Journal of Environment and Ecology
ISSN 2157-6092
2014, Vol. 5, No. 2

Management of Biodiversity in Australia

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Received: October 1, 2014 Accepted: November 10, 2014 Published: December 7, 2014

doi:10.5296/jee.v5i2.6741 URL: http://dx.doi.org/10.5296/jee.v5i2.6741

Abstract

The concept of holistic ecosystem research, termed community-physiology, has gradually developed over the last 150 years. The discipline of community-physiology investigates the physico-chemical processes that determine the structure, growth and biodiversity of plant communities (with associated consumers and decomposers), both above and below ground, in space and time, from the tropical north to the temperate south of Australia. These physico-chemical processes (aerodynamic fluxes — frictional, thermal, evaporative ± atmospheric salinity — plus available soil water and soil nutrients) need to be clearly enunciated and integrated in 'ecosystem models' in order to predict the effect of perturbations (such as Global Warming, nutrient pollution, invasive biota, fire, overgrazing, etc.) on Australian ecosystems. An increase in global temperatures of 2°C is predicted to affect the development of the foliage covers of overstorey and understorey strata resulting in open-forests —> woodlands —> open-woodlands —> tall shrublands —> low shrublands throughout Australia.

In order to conserve Australian biota for posterity, community-physiologists, ecosystem modelers and environmental impact ecologists must have a deep understanding of the eco-physiology of producers, consumers and decomposers that compose an ecosystem and how these organisms interact with the continually-changing physico-chemical processes in the atmosphere and soil, in space and time.

Keywords: Ecosystems, Biodiversity, Community-physiology, Pollution, Global warming

1. The Development of Ecosystem Studies in Australia

The peculiarities of the Australian flora and fauna have excited the interest of amateur and professional biologists ever since collections of Australian plants and animals reached Europe from the voyages of discovery made by Capt. William Dampier (1688), Joseph Banks and Daniel Solander with Capt. James Cook (1770), Jacques-Julien Labillardière with Capt. J. A. B. d'Entrecastreaux (1792-3), Robert Brown with Capt. Matthew Flinders (1801-3), and Leschenault de la Tour with Capt. Nicolas Baudin and François Péron (1802).

Understandably, there was an impelling desire to discover and learn more about these unusual plants and animals. Gradually over the nineteenth century, the most important species were collected and described, grouped into genera, families, orders or phyla. The publication of Charles Darwin's *The Origin of Species* in 1859 gave new direction to biologists all over the world; many turned their attention towards elucidating the evolutionary relationships of the flora and fauna.

It was at this time that the three senior Australian universities — Sydney (1850), Melbourne (1853), and Adelaide (1874) — were founded. Before long, Departments of Natural History were established in each — Sydney (1882), Melbourne (1854), and Adelaide (1875). These departments fostered the evolutionary study of Australian plants and animals.

Every collector and taxonomist was aware that terrestrial plants and animals were to be found in preferred habitats — mangrove swamp, salt marsh, rainforest, eucalypt forest, brigalow, mallee or mulga scrub, grassland (± overstorey trees), heathland (± overstorey trees), saltbush or spinifex plain, etc. Darwin's ideas on natural selection with the concept of 'survival of the fittest' made biologists realise that these landscape entities were not static, but existed in a dynamic, ever-changing state and that the habitat, plants, and animals which comprised the landscape were interrelated with each other.

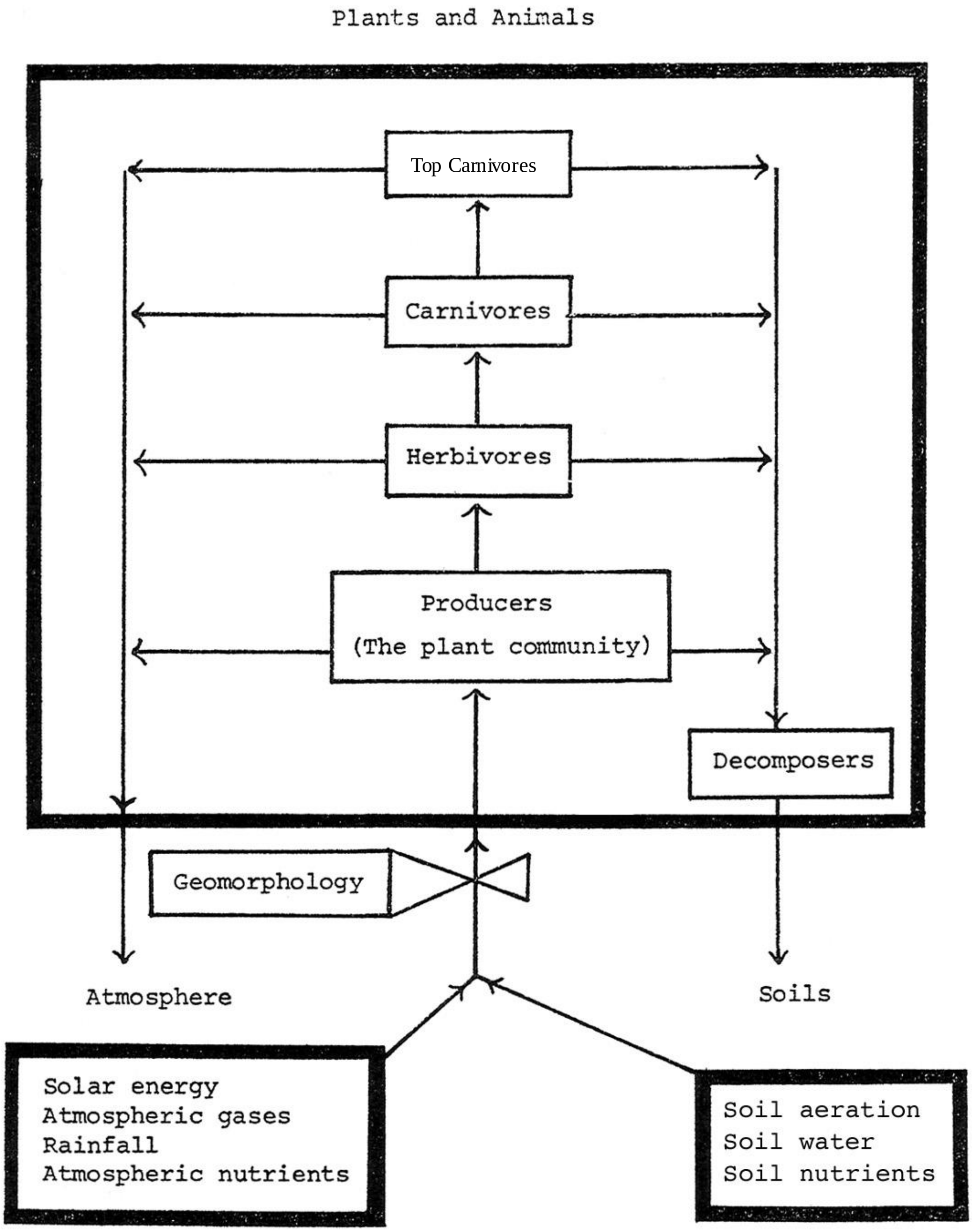
Thus in 1859, Saint-Hilaire stated in the introduction to his *Histoire générale des règnes organiques* that the last volume of his work would be devoted to the subject of *ethology* — the study of the relations of the organisms within the family and the society, in the aggregate and in the community. Unfortunately the last volume was never published and it was ten years later in 1869 that Haeckel proposed the term *Oekologie* — the relation of the organism to its organic as well as its inorganic environment, particularly its friendly or hostile relations to those animals or plants with which it comes in contact.

In the hundred years following Haeckel's enunciation of the discipline of ecology, the landscape-entity, rather vaguely understood by early collectors and taxonomists, has been defined as the *ecosystem* — the whole, relatively-stable complex of organisms (both plant and animal) and all the inorganic factors of the environment which influence them (Tansley 1935). The interrelationships of this entity may be illustrated as in the simplified diagram shown in Figure 1.

Journal of Environment and Ecology
ISSN 2157-6092
2014, Vol. 5, No. 2

FIGURE I

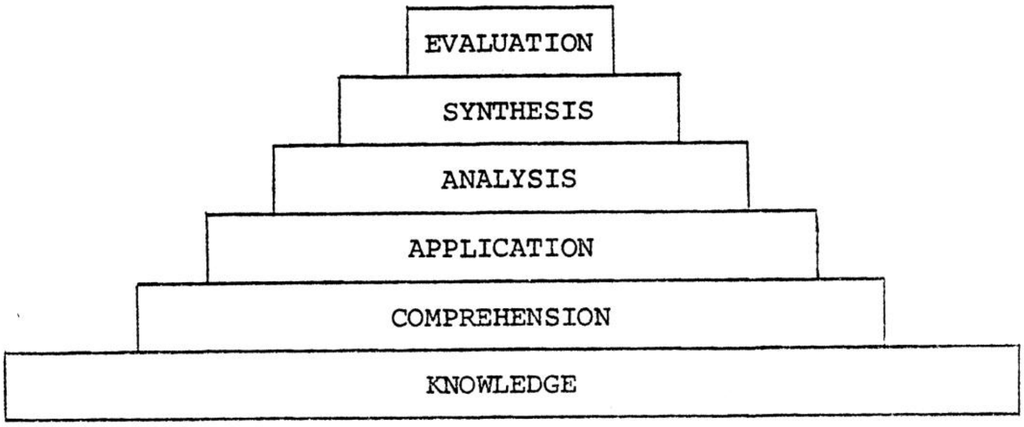
A simplified diagram showing the interrelations which exist in the ecosystem.



It should be the aim of ecologists to understand the biological, chemical, and physical processes operating between different organisms and between those same organisms and the environment and to understand how these processes are interwoven into a dynamic entity in space and time. In effect, the ecologist is asked to attain the highest level of intellectual thought as expressed in Bloom's Taxonomy of Educational Objectives (1956) in Figure 2.

FIGURE 2

The hierarchy of educational objectives expressed by Bloom (1956). The study of ecology, by definition, is aimed at the highest levels of attainment.



In order to achieve the pinnacle of synthesis and evaluation, the ecologist will find it necessary to amass facts or, more particularly, to explore the processes involved in one or more parts of an ecosystem. But, above all, he should not lose sight of his overall objective — the understanding of how the complete entity, the ecosystem, works and how it, as a whole, may react and adjust to external and internal perturbations.

As Man cannot be excluded from any ecosystem, the ecologist holds a position of extreme responsibility in the World today. It is he alone who should be able to assess the effects of Man's commercial and social enterprises on the landscape, and be able to give advice on the alleviation of disasters that have already occurred. The 'Environmental Impact Statements' are his responsibility. The conservation of the world's renewable (biological) and non-renewable (inorganic) resources should depend on his decisions.

Throughout the world, plant ecology has advanced more rapidly than animal ecology — largely because plants are sessile and lend themselves more readily to the study of local distribution patterns than do animals.

By the turn of this century, European plant ecology was well established as a discipline. Grisebach's *Die Vegetation der Erde* was published in Leipzig in 1872. Schimper's book on *Plant-geography upon a Physiological Basis*, published in German in 1898, was translated into English in 1903. Warming's book on the *Oecology of Plants* was published in 1909, based on a book summarising his lectures in Denmark — *Plantesamfund* (1895). The series of volumes *Die Vegetation der Erde*, edited by Engler and Drude, began to appear; in particular, Ludwig Diels had visited Australia and written Vol. 7 in this series *Die Pflanzenwelt von West-Australien südlich des Wendelkreises* in 1906. Clements in the United States was formulating his ideas on *Plant Succession*, published in 1916, 1928 and 1936. Tansley (1935) was active in England, Raunkiaer (1934) in Denmark, and Braun-Blanquet (1932) in Switzerland.

Apart from the visit of Diels, Australia was little influenced by overseas developments in plant ecology apart from the visit of the British Association for the Advancement of Science (BAAS) to Australia in 1914 before the First World War (WW1). It was at this time that T. G. B. Osborn, who had been appointed Professor of Botany, Vegetable Pathology and Parasitology in the University of Adelaide in 1912 as a young man of 25 years wrote an article on the vegetation around Adelaide, South Australia (Osborn 1914). After WW1, Osborn invited R. S. Adamson from the University of Manchester to spend some time in Adelaide during 1922. Osborn, who had previously spent most of his time lecturing, virtually on his own, to the whole of the first degree course in botany, plus acting as Consulting Botanist to the government of South Australia — largely as a plant pathologist — now turned his attention to plant ecology. Two important papers (Adamson & Osborn 1922, 1924) on the arid ecology of the Ooldea district and on the *Eucalyptus* forests of the Mount Lofty Ranges appeared with Adamson, who later became Professor of Botany at the University of Cape Town (Adamson 1938). Teaching and research in plant ecology exploded from the Adelaide school. J. G. Wood after graduating with an honours B.Sc. in chemistry, joined Osborn on the staff of the Department of Botany in 1923 and began a series of studies on the water relations, biochemistry and biogeography of South Australian vegetation. Ecological studies were further stimulated by the establishment in 1925 of Koonamore Vegetation Reserve (now the T. G. B. Osborn Reserve at Koonamore) in the arid zone of South Australia (Osborn 1928; Wood 1936; Hall *et al.* 1964; Sinclair 2004, 2005).

The ecological approach was strengthened in Adelaide on the establishment of the Waite Agricultural Research Institute in 1924 with research groups in climatology, soils, grassland, weeds, and insect ecology under A. E. V. Richardson, J. A. Prescott, J. Davidson and H. C. Trumble. H. G. Andrewartha, T. O. Browning, R. L. Crocker, N. S. Tiver, and J. A. K. Walker expanded these fields in the 1940s.

The major scientific interests of Prof. J. A. Prescott were in the development, chemistry and physics of Australian soils (Prescott 1936, 1938a, 1938b, 1944, 1949, Prescott & Pendleton 1952). Plant biochemist, Prof. J. G. Wood, was interested in the survival of native plants in the seasonally-droughted, nutrient-poor Australian landscapes (Wood 1925, 1932, 1933a, 1933b, 1934). Prescott understood clearly that research and education should proceed hand-in-hand; in 1947, he wrote to entomologist Charles Birch — "With few exceptions, research must be associated either with teaching or advisory work. The first helps to develop ideas more clearly, the second brings the problems of current importance to the notice of the research worker." (Stephens & Quirk 1988, p. 307).

Osborn's influence in plant ecology extended to the University of Sydney in 1928 when he became Professor of Botany there from 1928 until 1937, then Professor of Botany in the University of Oxford after the retirement of Professor Tansley. Wood continued to expand the strong ecological tradition established in Adelaide up until his death in 1959. The publication of Wood's handbook on the *Vegetation of South Australia* in 1937 was a landmark in the development of plant ecology in Australia.

In 1935, the holistic concept of the 'ecosystem' was promoted by A. G. Tansley, Professor of Botany of Oxford University (Tansley 1935). The 'ecosystem' concept, relating climate, soils and vegetation, over time (short- and long-term) was pursued by R. (Bob) L. Crocker of C.S.I.R. Soils Division and the Agronomy Department of the Waite Agricultural Research Institute, together with Professor J. G. Wood of the Botany Department, University of Adelaide (Crocker 1946; Crocker & Wood 1947). During 1947 and 1948 while on sabbatical leave in Cambridge University and the University of California, Berkeley, Bob Crocker developed the concepts of 'soil genesis and the pedogenic factors' and their interactions with the dynamics of plant communities — in space and time (Crocker 1952). The various eco-physiological facets of the ecosystem were to be explored and integrated by one scientist.

$$\textit{Vegetation} = \textit{Function (climate, parent material, relief, organisms, time)} \quad (1)$$

This holistic study of the dynamic processes that operate throughout the life cycle — from regeneration to maturity to senescence — of ecosystems in soil-vegetation chronosequences, post-fire succession, secondary succession after disturbance, etc., was initiated in the 1950s as the discipline of community-physiology (Specht & Rayson 1957; Specht 1963), to be promoted by the International Biological Program, Section PP, Sub-Section - Community-Physiological Processes in Terrestrial Ecosystems (Specht 1967).

The discipline of community-physiology attempts to study the processes that determine the complex interrelations of the many plants, animals and micro-organisms that form each ecosystem — quite distinct from descriptive studies of the component species of the whole ecosystem or the study of individual species within an ecosystem, such as eco-physiology and population ecology (Andrewartha & Birch 1954; Andrewartha 1961). Physico-chemical processes (aerodynamic fluxes, temperature, available soil water and mineral nutrition) determine the structure, growth and biodiversity of intact plant communities (and associated consumers and decomposers) that comprise the diversity of ecosystems in the field.

2. Evolution of Australian Ecosystems

Australian ecosystems have evolved on a heritage of Late Cretaceous lateritic soils (Prescott & Pendleton 1952), rich in kaolinite clay minerals that 'fixes' phosphate and molybdenate ions in an unavailable form within its crystalline lattice. The Gondwanan elements in the flora have persisted for over 50 million years (Hooker 1860; Specht 1958a, 1958b, 1981b, 1981c, 1988b; Clifford & Simon 1981; Johnson & Briggs 1981; Specht *et al.* 1992; Hill *et al.* 1999). During the Cainozoic, especially about 10 million years ago when Global Warming of 2-5^{o}C occurred (Shackleton & Kennett 1975), the perhumid climate of the Early Tertiary became increasingly arid (Martin 2006), thus subjecting the diverse life-forms in the producer section of each ecosystem to severe aerodynamic stresses (frictional, thermal, evaporative ±

atmospheric salinity) as the atmosphere flows over and through the plant community. Seasonal shoot and root growth (also flower and fruit production) of all life-forms within a plant community are determined by aerodynamic fluxes, in conjunction with mineral nutrition. Seasonal rhythms of all consumers and decomposers are intricately entwined with those of the plant species that form an ecosystem. As annual foliage growth (biomass per hectare) of the plant community changes, the biodiversity (number of species per hectare) of the producer, consumer and decomposer sections of each ecosystem shows a concomitant change. Controlled experiments on the effects of water, nutrients, grazing, etc. on the structure, growth and biodiversity of an ecosystem must be maintained for many decades — often logistically and economically impossible. It is better to study changes produced in ecosystems along environmental gradients, where 'Mother Nature' has conducted controlled experiments over many centuries.

3. Training of Community-Physiologists

It is essential to train scientists in community-physiology to investigate the physico-chemical processes that operate in the whole ecosystem — especially in the unique Australian ecosystems from the arid to the perhumid climatic zones in temperate, subtropical and tropical, also montane Australia — under the impact of the many environmental stresses imposed since European settlement.

Ecosystem Modelling is the course in which the ecologist synthesises and evaluates all the interlocking processes operating in an ecosystem (above and below ground) — as defined by controlled scientific experiments that form the 'major ideas' in all the previous courses. In Ecosystem Modelling, the ecologist is asked to attain the highest level of intellectual thought (Synthesis and Evaluation), as expressed in Bloom's *Taxonomy of Educational Objectives* (1956), by investigating the impact of perturbations on a variety of ecosystems, from the arid to the perhumid climatic zone, from the temperate to the tropical climatic region (Specht & Specht 1999).

Even in the 1970s, the training of community-physiologists in Biology Departments of Australian universities was almost impossible (Specht 1976, 1981a). Over the last two decades, ecological studies in Botany Departments — where the complex interactions of the many species in the producer, consumer and decomposer sections of an ecosystem were emphasised — have been submerged within Biology Departments where population ecology dealing with a single species prevail. As well, there has been increasing emphasise on molecular biology, paying less attention to the complex environmental studies that focus on the basic problems of sustainability of ecosystems throughout Australia.

Australian ecosystems (and those of other Gondwanan continents) have evolved on landscapes that are markedly different from the northern part of the world. Basic research on community-physiological processes that operate to determine the structure, growth and biodiversity of ecosystems is essential for scientific management to ensure sustainability far into the future.

The following physico-chemical processes that operate in Australian plant communities have been established: —

(1) Phosphorus nutrition — The lateritic soils (widespread across the Gondwanan continents) — and soils derived after degradation — contain a large percentage of kaolonitic clay minerals that 'fix' phosphates within their crystalline lattice. Australian ecosystems have evolved to conserve this essential nutrient — for example, as polyphosphate, stored in granules, during litter decomposition to be hydrolysed later to orthophosphate for transport to growing foliage apices (Coleman & Specht 1981; Specht *et al.* 1983). After European settlement, contamination by phosphate-rich litter has led to 'phosphorus toxicity' that causes the gradual degeneration of native plant communities (and associated consumers and decomposers) — a process accelerated by increase in microbial flora such as chytrids, Mundulla Yellows MY-RNA, *Phytophthora cinnamomi*, etc. (Specht 1963; Ozanne & Specht 1981; Specht & Specht 1989d).

The remarkable 'phosphate-fixation' of kaolinite could be used to bind 'phosphate-pollution' — mostly accumulated in the surface 1 cm of soil — along paths through native vegetation in many Australian ecosytems. (Specht 1981d).

(2) **Nitrate versus ammonium nutrition** — Solar radiation falling on soil within gaps in native Australian plant communities leads to the formation of nitrate ions — rather than ammonium ions — from decomposing litter (Stewart *et al.* 1990). Together with phosphate pollution, thin-leaved plants (mostly introduced), with high nitrate reductase activity in their leaves, invade the plant community (Specht & Clifford 1991).

(3) **Sodium, an essential (or toxic) nutrient** — The growth of C4 photosynthetic plants (many Arid Zone chenopods and tropical grasses) requires small quantities of sodium ions blown inland from sea-spray (Brownell 1965; Brownell & Crossland 1972). In contrast, sodium ions have a toxic effect on C3 photosynthetic plants reducing growth and species richness of plant communities dominated by these species (Rich 1996; Specht & Specht 1999; Specht 2007).

(4**) Cytoplasmic organelles in desiccated leaves of C4 grasses** (such as *Astrebla lappacea*) may be restored to normal within a day after rain falls, thus restoring their photosynthetic potential (Doley & Trivett 1974; Mittelheuser 1977).

(5) **Calciphile versus calciphobe nutrition** — Calcareous dust composed of aragonite from foraminifera and cockles, blown inland off the exposed coastal shelf during Recent Ice Ages, has induced extensive areas of calciphile mallee vegetation across southern Australia (Parsons 1968, 1969; Parsons & Specht 1967). The calcitic dust derived from calareous coralline algae in northern Australia, inhibits the development of woody plants on coastal dunes (Specht 1958a; Byrnes *et al.* 1977), also sea-grasses between coral reefs (Waycott *et al.* 2007).

(6) **Foliage shoots** are initiated annually when the temperature in the boundary layer surrounding a shoot apex lies between critical ranges for nanotherms, microtherms, mesotherms, macrotherms, and megatherms (Specht & Rayson 1957; Specht & Brouwer 1975; Specht *et al.* 1981; Specht A. 1985; Specht 1986; Hegarty 1990). These boundary layer

temperatures can be determined (1) in the gradient from the temperate to the tropical regions (Specht 1981f) and (2) in the air entrapped between leaves of various density of packing on dicotyledonous shoot or in monocotyledonous clumps (Specht & Yates 1990; Specht *et al.* 1991).

(7) **Aerodynamic fluxes (frictional, thermal, evaporative)** abrade the annual foliage growth at the edges of all plants within a plant community so that the sum of Foliage Projective Covers of overstorey (FPC_o) and understorey (FPC_u) — $\Sigma(FPC_o + FPC_u)$ — remains constant in space and time — throughout the life-cycle of the plant community (Specht & Morgan 1981; Specht 1983; Specht & Specht 1999; Specht 2000). This balance between overstorey and understorey Foliage Projective Covers determines the Evaporative Coefficient (k) — the monthly ratio of actual to potential evapotranspiration per available soil water — a constant unaffected by variation in rainfall during the year and between years (Specht 1972a, 1972b, 1981f).

(8) **Closed-forests /dry-scrubs on median-nutrient soils and closed-heathlands (with tall Proteaceae) on nutrient-poor soils** result wherever optimal soil water is available during the short period of annual shoot growth in the overstorey — with the Evaporative Coefficient (k) asymptoting to unity (Specht 1972a, 1981f; Specht & Specht 1999; Specht & Moll 2014).

(9) **Species richness** (number of species per unit area) of plants, vertebrates, and probably invertebrates is correlated with Annual Shoot Growth (per hectare) and Leaf Area Index (area of all leaves per hectare) of the overstorey in a plant community — and thus with the annual fixation of solar enegy by photosynthesis (Braithwaite *et al.* 1985; Specht A. 1988; Specht & Specht 1989a, 1989b; Specht *et al.* 1990, 2006; Specht A. & Specht 1993, 1994; Specht 1994; Specht & Tyler 2010; Specht 2012).

A program of undergraduate education for ecologists, community-physiologists and ecosystem modellers — based on '**Major Ideas'** for the '**Inquiry Method'** of teaching (such as developed for the Australian Biological Sciences Curriculum Study (B.S.C.S.) *'The Web of Life*' by Morgan *et al.* (1967) — has been developed so that the material can be adapted for discovery-learning by undergraduates in various regions of Australia: —

> Specht, R. L. & Specht, A. (1999). *Australian Plant Communities. Dynamics of Structure, Growth and Biodiversity.* Oxford University Press, Melbourne.

The first half of this book deals with the description of Australian ecosystems (Specht *et al.* 1974, 1995), their biogeography since the Late Cretaceous, and Aboriginal impact on these ecosystems — based on long-term studies (up to 50 years duration), such as: —

> Subtropical rainforest (Hegarty 1990; Lamb 1980; Doley *et al.* 1987; Stewart *et al.* 1990; Specht A. 1988; Specht & Specht 2010; Specht 2007).

> Montain ash tall open-forest (Ashton 1976; Langford 1976).

> Eucalypt open-forest (Specht & Specht A. 1989a, 1989b, 1999, 2010; Specht & Rundel 1990; Specht A. & Specht 1993, 1994; Specht *et al.* 2006; Qld Dept Environment & Resource Management 2010).

Brigalow open-forest (Johnson 1964, 2004; Russell *et al.* 1967; Connor *et al.* 1971).

Mulga tall shrublands (Burrows & Beale 1969).

Heathlands (Specht *et al.* 1958; Specht 1963; Heddle & Specht 1975; Specht 1981c; Specht & Specht 1989c).

Chenopod low shrublands (Wood 1936; Hall *et al.* 1964; Carrodus & Specht 1965; Noble 1977; Noble & Crisp 1980; Sinclair 2004, 2005).

Mitchell grass open-grassland (Roe 1962; Williams & Roe 1975; Doley & Trivett 1974).

Sub-alpine grassland (Carr & Turner 1959; Williams & Ashton 1987a, 1987b, 1988; Wimbush & Costin 1979, 1983).

Wetlands (Specht A. 1988-2005; Specht 1990, 2009).

Coastal dunes (Specht 1997).

Coastal wetlands (Saenger *et al.* 1977).

The second half of the book deals with dynamic community-physiological processes that determine the structure, growth and biodiversity of plant communities (with associated consumers and decomposers), and ecosystem modelling of these processes.

Chapter 9 — Energetics; Chapter 10 — Temperature; Chapter 11 — Evaporative aerodynamics; Chapter 12 — Available water; Chapter 13 — Eco-physiological leaf attributes; Chapter 14 — Waterlogging; Chapter 15 — Nutrient deficiencies; Chapter 16 — Nutrient toxicities; Chapter 17 — Biodiversity and energetics; Chapter 18 — Monitoring; Chapter 19 — Scientific management.

4. Conclusions

An understanding of community-physiological processes is essential for the scientific management of the structure, growth and biodiversity of Australia's diverse ecosystems — from the arid to the perhumid zones in the temperate south to the tropical north of the continent. These physico-chemical processes need to be clearly defined and integrated in 'ecosystem models' in order to predict the effect of perturbations such as nutrient pollution, invasive biota, fire, overgrazing and Global Warming (Specht 1988a; Specht & Specht 1995, 1999).

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