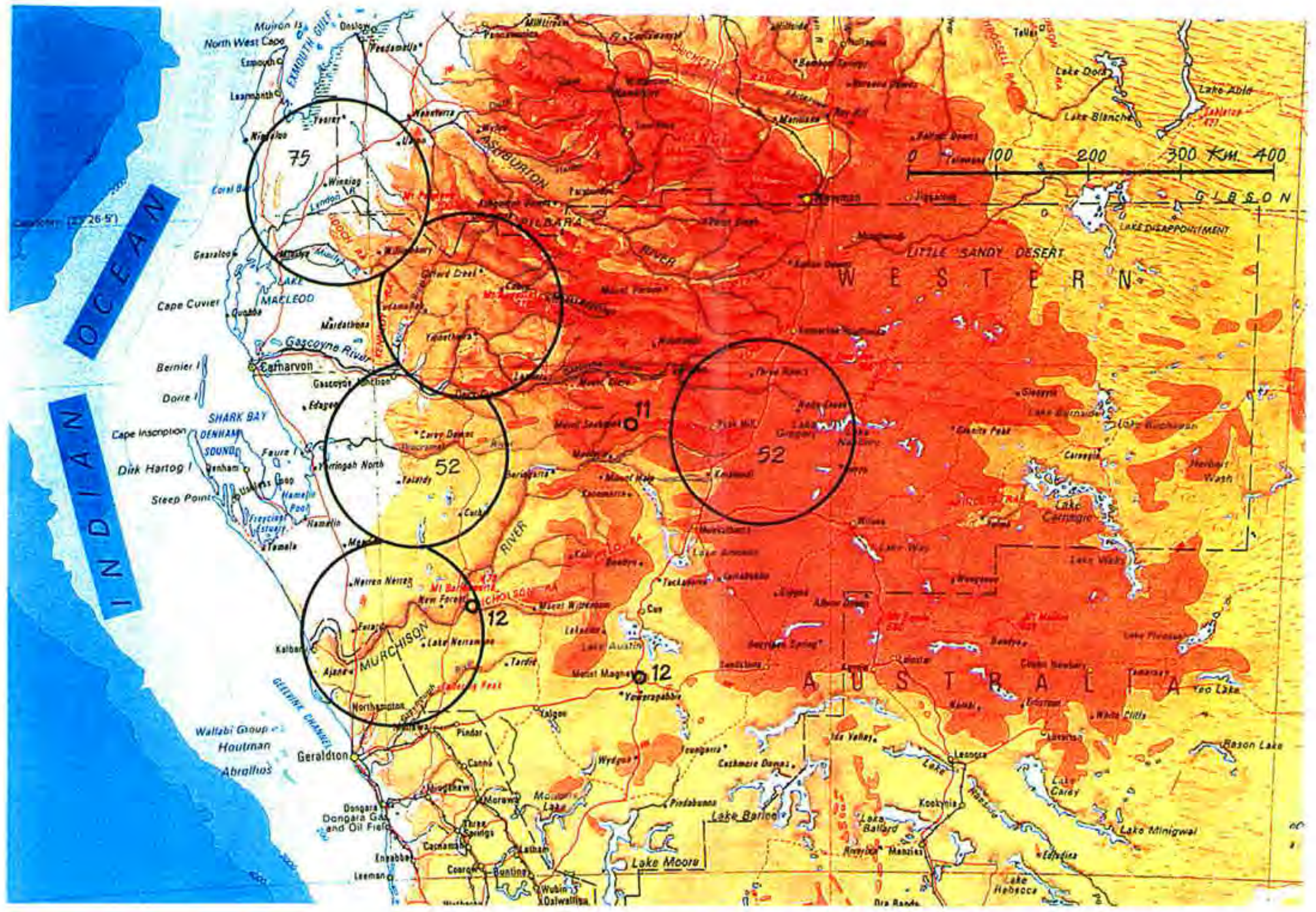

INDIAN OCEAN
116°E
122° E
24°S
26°S
28°S
Exmouth
Tom Price
Paraburdoo
Newman
Carnarvon
Gascoyne Junction
Meekatharra
Wiluna
Cue
Mt Magnet
Yalgoo
Geraldton
Mullewa
Mingenew
Dongara
Leonora
Laverton
1 Stony soil
2 Calcareous stony soil
7 Red shallow sand
9 Pale deep sand
10 Yellow deep sand
11 Red deep sand
13 Calcareous deep sand
18 Red sandy earth
25 Red deep sandy duplex
27 Red shallow loam
28 Redbrown hardpan shallow loam
29 Calcareous shallow loam
31 Red loamy earth
32 Yellow loamy earth
33 Calcareous loamy earth
36 Alkaline red shallow loamy duplex
39 Self-mulching cracking clays
42 Redbrown non-cracking clay
44 Saltlake soil
47 Tidal soil
Fig. 13
SOILS
- Dominant Groups -
(from: 1:3 million map of Dominant Soil Groups of W.A. by Natural Resources Assessment Group Dept. Agriculture 1995).
50 0 50 100 150 200 250 kilometr

Fig. 13

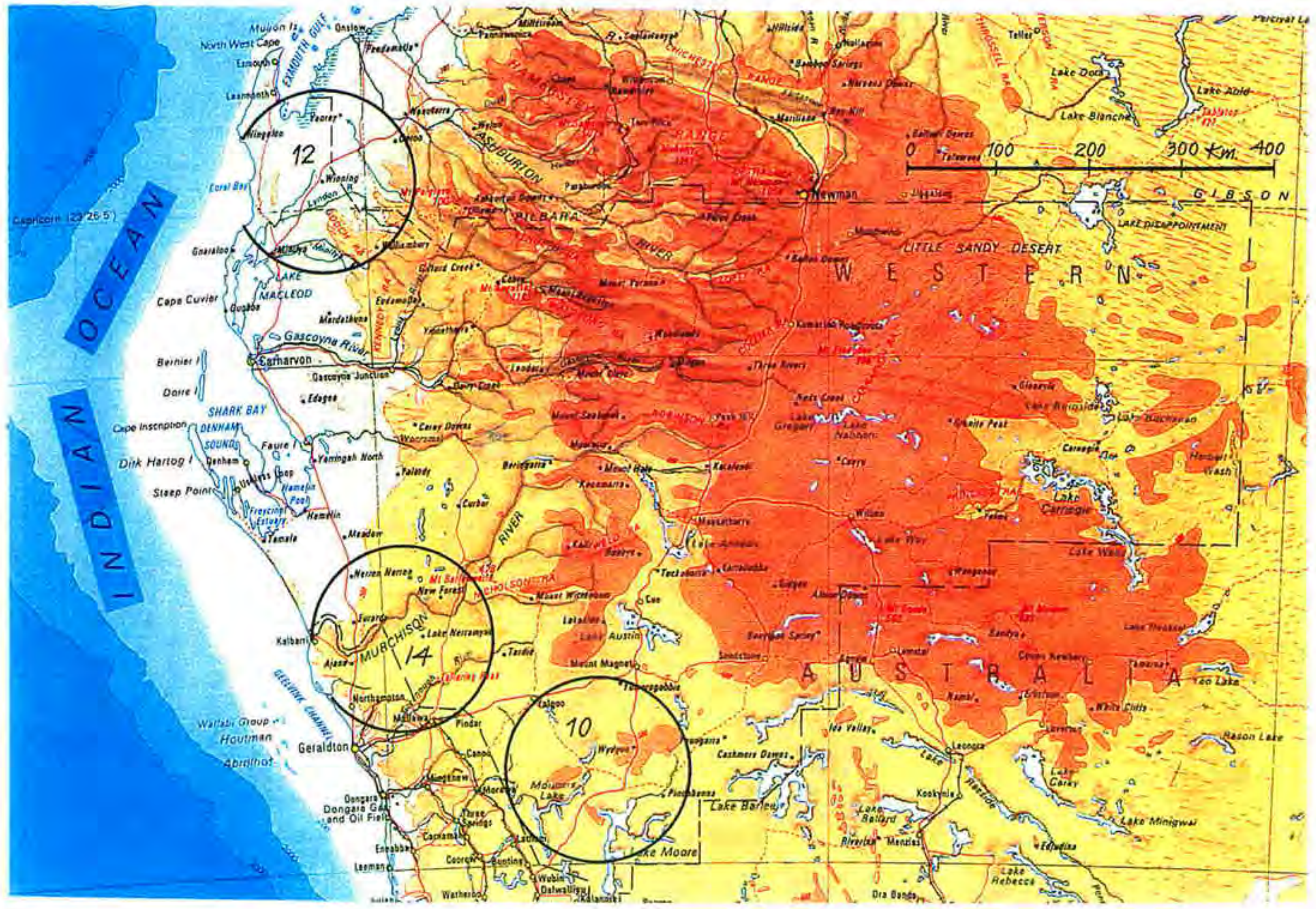

TROPICAL - SUBTROPICAL ARID SAVANNA - SUBDESERT BIOME TYPE
EQUATOR
300 km
Fig. 14
VEGETATION TYPES
(Beard).
Fig. 14
For legend: Damien Shepherd
Fig. 14



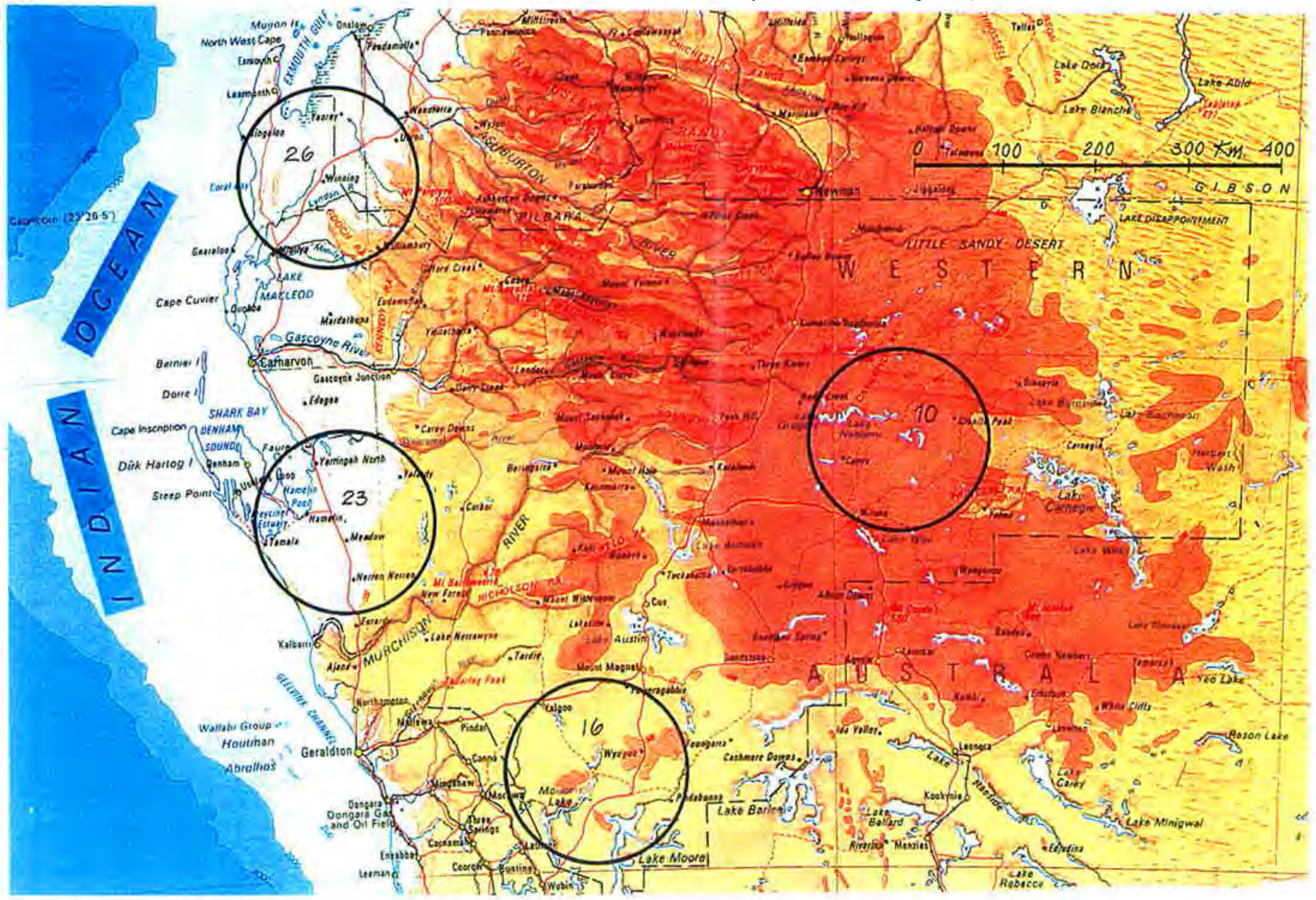
A. **Relief:** areas of greatest diversity



B. **Geology:** highest rock type diversity areas within 100 km radii, and at the local scale within 5 km radii (from 1:250 000 geological maps).



C. **Soils:** highest diversity areas of dominant groups within 100 km radii (from 1: 3 million soil map).



D. **Vegetation Types:** highest diversity areas within 100 km radii (from Beard 1975,1976a 1:1 million map scale).

FIG. 15 AREAS OF HIGHEST ROCK, SOIL & VEGETATION TYPE DIVERSITY.

Fig. 15

Fig. 16 ECOJUNCTIONS OF HIGHEST INTERSPERSION WITHIN 10×10 Km GRID OF THE GMS AREA.

(GIS generated by Damien Shepherd from Rangeland landsystem maps).

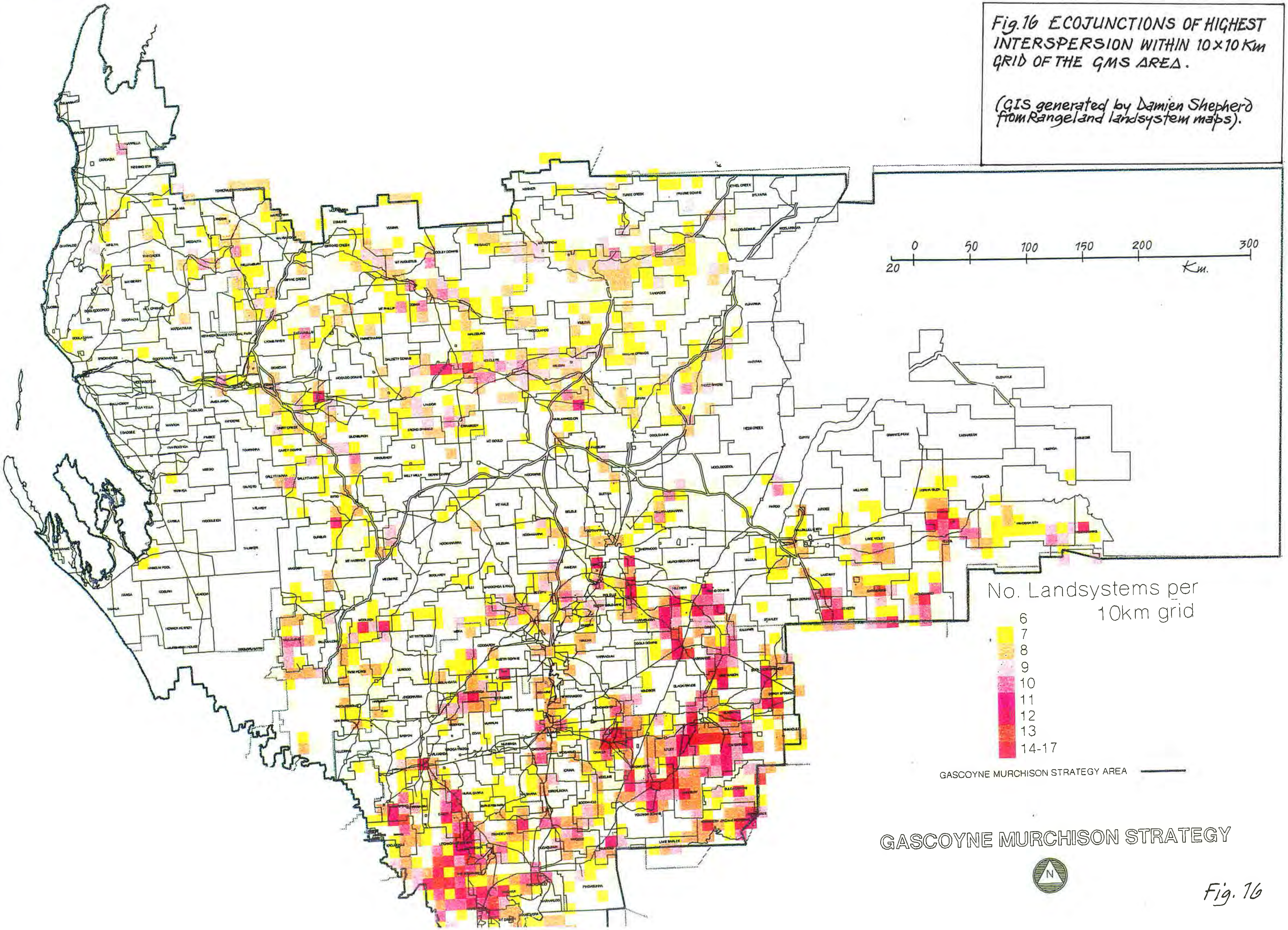


Fig. 16

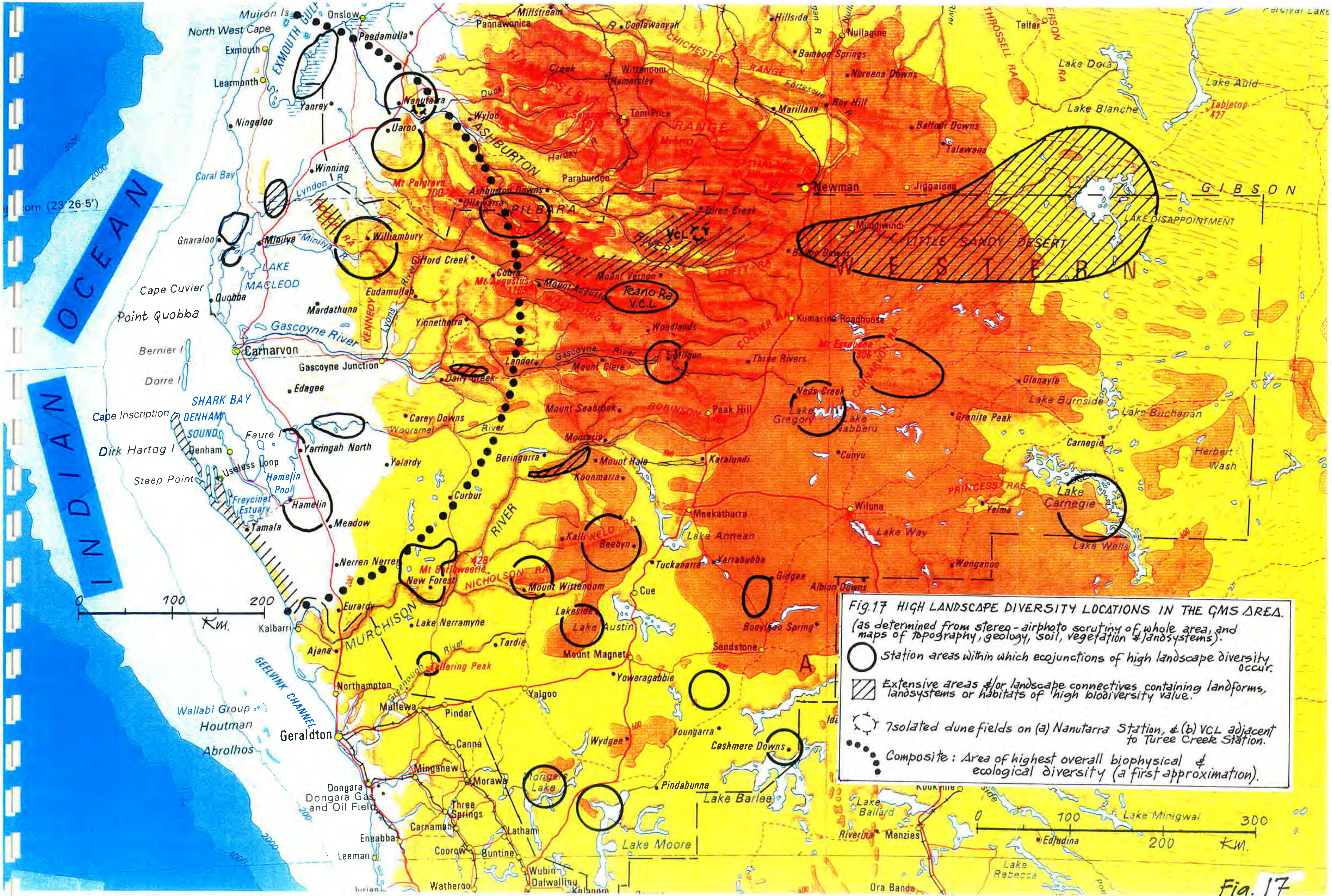


Fig.17 HIGH LANDSCAPE DIVERSITY LOCATIONS IN THE GMS AREA.
(as determined from stereo-airphoto scrutiny of whole area, and maps of topography, geology, soil, vegetation & landsystems).
Station areas within which ecojunctions of high landscape diversity occur.
Extensive areas &/or landscape connectives containing landforms, landsystems or habitats of high biodiversity value.
Isolated dunefields on (a) Nanutarra Station, & (b) VCL adjacent to Turee Creek Station.
Composite: Area of highest overall biophysical & ecological diversity (a first approximation).
0
100
200
Km.
0
100
200
300
Km.
INDIAN
OCEAN
Muiron Is
North West Cape
Exmouth
Learmonth
EXMOUTH GULF
Onslow
Peedamulla
Yanrey
Nanutarra
Uaroo
Ningaloo
Coral Bay
Winning
Lyndon R
Gnaraloo
Minilya
Minilya R
LAKE MACLEOD
Cape Cuvier
Quobba
Point Quobba
Mardathuna
Gascoyne River
Bernier I
Carnarvon
Gascoyne Junction
Dorre I
Edagee
SHARK BAY
Cape Inscription
DENHAM SOUND
Dirk Hartog I
Denham
Faure I
Useless Loop
Steep Point
Hamelin Pool
Freycinet Estuary
Hamelin
Tamala
Meadow
Yarringah North
Yalardy
Nerren Nerren
New Forest
Kalbarri
Eurardy
Ajana
MURCHISON
Lake Nerramyne
Tardie
Northampton
Mullewa
Pindar
Yalgoo
Wallabi Group
Houtman
Abrolhos
GEELVINK CHANNEL
Geraldton
Canna
Mingenew
Morawa
Dongara
Dongara Gas and Oil Field
Three Springs
Carnamah
Latham
Eneabba
Coorow
Buntine
Leeman
Wubin
Dalwallinu
Watheroo
Pannawonica
Millstream
Coolawanyah
CHICHESTER RANGE
Wittenoom
Hamersley
Tom Price
Hillside
Nullagine
Bamboo Springs
Noreena Downs
Marillana
Roy Hill
Balfour Downs
Talawana
ASHBURTON
Wyloo
Hardey R
Paraburdoo
Ashburton Downs
Ullawarra
PILBARA
Mt Palgrave
Newman
Jiggalong
Three Creek
VCL
Mundiwindi
LITTLE SANDY DESERT
Williambury
Gifford Creek
Cobra
Mt Augustus
Mount Augustus
Mount Vernon
Rano Ra V.C.L.
Eudamullah
KENNEDY RA
Lyons River
Yinnetharra
Woodlands
Kumarina Roadhouse
Landor
Gascoyne River
Mount Clere
Milgun
Three Rivers
Daily Creek
Mount Seabrook
Peak Hill
Neds Creek
Lake Gregory
Lake Nabberu
Carey Downs
Wooramel River
Mooragie
Beringarra
Mount Hale
Karalundi
Koonmarra
Curbur
RIVER
Meekatharra
Wiluna
Lake Way
Lake Annean
Kalli
Beebyn
WELD RA
Tuckanarra
Yarrabubba
Gidgee
Mt Bellaweerie
NICHOLSON RA
Mount Wittenoom
Cue
Albion Downs
Lakeside
Lake Austin
Booylgoo Spring
Sandstone
Mount Magnet
Tallering Peak
Yoweragabbie
Youngarra
Wydgee
Cashmere Downs
Pindabunna
Lake Barlee
Lake Moore
Lake Ballard
Riverina
Menzies
Ora Banda
Telfer
Lake Dora
Lake Auld
Lake Blanche
Tabletop 427
GIBSON
LAKE DISAPPOINTMENT
WESTERN
Glenayle
Lake Burnside
Lake Buchanan
Granite Peak
Carnegie
Herbert Wash
PRINCESS RA
Yelma
Lake Carnegie
Lake Wells
Wongawol
Lake Minigwal
Edjudina
Lake Rebecca

Fig. 17

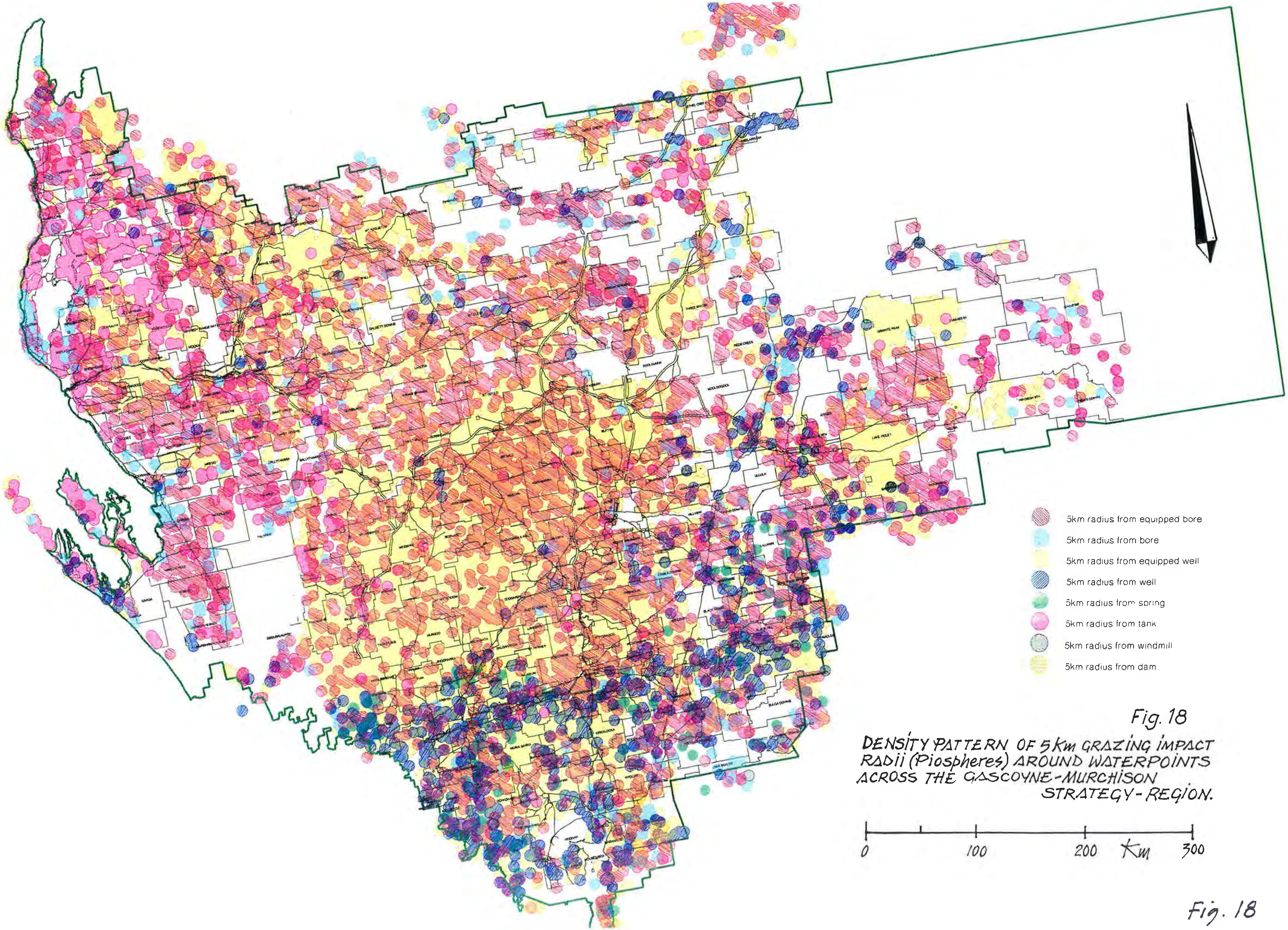


Fig. 18

DENSITY PATTERN OF 5 Km GRAZING IMPACT RADII (Piospheres) AROUND WATERPOINTS ACROSS THE GASCOYNE-MURCHISON STRATEGY-REGION.

Fig. 18

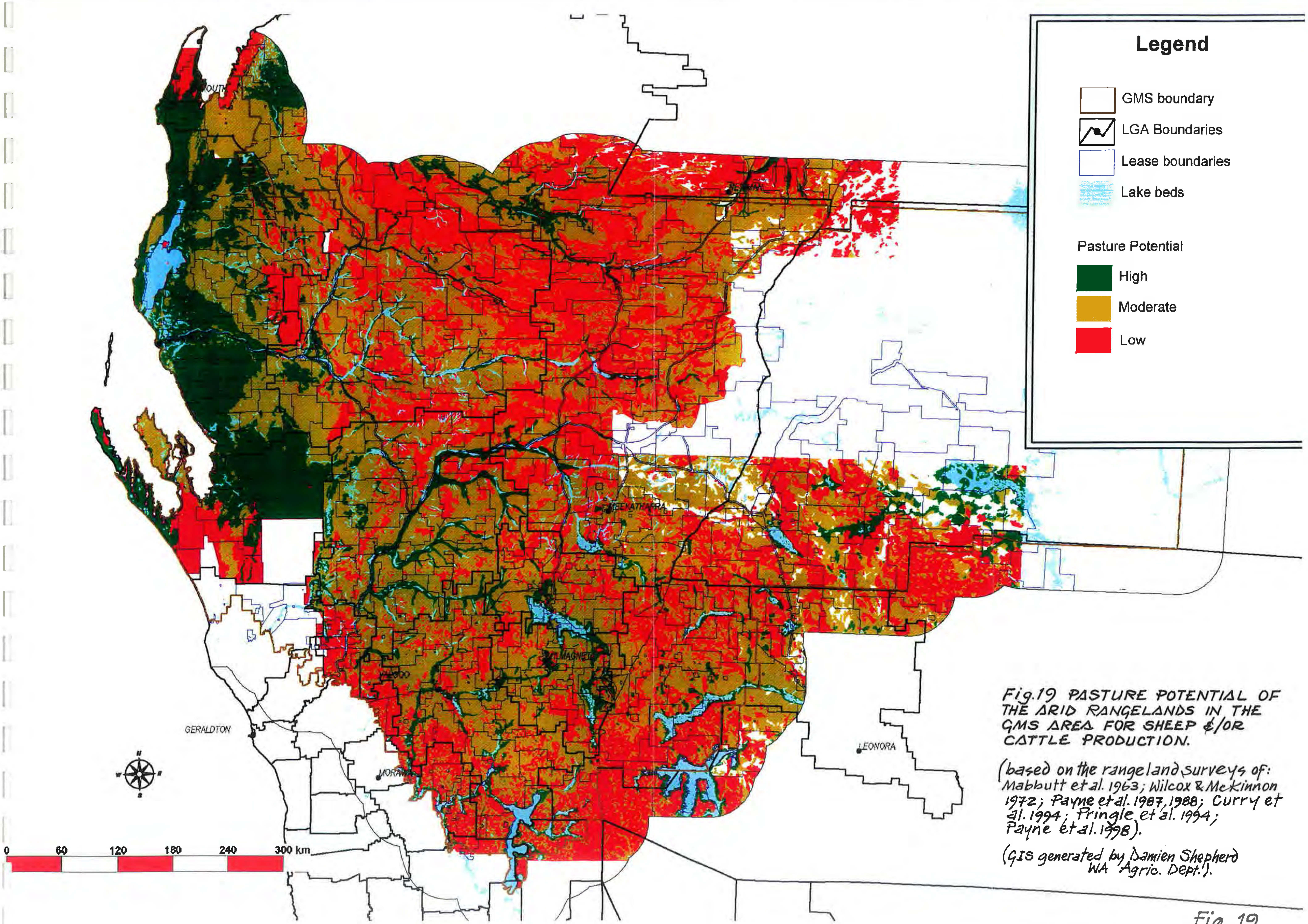


Fig.19 PASTURE POTENTIAL OF THE ARID RANGELANDS IN THE GMS AREA FOR SHEEP &/OR CATTLE PRODUCTION.

(based on the rangeland surveys of: Mabbutt et al. 1963; Wilcox & McKinnon 1972; Payne et al. 1987, 1988; Curry et al. 1994; Pringle et al. 1994; Payne et al. 1998).

(GIS generated by Damien Shepherd WA Agric. Dept.).

Fig. 19