Ecosystems and Ecological Communities in Western Australia:

A Nested Set of Entities

A Discussion Paper

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Summary

Within the rapidly developing scientific literature and formal (statutory) protocols relating to biodiversity conservation, there is a wide range of terms and concepts describing the environment and its associated biota. The entities that are described by these terms vary in scale and definition. Within the scientific literature, the entities are reasonable well understood. But the recent adoption of a separate nomenclature for the purposes of implementing statutory controls has introduced a set of new terms and concepts – these have yet to be effectively correlated with the scientifically-described entities. This paper is intended to initiate the discussion to bring the various different terms and concepts together.

The development of the nomenclature for describing soils and landscapes in Australia is described. The concept of the land system, as proposed by Christian and Stewart (1947) has become central to describing and mapping soils and landscapes, including Australia's rangelands. The system concept has also been adopted in vegetation mapping, describing a similar, broad-scale unit of the environment. A range of more finely discriminated units exists for the different disciplines – for vegetation mapping, they are the vegetation association, and the vegetation or plant community. The environmental units can be grouped into sets within discipline areas; within each set there is usually an hierarchy from regional to local-scale units, or from small scale to large scale units .

Two other concepts or environmental units require matching with the mapping units: ecosystems and ecological communities. These units are considered to be most suitable for planning for nature conservation and are widely used for this purpose. The Ecosystem and Ecological Communities project database ECOSTATUS (Morgan and Hopkins 1999) contains examples of both types of units, but they are maintained as separate data layers in the GIS. An ecosystem is considered to be, in general, a broad-scale unit, whereas an ecological community is likely to be smaller, or restricted in area. An ecosystem may include several ecological communities. A system of categorising the ECOSTATUS ecosystems and ecological communities into nine types based on issues of scale and level of discrimination, as well as data type, is described.

1. Introduction

Over the past 25 years especially, a range of units have been proposed through the scientific literature and through formal processes (including statutory processes) for use in practical nature conservation. At the level above species, these have included such entities as bioregions, biomes, ecosystems, vegetation associations, vegetation communities, vegetation systems, land systems, land units, communities and ecological communities. These entities differ in scale and level of definition, and some are clearly organised in neat hierarchies. Others, however, describe the environment and and/or the biota in different ways, and so can be considered equivalent rather than a part of the same hierarchy. There is, therefore, a need to clearly understand each of the concepts so that the terminology is used with precision, and so that confusion can be avoided.

The objective in preparing this discussion paper is to raise the issue of how these entities might relate to each other as a means of initiating a debate about the use of terminology. The paper is a first attempt to deal with issues of scale and relativity raised through the project entitled *An interim framework for developing a comprehensive, adequate and representative protected areas system in Western Australia*, a major part of which was to develop a comprehensive inventory of ecosystems and ecological communities in the State (Morgan and Hopkins 1999). It is relevant too to discussions about the limits of the ecological community concept in the context of the need to identify Threatened Ecological Communities in Western Australia – a non-statutory process in this State but present, and in Australia under the Environmental Protection and Biodiversity Act 1999 (Cwlth).

2. Environmental units in Western Australia

Table 1, adapted from Gentilli (1979), gives a clear indication of the existence in the scientific literature of a wide range of names and concepts used to identify and describe units or components of the environment, and the way in which these are or can be organised into hierarchies or nested sets. An example drawn from this table that is familiar is the set of terms used to describe physiographic units that grade from Division at the sub-continental scale through Province, Region, District/Land System to Land Unit and Facet at the local scale. A similar, nested set of units has been described for Western Australia by Beard (1980): Province, District, Sub-district and System, into which fit various Vegetation Associations.

It is instructive to look briefly at the history of use of these kinds of names and concepts within Australia. It would appear that there has been a process of parallel evolution of describable environmental units as the need and capacity to describe, map and understand the environment has increased. Two particular streams of the evolutionary process are relevant. The first stream deals primarily with soils and landforms and comes from a production perspective. The second deals with native vegetation and has a natural history perspective.

In 1946, CSIRO responded to the identified need to describe and map the extensive, less-developed parts of Australia by establishing a Division of Land Research and Regional Survey, and resourcing survey teams for the task. Amongst the survey team members were C.S. Christian and G.A. Stewart, who soon developed the land survey

Table 1. Scale, size and examples of regional units (simplified from Gentilli 1979).

Preferred limiting scale 1:	Indicative size km^2	WA Examples	Term (reference)
	100,000	Winter-rain Zone Sandridge Division Perth-Fremantle Hinterland	Planetary/Phyto-climatic Zone Physiographic Division (Jutson) Realm (Whittesey)[land-use]
10,000,000			
	10,000 - 150,000	Stirling Block Perth Coastal Plain [Northern] Beef Pastoral Areas	[Geo]morphological Province (Gvozdetskii) Province (Whittesey)[land-use]
1,000,000			
	1,000 - 30,000	Salt lake Region; Karri Forest Great Southern Wheatbelt Canning System	Region (Herbertson, Unstead, Clarke) Landscape type (Sestini) Complex land system (Christian)
200,000			
	100 - 5,000	Canning Basin Dune Systems Darling Scarp Abrolhos Serpentine Catchment	Landscape (Passarge, Troll, Schmithusen) *Pays* (Vidal de la Blache, Gallois) *Gegend* (Hommeyer) *Oblast* (Gvizdetskii) District (Whittlesey, James) Terrain province (Grant) Land system (Christian)
50,000			
	10 - 1,000	Pardoo Sands Lower Gascoyne Point Peron Swan (Landform)	Locality (Whittlesey, James) Site (Bourne) Tract (Unstead) *Ort* (Hommeyer) Ecotope (Tansley) Geotope (Schmitusen) Land unit (Christian) Unit area (Bryan) Terrain unit (Grant) Landscape element (Sestini)
10,000			
	<100	Merredin Rock Booragoon Swamp Red Hill, Upper Swan	Stow (Unstead), [Landscape] cell (Paffen) [Ecological] synusia (Gams) [Geo]biocenosis (Sukschev) Geomorphological facet (Wooldridge) Terrain component (Grant) [Morphological] catena (Milne) Land element (Haantjens) Landform element (Speight)

Note: Placement in the same hierarchical position and approximate size category does *not* imply the exact equivalence of terms which are used in different sciences. Hierarchical terms formed with 'small', 'minor', 'great', 'major', 'group' etc have been omitted.

protocols that are at the foundation of our present methods and nomenclature. They described land unit as a particular land form which, at each of its various occurrences, has associated with it the same group of soils and vegetation communities. The underlying idea is that strict associations of characteristics are likely to occur only if the various occurrences of the landform have a common genesis, and if the factors acting on that landform over evolutionary time eg climate, weathering patterns etc.have been comparable. The land system was described as a naturally-occurring pattern of land units that are geomorphologically associated and morphologically related. It was considered that the boundary of any land system would coincide with the limits of major geological, geomorphological, climatological or biological features in the landscape. CSIRO focussed on mapping land systems, which they believed to be identifiable as " distinctive patterns of country" (Christian 1959, Christian and Stewart 1947).

The Christian and Stewart landscape mapping and classification scheme was widely used in northern and central Australia, and subsequently was modified to be more specific for rangelands surveys and mapping, and for soil surveys and mapping. In the course of this, a smaller-scale unit added was added to the scheme – the land zone, regarded as a grouping of land systems into an identifiable region or zone.

The Christian and Stewart protocols were applied within Western Australia early in the program, and involved two people who became significant in the more widespread application of them. A major contributor to the North Kimberley project (Speck *et al.* 1960) was N.H. Speck, who later mapped an area Wiluna-Meekatharra as part of a project that also involved D.G. Wilcox (Mabbutt *et al.* 1963). Speck worked on his PhD research at the same time as these two rangelands surveys, and successfully tarnsferred the land system mapping and description protocols to vegetation survey, naming and describing 26 vegetation systems in the Darling, Lesueur and Irwin Botanical Districts (Speck, 1958). Speck also created the Botanical District concept, later used widely by Beard. Wilcox was instrumental in having the Western Australian rangelands survey unit, established in the late 1960s, adopt the practise of identifying and mapping land systems eg Wilcox and McKinnon (1972). Land system mapping has grown in extent and sophistocation over the last 30 years, and now covers all Western Australia's rangelands except the western Nullarbor and the southern Goldfields (eg Pringle *et al.* 1994).

The land system mapping approach has also been adopted by the soils mapping group in Agriculture Western Australia. The present nested set of terms being used by this group goes from region through district, zone, soil landscape system, soil landscape sub-system (≈ unit), to soil landscape phase (≈ facies). Polygons of soil type can be mapped at a larger scale than soil landscape phase eg 1:5,000 vs 1:25,000. As an example of how this taxonomy works, some 20 zones are now recognised in the South West and Eucla Land Divisions and, within this, there are about 300 soil landscape systems (N. Schoknecht, Agriculture Western Australia, personal communication September 2000).

The parallel process, identifying environmental units in Western Australia based principally on vegetation characteristics, began with von Mueller and Diels (von Mueller 1867, 1983, Diels 1906) and was developed further by Gardner (Gardner 1942, Gardner and Bennetts 1956). These workers produced preliminary maps of the Botanical Provinces and Districts throughout the State. The phytogeographic regionalisation concept was developed further by Speck, who introduced the Christian and Steward land system-level unit, the vegetation system (Speck 1958). The vegetation systam was subsequently adopted by both Beard and Smith in their vegetation mapping projects in Western Australia (eg see Beard and Webb 1974, Smith 1972, 1973, 1974).

Beard refined and extended the phytogeographic regionalisation and natural region concepts substantially, based on the deep insights gained in the course of the Vegetation Survey of Western Australia project (Beard and Webb 1974). Beard began to incorporate redefined boundaries on his published 1:1,000,000 vegetation maps (eg.see Beard 1974) and, in 1978, compiled the first detailed, State-wide map of his regionalisation at the scale of 1:2,500,000 and it was subsequently published with detailed explanatory notes (Beard 1980). The Phytogeographic Regions represent a very considerable refinement of the scheme of Gardner and Bennetts (1956) with boundaries that are largely coincident with boundaries of vegetation units mapped by Beard at the scale of 1:250,000, selected on the basis on factors such as geology and climate as well as vegetation. Beard recognised three major Provinces and an Interzone and, within these, 21 Districts. Beard also recognised Subdistricts - these are shown on the individual 1:250,000 map sheets. Some 32 vegetation systems are mapped for the South-western Botanical Province, the only region for which this level of mapping was published. Beard likened his concept of vegetation system to a catenary sequence - a repeating geomorphological patten supporting vegetation units that show a repeating pattern related to geomorphology and soils (Beard 1969, Beard and Webb 1974).

In later publications, Beard referred to the phytogeographic regions to natural regions (Beard 1990, Beard and Sprenger 1984). The regionalisation was subsequently incorporated with minor changes into a national regionalisation called the Interim Biogeographic Regionalisation for Australia (IBRA) (Thackway and Cresswell 1994).

In describing the terms and concepts used in the Vegetation Survey of Western Australia project, Beard elaborated the following hierarchy (Table 2):

Table 2. Table showing the relationships between the classification adopted for the Vegetation Survey of Western Australia project and major world systems of soil classification (from Beard 1969, Beard and Webb 1974).

	Unit 1	Unit 2	Unit 3	Unit 4	Unit 5	Unit 6
Vegetation classification	Faciation, society etc	Plant association (floristic)	Plant formation (physiognomic)	Vegetation system	Botanical district	Botanical province
U.S. Soil Survey classification	Soil phase or variant	Soil type	Soil series and soil complex	—	—	—
British Soil Survey classification	Subtype	Soil type	Soil series and soil complex	Soil association (Scotland) Catenas and mosaics (England)	Major region	—
Russian Soil Survey classification	Soil individual	Soil variety	Soil complex	Elementary landscape	Soil Region	Soil province

Beard's vegetation nomenclature is in close agreement with that proposed by Beadle and Costin (1952). Those authors described the association, sub-association and society thus:

An Association is defined as a climax community of which the dominant stratum has a qualitatively uniform floristic composition and which exhibits a uniform structure as a whole.

A Sub-Association is a sub-division of the association determined by a variation in the most important subordinate stratum of the association, without significant qualitative changes in the dominant stratum.

A Society is defined as a subordinate community contained within the structure of the association or sub-association (Beadle and Costin 1952 pp64-67).

Beadle and Costin (1952) also proposed the use of terms: Alliance - to cover a grouping of floristically-related associations of similar structure; Sub-Alliance - for a subdivision of an alliance, obtained by arranging the component associations into groups of maximum affinity; Formation – for the structural unit to which are referred all climax communities exhibiting the same structural form, irrespective of floristic composition; and Sub-formation – for the subordinate synthetic structural unit within which the general pattern of a formation, to which are referred all climax communities exhibiting the same structural sub-form, irrespective of floristic composition. In this set of terms, the sub-formation and sub-alliance concepts might be considered difficult to apply in any practical way; however, the sub-formation concept might be clarified by including consideration of the sub-dominant stratum in the definition of formation and sub-formation. In other words, an open woodland with a shrub understorey might be distinguished from an open woodland with a grassy understorey at the sub-formation level.

The vegetation mapping terms and concepts can be seen to form an hierarchy, from formation through alliance and sub-alliance to association, sub-association and society. The word "community" is used rather loosely – in the Glossary as "any assemblage of plants and their dependant fauna" – however, the definitions suggest that the sub-association level or perhaps the society level units are most in accordance with the contemporary concept of plant community, being a unit defined primarily on the basis of floristic composition (eg see discussion in Sivertsen and Metcalf 1995).

Recently, an hierarchial classification of mappable vegetation units has been devised for the National Vegetation Information System (NVIS), a project being run under the umbrella of the National Land and Water Resources Audit (Commonwealth) (NLWRA 1998).The objective of NVIS project is to compile consistent vegetation mapping data for the whole of Australia, ultimately to facilitate improved land-use planning and management, and related decision-making, at the Commonwealth level. The NVIS Hierarchy is illustrated in Table 3.

Table 3. The hierarchy of vegetation mapping units proposed to be incorporated into the National Vegetation Information System (from ERIN 1999).

Hierarchical Level	**Level Definition**	**Physiognomic Description**	**Example NVIS Name**
Class	A description defining growth form and broad structure of the community	Growth form	Tree
Structural Formation	Formation classes defined by growth form and crown separation (woody plants) or foliage cover (ground stratum) and qualified by height class	Growth from, cover and height	Tall woodland
Sub-Formation	(no agreed definition as yet)	Growth form, height and cover, and floristic	*Eucalyptus* Tall woodland or *Acacia*

		information	Tall shrulband
Association	A climax community of which the dominant stratum has a qualitatively uniform floristic composition and whicl exhibits a uniform structure as a whole	Growth form, height, cover and floristic information for the foremost species in the uppermost or ecologically stratum	*E. miniata, E. tetradonta* Tall woodland or *Triodia pungens* Tall open hummock grassland with *Sorghum stipoideum* tussock grassland
Sub-Association	A sub-division of the association determined by a variation in the most important subordinate stratum of the association, without significant qualitative changes in the dominant stratum	Growth form, height, cover and floristic information for the foremost diagnostic species in all strata	*E. miniata, E. tetradonta* Tall woodland with *Sorghum stipoideum* tussock grassland
Community	The finest level in the hierarchy. As for sub-association but including full species lists and physical environmental attributes		

The table shows that the environmental unit called a [plant/vegetation] community is considered to be more finely discriminated than the vegetation association or sub-association. The vegetation community is defined primarily on the basis of the grouping of species present, rather than on structural or physiognomic characteristics. Throughout Australia, units given the rank of vegetation community are invariably identified using at least qualitative analysis of data on floristic composition (eg Sivertsen and Metcalf 1995).

In summary, this brief review has shown the existence in the scientific literature of a wide range of names and concepts used to identify and describe units or components of the environment. The review has shown or implied how units or concepts have been transferred from one environmental discipline to another. Some authors have attempted to illustrate the relationships between the various units – those within a particular discipline can be organised into hierarchies or nested sets that may be matched with units at a similar scale drawn from other disciplines.

3. The ecosystem concept and its application

A key concept and environmental unit was introduced into the biological lexicon in1935 by the noted British plant ecologist A G Tansley. He proposed the concept of the *ecosystem* as a holistic one that combined living organisms and their physical environments into an integrated unit or system. At the time, there were two schools of thought on the nature of plant communities. One view held that species responded individually to environmental gradients to form a continuum of vegetation, and that overlap in species distribution was due to the chance occurrence of different species with similar environmental needs (the individualistic concept). The other held that the climax vegetation of a region consisted of groups of coevolved species that formed a complex organism which exhibited a life cycle much the same as that of the individual organism (the community concept). Tansley attempted to unite these opposing views by proposing that the combination of organisms and their physical environment together comprise a system, the ecosystem, which could be viewed as the basic unit of nature:

But the more fundamental conception is, as it seems to me, the whole *system* (in the sense of physics), including not only the organism complex, but also the whole complex of physical factors forming what we call the environment of the biome—the habitat factors in the widest sense.

It is the systems so formed which, from the point of view of the ecologist, are the basic units of nature on the face of the earth.

These *ecosystems*, as we may call them, are of the most various kinds and sizes. They form one category of the multitudinous physical systems of the universe, which range from the universe as a whole down to the atom. (Tansley 1935, p 299).

The concept was generally well received by the scientific community, but it was some time before the ecosystem concept began to be applied in a practical sense (Golley 1993). A major challenge appears to have been translating a concept that could "...range from the universe... down to the atom" into a practical unit of the environment. Originally the concept was applied to aquatic ecology, since the boundaries of aquatic ecosystems were relatively easy to define. Lindeman (1942) studied trophic dynamics within a lake by comparing the amount of energy or food flowing from one trophic level to another, and was the first to quantitatively implement Tansley's ecosystem concept. Most importantly, Lindeman's rudimentary mathematical description of the ecosystem included not only energy and nutrient flows between species, but also between species populations and the non-living components of the system.

The ecosystem concept became popularised with the publication of E P Odum's *Fundamentals of Ecology* (Odum 1953) so that, by the mid-1960s it was a dominant concept in ecology. At the same time, ecosystem studies progressed, but with an increasing concentration on individual properties of the system – the reductionist approach that was a feature of the times – and few attempted to study the ecosystem as a whole.

There was, however, continuing confusion about the application of the concept, due to multiple usages of the term ecosystem, problems of boundary definition, and disagreements between holistic and reductionist approaches. The landmark study of a terrestrial ecosystem in terms of chemical nutrient flow by Bormann and Likens (1967, 1979) addressed these problems to some extent— they defined their ecosystem as a complete catchment, bounded by watersheds. The interpretation of a terrestrial ecosystem as a geographical unit, and its study as a whole, provided the impetus to shift the focus of ecosystem studies back towards understanding major features of ecosystem processes.

As the environmental movement gained momentum in the late 1950s, public awareness of the detrimental effects of human activity on natural systems increased. The concept became popular as a means of understanding the place of humans in nature, and use of the term ecosystem signified an understanding of the interrelatedness of natural processes (Golley, 1993). This use of the ecosystem concept has been particularly useful in the area of nature conservation, perhaps due to the fact that it can be applied at any level. Large-scale environmental problems have stimulated the science of global biogeochemistry, which treats the earth as a single ecosystem, while smaller scale ecosystem studies are useful for assessing the effects of human interactions with the environment at a local or regional level.

While studies of whole ecosystems are still relevant to some areas of ecology, rapid environmental change means that land use planning decisions must often be made on the basis of available information, without the benefit of long-term ecosystem studies. In the case of reserve system planning, defining ecological units as ecosystems acknowledges the desire to conserve all biotic and abiotic components within a specified area. The reserve system can then be aimed at maintaining representative samples of all original ecosystems for the purposes of *in-situ* nature conservation. Applied in this way, the ecosystem concept provides a useful means of reducing the complexity of natural systems to manageable units.

However, the challenge in the use of the ecosystem concept, defining them as practical environmental units remains, and is exacerbated by attempts to use ecosystems in designing a conservation reserve system. Effective planning of such a reserve system requires a mappable environmental unit for consistent assessment and upgrading of the system. Although the definition of an ecosystem is unambiguous, in that it incorporates all abiotic and biotic components of natural systems, the application of the concept is difficult at a practical level (Haila *et al.*, 1993). The energy and nutrient flows of an ecosystem include input from, and output to, other natural systems, creating a web of interactions that link ecosystems in a continuum across the landscape. In other words, there is no absolute concept of an ecosystem (or ecological community) in surveying and mapping, since the concept refers to natural processes and habitats at a range of scales (Beard, 1981). The scale used and the way in which units are represented on the map affect both the number and size of the ecosystems and ecological communities defined.

To overcome these problems, ecosystem classifications use synthetic ecological units derived from biotic and abiotic classifications. In essence, these classifications are based on the structural entities of ecosystems, with functional aspects implied. For example, the *Guidelines for Establishing the National Representative System of Marine Protected Areas* (Environment Australia, 1998) summarises the representation of ecosystems as geographical units as follows:

An ecosystem classification may be derived by digital and/or manual spatial classification of abiotic and/or biotic data and be represented as mapped units. An ecosystem map unit should normally be discriminated at a resolution requiring a map-standard scale of 1:1,000,000 to 1:250,000.

The Biogeoclimatic Ecosystem Classification (BEC) for terrestrial ecosystems uses vegetation and soils to define each ecosystem (Meidinger and Pojar, 1991). These factors were chosen based on the fact that climate, organisms, topography, parent material, and time combine to produce vegetation and soil. In addition, soils and plants are easy to observe and assess. Using this method, ecosystems are delineated on the basis of the extent of a plant community and its associated soil type. The BEC has been used successfully in forest management in British Columbia since 1975.

In Victoria, the approach now is to define and map units called Ecological Vegetation Classes (EVCs) across the State. The Ecological Vegetation Classes system identifies:

floristic communities that grow under comparable environmental conditions [and] have similar life forms and vegetation structure (Woodgate *et al.* 1994).

Other ecosystem classifications also use vegetation classifications mapped at a consistent scale, combined with geoclimatic data, to represent ecosystems (Host *et al.*1996; Noss *et al*, 1995). However, there are many ecosystems that are not covered by this approach, such as caves, groundwater systems and ecosystems dominated by microbial assemblages. Furthermore, some species, particularly animals, have distributions that do not conform with vegetation patterns, and/or are not accurately predicted by physical environmental parameters. Thus, it is necessary to identify ecosystems at a range of spatial scales and from the perspective of a variety of different types of organisms in order to identify important elements of the hierarchy of ecosystems that may be obscured by classification at a single scale (eg Noss *et al.* 1995).

4. Concept of ecological communities

The concept of a community of organisms coexisting as a discrete and independent unit in space has long been debated in the ecological literature (Andersen 1995, Clements (1936), Gleason 1926a, Walter and Paterson 1994, 1995). As mentioned above, the original debate centred around whether species were individualistic or existed as communities of coevolved species. It is now generally accepted that species assemblages do often occur in repeated patterns (cf. English and Blyth, 1997, Paine 1980), and that the distribution and abundance of species within these communities can be explained by a variety of biotic (Patterson and Brown, 1991) and abiotic factors (Austin and Heyligers 1989; Crawley, 1993, Wright *et al.* 1998), but without the assumption of coevolution of species (Andersen 1995). This does not exclude species interactions, but merely accepts that interactions between species did not necessarily cause their co-occurrence.

Like the ecosystem concept, there is no absolute definition of a community, as it may refer to species assemblages at a number of scales. However, since communities are often the result of overlap of distribution of species with similar environmental needs, they are usually defined by their collective response to environmental scalars such as temperature, altitude and soil moisture. Of course, it should not be overlooked that communities operate in environmental space and can co-occur in geographical space, for instance, depending on the intersections in the relevant environmental scalars (eg. McKenzie *et al.* in press). For pragmatic reasons, ecological communities are converted to geographical units for land use planning. The Endangered Species Scientific Subcommittee (1995) considers that the recognition of the boundaries of a community or ecosystem is a matter of scientific judgement in the same way as species definition.

Ecological community is a synthetic term, designed for use in an operational sense. An ecological community is defined by the Commonwealth's *Environmental Protection and Biodiversity Conservation Act* (1999) as:

an assemblage of native species that:
(a) inhabits a particular area in nature; and
(b) meets the additional criteria specified in the regulation (if any) made for the purposes of this definition.

Use of the term ecological community sidesteps debate about the nature of communities by providing a specific definition for communities represented as geographical units. The term provides a useful communication tool, particularly for the purposes of land-use planning.

5. Legislative requirements

As discussed above, the *Environmental Protection and Biodiversity Conservation Act* 1999 (Cwlth) provides a definition of an ecological community. Current legislation in some Australian States also provides for listing of threatened ecological communities (Victoria's *Flora and Fauna Guarantee Act* 1988; the New South Wales *Threatened Species Conservation Act* 1995; the Australian Capital Territory's *Nature*

Conservation Act, 1980). Western Australian legislation (*Wildlife Conservation Act* 1950) does not provide for listing of threatened communities at present. However, the Department of Conservation and Land Management maintains a non-statutory database of threatened ecological communities.

The *Environmental Protection and Biodiversity Conservation Act* 1999 also contains a definition of ecosystem:

Means a dynamic complex of plant, animal and micro-organism communities and their non-living environment interacting as a functional unit.

The manner in which the provisions of the Act are laid out makes it clear that ecosystems and ecological communities are considered to be different kinds of entities and that the concepts are intended to be used differently. For example, Chapter 12 – Conservation of Biodiversity, Part 12 – Identifying and monitoring biodiversity and making bioregional plans, section 171 defines components of biodiversity as "...includes species, habitats, ecological communities, genes, ecosystems and ecological processes.Part 13 – Species and communities deals with threatened species, threatened ecological communities, threatening processes and critical habitat. It does not refer to ecosystems.

The *National Strategy for the Conservation of Australia's Biological Diversity* recommends a combination of species and ecosystem approaches to nature conservation. However, as the brief summary above reveals, ecosystems are not explicitly provided for in current legislation, and there is no mechanism to deal with threatened ecosystems. Listing of threatened ecological communities (TECs) may acts to conserve whole ecosystems or substantial parts of ecosystems, since abiotic factors are used to define the habitats of those communities.

6. Definitions for the Ecosystems and Ecological Communities database project

There is an emerging consensus that ecosystems and ecological communities are appropriate basic units for planning a comprehensive, adequate and representative protected area system for nature conservation. The issue then becomes one of defining ecosystems and ecological communities in such a way that they can become operational.

For the purposes of the database project (Morgan and Hopkins 1999), vegetation types identified and mapped at the association level are being used as surrogates for ecosystems. Each vegetation polygon is considered to be a separate ecosystem, with polygons of the same vegetation association being the same ecosystem type.

Where additional environmental information is available, the ecosystems defined on the basis of vegetation are spatially refined and further defined in terms of those environmental factors.

Particular ecosystems that have been identified and mapped through some process other than vegetation mapping are being incorporated into the database.

Ecological communities defined by assemblages of organisms at a range of scales, that satisfy the guidelines developed by the Endangered Species Scientific Subcommittee (1995), and that have some geographical dimensions (ie they can be mapped), are being incorporated separately.

The ecosystems and ecological communities in the ECOSTATUS database can be considered to make up nine different but related data types. In GIS terminology, these can be referred to as data layers in the database. A preliminary ordering of those data layers, given below, suggests that they can be considered as a nested set of entities.

An ecosystem is considered to be, in general, a broadscale unit, whereas an ecological community is likely to be smaller, or restricted in area. An ecosystem may include several ecological communities; for example, a lake may include within its boundaries a fringing vegetation community, an aquatic invertebrate community and a fish community. Furthermore, the same fish community may occur in several related lakes as well as in some streams (Figure 1).

The different types of ecosystems and also of ecological communities have been distinguished on the basis of data type and quality. As knowledge about the State's environments and biota improve, individual entities will be able to be reclassified from one type to another. For example, results from fauna surveys in a region where floristically defined communities are already documented will provide the basis for defining new communities, or redefining the floristic communities in a holistic way.

Ecosystem Type 1: the 1:250,000 scale vegetation map units (Associations) as mapped by J S Beard & A J M Hopkins throughout the whole State.

Ecosystem Type 2: more finely discriminated vegetation units (eg Sub-associations) defined through larger-scale mapping, or through subdivision of Beard/Hopkins units.

Ecosystem Type 3: other ecosystems defined on the basis of biophysical data eg a lake containing algal mats that are at least partially documented.

Ecosystem Type 4: other entities that are defined on the basis of physical parameters only eg a sub-catchment or a lake with a little-known biota.

Ecological Community Type 1: biotic assemblages defined using classification/ ordination procedures of comprehensive biological data following survey.

Ecological Community Type 2: floristic assemblages defined using classification/ ordination procedures of floristics-only data following survey.

Ecological Community Type 3: faunal assemblages defined using classification/ ordination procedures of faunal data following survey.

Ecological Community Type 4: assemblages of fungi, plants or animals or any combination that are well documented from at least one site.

Ecological Community Type 5: assemblages of fungi, plants or animals or any combination, that are not well documented (data deficient) but considered important.

7. Summary and Conclusions

A wide range of names and concepts have been developed to identify, describe and map units or components of the environment. The objective of these descriptive exercises is to improve our knowledge of the environment so that we can better manage it. The many disciplines with an interest in managing the environment have each tended to develop specialist terminologies, although there has been some transfer between disciplines. The review has highlighted relationships between the various units, and the fact that those within a particular discipline can be organised into hierarchies or nested sets that may be matched with units at a similar scale drawn from other disciplines. A fine example of the matching is the concept of systems that is common between soild mapping, rangelands mapping and vegetation mapping. The system is equivalent to a catenary sequence repeated across the landscape. A system will contain at least two or three larger scale environmental units – in the case of vegetation units these are the vegetation associations, and the plant communities within each association.

Ecosystems and ecological communities are synthetic concepts with origins outside the practical, descriptive and mapping disciplines. The ecosystem concept originated in theoretical ecology as a contribution to the debate how nature and natural systems are organised. Ecosystems are now considered to be basis planning units for nature conservation world-wide. This is despite the fact that they are difficult to define in practical terms. In contrast, the ecological community concept has origins in the development of statutory processes underpinning nature conservation in Australia. It too creates problems in its practical application. Neither concept fits readily within the framework of environmental terms and concepts that have evolved through practical application.

For the purposes of the Ecosystem and Ecological Communities project, an ecosystem is considered to be, in general, a broad-scale unit, whereas an ecological community is likely to be smaller, or restricted in area. An ecosystem may include several ecological communities. For the project, vegetation associations mapped at the scale of 1:250,000 are considered to be surrogates for ecosystems. The project database ECOSTATUS (Morgan and Hopkins 1999) contains examples of both types of units, but they are maintained as separate data layers in the GIS. A system of categorising the ECOSTATUS ecosystems and ecological communities into nine types based on issues of scale and level of discrimination, as well as data type, is described.

This paper addresses an emerging need within in broad arena of people involved in managing the environment, particularly the nature conservation aspects, to better understand the concepts developed for identifying and describing the environment, and to exercise greater precision in the use of those concepts. The paper attempts to provide a basis for the discussion that is needed for the clarity to emerge.

8. References

*Andersen, A.N. (1995), Comment: palaeontology, adaptation and community ecology: A response to Walter and Paterson (1994). *Australian Journal of Ecology*, **20**: 458-462.

*Austin, M.P. and Heyligers, P.C. (1989), Vegetation survey design for conservation gradsec sampling of forests in north-eastern New South Wales. *Biological Conservation*. **50**:13-32.

Beadle, N.C.W. and Costin, A.B. (1952), Ecological classification and nomenclature. *Proceedings of the Linnean Society of New South Wales* **77**, 62-78.

Beard, J.S. (1969), The vegetation of the Boorabbin and Lake Johnston areas, Western Australia. *Proceedings of the Linnnean Society of New South Wales* **93**, 239-269.

Beard, J.S.(1974a), Vegetation Survey of Western Australia. 1:1 000 000 Series. Sheet 2. Great Sandy Desert. Part II. Map and Expanatory Notes. University of Western Australia Press, Nedlands.

Beard, J.S.(1974b), Vegetation Survey of Western Australia. 1:1 000 000 Series. Sheet 3. Great Victoria Desert. Map and Expanatory Notes. University of Western Australia Press, Nedlands.

Beard, J.S.(1980), A new phytogeographic map for Western Australia. Research Notes of the Western Australian Herbarium 3, 37 - 58.

Beard, J.S. (1981), Classification in relation to vegetation mapping. Pp. 97-106 *in* Vegetation Classification in Australia ed. By A.N. Gillison and D.J. Anderson. Commonwealth Scientific and Industrial Research Organisation, Australia in association with Australian National University Press, Canberra, Australia.

Beard, J.S. and Sprenger, B.S. (1984), Geographical data from the vegetation survey of Western Australia. Vegetation Survey of Western Australia. Occasional Paper No 2. Vegmap Publications, Applecross.

Beard, J.S. and Webb, M.J. (1974), Vegetation Survey of Western Australia. 1:1 000 000 Series. Sheet 2. Great Sandy Desert. Map and Expanatory Notes. Part 1. The Vegetation Survey of Western Australia: Its Aims, Objects and Methods. University of Western Australia Press, Nedlands.

Bormann, F.H. and Likens, G.E. (1967), Nutrient cycling. *Science*, **155(3461)**:424-429.

Christian, C.S. (1959), The eco-complex in its importance for agricultural assessment. In A. Keast, R. L, Crocker and C. S. Stewart (editors) Biogeography and Ecology in Australia. Uitgeverij Dr W Junk, the Hague. pp587-605.

Christian, C.S. and Stewart, G.A. (1947), North Australia Regional Survey 1946. Katherine-Darwin Region. General report on land classification and development of local industries. Mimeograph. CSIRO, Melbourne.

Clements, F.E. (1936), Nature and structure of the climax. *Journal of Ecology*, **24**: 252-284.

Commonwealth of Australia (1996), The National Strategy for the Conservation of Australia's Biological Diversity. Commonwealth Department of the Environment, Sport and Territories, Canberra, Australia.

Crawley, M.J. (1993) GLIM for Ecologists. Blackwell Scientific Publications, Oxford.

Diels, L. (1906), *Die Pflanzenwelt von West-Australien sudlich des Wendekreises. Vegetation der Erde* 7. Leipsig.

Endangered Species Scientific Subcommittee (1995), Draft Criteria for Listing Ecological Communities Under the *Endangered Species Protection Act* 1992. Australian Nature Conservation Agency, Canberra.

Environmental Resources Information Network (ERIN) (1999), National Vegetation Information System. Vegetation attributes. Version 4, October 1999. Unpublished Report. ERIN Environment Australia, Canberra.

English, V. and Blyth, J. (1999), Development and application of procedures to identify and conserve threatened ecological communities in the South-West Botanical Province of Western Australia. *Pacific Conservation Biology* **5**, 124-138.

Environment Australia (1998), Guidelines for Establishing the National Representative System of Marine Protected Areas. Draft Version 2.0. Portfolio Marine Group guidelines developed for ANZECC.

Franklin, J.F. (1993), Preserving biodiversity: species, ecosystems, or landscapes? *Ecological Applications*, **3(2)**:202-205.

Gardner, C.A. and Bennetts, H.W. (1956), *The Toxic Plants of Western Australia.* Western Australian Newspapers, Perth.

Gentilli, J. (1979), Regions and landscapes: nature and size, functions and change. In Gentilli, J. (ed), *Western Landscapes.* University of Western Australia Press, Nedlands. pp 3 - 48.

Gleason, H.A. (1926), The individualistic concept of the plant association. *Bulletin of the Torrey Botanical Club*, **53**:7-26.

Golley, F.B. (1993), A History of the Ecosystem Concept in Ecology: More Than the Sum of the Parts. Yale University Press, New Haven.

Haila, Y., Saunders, D.A. and Hobbs, R.J. (1993), What do we presently understand about ecosystem fragmentation? Pp. 45-55 *in* Nature Conservation 3: Reconstruction of Fragmented Ecosystems ed. By D.A. Saunders, R.J. Hobbs and P.R. Ehrlich. Surrey Beatty and Sons. Australia.

Host, G.E., Poltzer, P.L., Mladenoff, D.J., White, M.A. and Crow, T.R. (1996), A quantitative approach to developing regional ecosystem classifications. *Ecological Applications*, **6**:608-618.

Lindeman, R.L. (1942), The trophic-dynamic aspect of ecology. *Ecology*, **23(4)**:399-418.

Mabbutt, J.A., Licthfield, W.H., Speck, N.H., Sofoulis, J., Wilcox, D.G., Arnold, J.M., Brookfield, M. and Wright, R.L. (1963), General report on lands of the Willuna-Meekatharra area, Western Australia, 1958. CSIRO Land Research Series No 7.

McKenzie, N.L., Hall, N., and Muir, W.P. (in press), Non-volant mammals of the southern Carnarvon Basin, Western Australia. Records of the Western Australian Museum Supplement.

McKenzie, N.L., Rolfe, J.K., Aplin, K., Cowan, M. and Smith, L.A. (in press), Herpetofauna of the southern Carnarvon Basin. Records of the Western Australian Museum Supplement.

Meidinger, D. and Pojar, J. (1991), Ecosystems of British Columbia. British Columbia Ministry of Forests, British Columbia.

Morgan, R. and Hopkins A.J.M. (1999). An interim framework for developing a comprehensive, adequate and representative protected areas system in Western Australia. Department of Conservation and Land Management, Western Australia. Unpublished Report.

National Land and Water Resources Audit (NLWRA) (1998), Strategic Plan. 1998-2001. National Land and Water Resources Audit, Canberra.

Noss, R.F., LaRoe III, E.T. and Scott, J.M. (1995), Endangered Ecosystems of the United States: A Preliminary Assessment of Loss and Degradation. Technical Report Series. Biological Report 28. U.S. Department of the Interior National Biological Service. Washington D.C.

Odum, E.P. (1953), Fundamentals of Ecology. W.B. Saunders, Philadelphia.

Paine, R.T. (1980), Food webs: linkage, interaction strength and community infrastructure. *Journal of Animal Ecology*. **49**: 667-685.

Patterson, B.D. and Brown, J.H. (1991), Regionally nested patterns of species composition in granivorous rodent assemblages. *Journal of Biogeography*. **18**: 395-402.

Pringle, H.J.R. (1994), Methodology. In H. J. R. Pringle, A. M. E. van Vreeswyk and S. A. Gilligan (editors) An inventory and condition survey of rangelands in the north-eastern Goldfields, Western Australia. Department of Agriculture Western Australia Technical Bulletin No **87**:76-85.

Sivertsen, D. and Metcalf, L. (1995), Natural vegetation of the southern wheat-belt (Forbes and Carelligo 1:250 000 map sheets). Cunninghamia **4**, 103-128 (plus map).

Smith, G.T. and McKenzie, N.L. (in press), Biogeography of scorpion communities in the southern Carnarvon Basin, Records of the Western Australian Museum Supplement.

Smith, F.G. (1972), Vegetation Survey of Western Australia. 1:250 000 Series. Pemberton & Irwin Inlet. Department of Agriculture, South Perth.

Smith, F.G.(1973), Vegetation Survey of Western Australia. 1:250 000 Series. Busselton/Augusta. Department of Agriculture, South Perth.

Smith, F.G.(1974), Vegetation Survey of Western Australia. 1:250 000 Series. Collie. Department of Agriculture, South Perth.

Speck, N.H. (1958), The vegetation of the Darling-Irwin Botanical Districts and an investigation of the distribution of the Family Proteaceae in south-western Western Australia. Thesis, Botany Department, University of Western Australia, Crawley.

Speck, N.H., Bradley, J., Lazarides, M., Patterson, R.A., Slatyer, R.O., Stewart, G.A. and Twidale, C.R. (1960), Lands and pastoral resources of the north Kimberley area, W.A. CSIRO Land Research Series No 4.

Tansley, A.G. (1935), The use and abuse of vegetational concepts and terms. *Ecology*, **16(3)**:284-307.

Thackway, R. and Cresswell, I.D. (1995), An Interim Biogeographic Regionalisation for Australia: A framework for setting priorities in the National Reserves System Cooperative Program. Version 4.0. Reserves System Unit, Australian Nature Conservation Agency, Canberra.

von Mueller, F. (1867), Australian vegetation. Intercolonial Exhibition Essays pp 251-261.

von Mueller, F. (1883), *Plants Indigenous Around Shark Bay and its Vicinity*. Government Printer, Perth.

Walter, G.H. and Paterson, H.E.H. (1995), Levels of understanding in ecology, interspecific competition and community ecology. *Australian Journal of Ecology*, **20**: 463-466.

Wilcox, D. G. and McKinnon. E. A. (1972), A report on the condition of the Gascoyne catchment. Western Australian Department of Agriculture Technical Report No **2**.

Woodgate, P., Peel, W., Ritman, K., Corman, J., Brady, A., Rule, A. and Banks, J (1994), A study of old-growth forests of East Gippsland. Department of Conservation and Natural Resources, Victoria, Melbourne.

Wright, D.H., Patterson, B.D., Mikkelson, G.M., Cutler, A. and Atmar, W. (1998), A comparative analysis of nested subset patterns of species composition. *Oecologia*, **113**:1-20.

Figure 1. Illustration of the interrelationship of ecosystems and ecological communities as incorporated in the ECOSTATUS database. Ecosystem 1 contains three different ecological community types. Ecological community A also occurs in Ecosystem 3.