Review Article

Development of Ecosystem Research

Raymond Louis Specht^{1,2,3,4,5}

¹ Department of Botany, The University of Queensland, Brisbane QLD 4072, Australia

² Department of Botany, The University of Adelaide, Adelaide, SA 5005, Australia

³ Department of Botany, The University of Melbourne, Melbourne, VIC 3010, Australia

⁴ Kearney Foundation of Mineral Nutrition, University of California, Berkeley, CA 94720, USA

⁵ Agriculture and Forestry Departments, University of Oxford, Oxford OX1 2JD, UK

Correspondence should be addressed to Raymond Louis Specht, r.specht@uqconnect.net

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Experimental studies established the major community-physiological processes that determine the structure, growth and biodiversity of overstorey and understorey plants and resident vertebrates in an ecosystem. These community-physiological studies were promoted internationally by the UNESCO Arid Zone Research Program, the International Biological Program (Sections Productivity, Production Processes and Conservation), the International Union for the Conservation of Nature and, finally, the International Geosphere-Biosphere Program that is studying the impact of Global Warming on the World's ecosystems. During the short period of annual foliage growth in evergreen plant communities, aerodynamic fluxes (frictional, thermal, evaporative) in the atmosphere as it flows over and through a plant community determine the foliage projective covers and leaf attributes in overstorey and understorey strata. These foliar attributes determine the community-physiological constant, the evaporative coefficient, of the plant community. An increase in air temperature of 2°C during this period of annual foliage growth will affect the structure of the plant community, so that tall open-forests → open forests → woodlands → open scrub → low open-shrubland → desert communities. Variation in available soil water during this short period of annual foliage growth will influence vertical shoot growth but not foliage projective covers and leaf attributes produced in the overstorey stratum.

1. Introduction: Ecosystem Science—University of Adelaide (1940s)

The integrated study of producers, consumers, and decomposers in relation to climate, topography, and soils in space and time—ecosystem research—was proposed by Professor Tansley of Oxford University in Volume 16 of *Ecology* [1]. My initiation into ecological research in the 1940s occurred at the same time as pedologist-ecologist, Crocker, of the Waite Agricultural Research Institute and Prof. Wood, the Professor of Botany of the University of Adelaide, were attempting to integrate the changing climates of the Quaternary with the soil-forming processes and vegetation patterns of South Australia [2–5]. The input of calcareous dust and sodium chloride blown inland from the sea-beds exposed when sea levels fell had a marked effect on both soils and vegetation. Massive movements of sand dunes swept across the South East into Victoria [6]; a swirling system of sand-dunes resulted in the Arid Centre of Australia [7].

Professor Prescott, jointly Director of the Waite Agricultural Research Institute and C.S.I.R.O. Soils Division, had investigated the effect of climate (monthly values of the Transeau Ratio P/E, the Meyer Ratio P/s.d., the Prescott Ratio P/s.d.^{0.75}, where P = precipitation, E = pan evaporation, equivalent to optimal evapotranspiration, s.d. = saturation deficit) on the development of soils and agriculture throughout the continent [8]. In the late 1940s, Butler was using gypsum blocks to monitor soil water levels under the rotational wheat field on the Waite Institute grounds [9].

Two distinctive plant formations [10]—with a grassy understorey on medium-nutrient soils and with a heathy understorey on nutrient-poor soils—had survived in the humid to subhumid areas of the State for over 50 million years, since the break-up of Gondwanaland [11].

Intensive research was being undertaken on improving the nutrition of crops and pastures on medium-nutrient soils in the State—all of which needed added phosphate

fertiliser (+ nitrogen fixed by legumes) to survive. Pastures on the nutrient-poor soils, however, needed added trace elements, such as copper, zinc, even cobalt (for animals) for development. The truncated lateritic podzols of the Fleurieu Peninsula and on Kangaroo Island not only fixed large amounts of superphosphate within the crystalline lattice of their kaolinite clay, but fixed traces of molybdenum, making these nutrients unavailable to plants [12, 13].

Professor Wood, a world leader in plant biochemistry who had previously studied the water-conservation physiology of arid zone and sclerophyllous (heathy) plants [14–16], had turned the talents of the Botany Department to study the biochemistry of nitrogen (ammonium versus nitrate metabolism), phosphate, potassium, copper, zinc, and molybdenum nutrition. My postgraduate student, Brownell, demonstrated that minute traces of sodium in sea-spray were essential for the nutrition of Arid Zone chenopods [17]—and, later in James Cook University at Townsville, in tropical grasses [18]—most of which are C4-photosynthetic plants [19].

Field experiments were established on Dark Island heathland north-east of Keith in the Ninety-Mile Plain to examine the effect of added superphosphate, nitrate, copper and zinc fertilizers [20–22]. This vegetation had flourished for millions of years on nutrient-poor soils with exceedingly low levels of these nutrients—essential for the establishment of pastures in the region. Remarkably, most heathland species responded to the addition of superphosphate—greatly in short-lived understorey species, least in species that survived for a long time in postfire succession.

Comparative studies were made on the uptake of radioactive-labelled phosphate and its translocation from roots to tops on seedlings of *Banksia ornata* and *Avena sativa* [23, page 295]. The polyphosphate-conservation strategy that enables low-nutrient heathland and eucalypts to survive was elucidated in the University of Melbourne [24–28]. In southern Australia where a cool wet season alternates with summer drought, orthophosphate is released from decomposing litter during spring to be stored as polyphosphate granules in rootlets and associated rhizosphere organisms; these polyphosphate granules are later hydrolysed to orthophosphate and transported to foliage shoots that begin to grow some weeks later at the beginning of summer [23, Figures 15 and 18, page 298].

2. Inquiry Method of Teaching (Biological Sciences Curriculum Studies)

During his childhood holidays, the world renowned plant biochemist, Prof. Wood, had roamed with Aboriginal children on Point McLeay Mission where he innately learnt

that the “inquiry method” was the best way to understand the intricacies of the native vegetation of Australia. As the education of secondary school students in biology was a responsibility of the Professor of Botany, the Botany Department of the University of Adelaide conducted an introductory workshop for science teachers in December 1942 and introduced an evening subject, titled Biology I, to enable these teachers to feel confident in teaching the biology section of “*Intermediate General Science*” [29]. Thanks to the inspiring example of my Mathematics–Science teacher and lifelong colleague Stanley J. Edmonds [30], University Scholarship recipient Ray Specht was diverted, by the Education Department of South Australia, from Physics–Mathematics to study Biology, Educational Methods, and Educational Psychology—disciplines that provided a sound basis for the development of teaching and holistic research into the physicochemical processes operating in plant communities and associated consumers and decomposers (Specht 1976) [31].

The usual way of teaching biological concepts is by the “chalk-and-talk” or “lecturing” method. It was only after the Russian satellite Sputnik was launched in 1958 that educators in Europe and the United States began to question the training of students in science. Materials for the “inquiry method of teaching” of biology were developed by the Biological Sciences Curriculum Study (BSCS) in Colorado, United States; three alternative sets of resource materials (teaching strategies to discover “major ideas”) were produced based either on the cell, the whole organism, or the ecosystem. The BSCS approach to teaching biology was eagerly promoted by biological science teachers in South Australia and Victoria, but teaching materials had to be adapted to the distinctive Australian biota. The “inquiry” teaching strategy was strongly supported in the Australian Academy of Science by Robertson and Turner who were, respectively, Professors of Botany in the University of Adelaide and Melbourne at that time. The Academy mortgaged its building to provide the necessary finance for the preparation of teaching materials for an advanced secondary biology course, “*Biological Science: The Web of Life*” [32], in which a team of biological scientists and teachers integrated the three BSCS sets of teaching materials dealing with cell, organism, and ecosystem. The teaching materials were used initially in South Australia, Victoria, and Queensland [33, 34] and soon spread to all States of the Commonwealth. For many years, the number of copies of these teaching materials that were published annually by the Academy was exceeded only by the print run of the N.S.W. telephone book.

3. American–Australian Scientific Expedition to Arnhem Land (1948)

During my B.S. Honours studies in 1946, I was invited to join a National Geographic Society Expedition to study the flora, ecology, and ethnobotany of the Arnhem Land Aboriginal Reserve in the Northern Territory. By 1948, I had been asked to collect plant specimens for six herbaria in Australia and four overseas. Contacts were made with

the Smithsonian Institution in Washington, DC, that was sending three zoologists and an archaeologist on the Arnhem Land Expedition; the Arnold Arboretum of Jamaica Plain, Massachusetts, that had sponsored the Archbold Expeditions to New Guinea and the Solomon Islands; the Royal Botanic Gardens, Kew, England; the Rijksherbarium, Leiden, The Netherlands that was embarking on the “*Flora Malesiana*.”

Before I left on the expedition, the Queensland Government Botanist, Cyril T. White, drew my attention to Joseph Hooker’s 1860 essay “*On the Flora of Australia, being part of an introductory essay to Flora Tasmaniae*” [35]. Hooker had noted the striking similarities between the landscape of the sandstone tablelands of northern Australia and that of the sandstone ranges of western Bengal and central India. He presented a list of nearly 500 Indian species belonging to 273 genera that had been recorded in northern Australia, but was unable to cite any typically Australian species whose range extended from northern Australia to India.

After my collection of Arnhem Land specimens had been identified, I critically investigated Hooker’s biogeographical observations on the northern Australian flora. A search through the botanical literature—aided by botanists such as Dr. Ron Melville in the Royal Botanic Gardens, Kew, Prof. van Steenis in the Rijksherbarium in Leiden, the staff of the Queensland Herbarium, the National Herbarium in Sydney, and the National Herbarium in Melbourne—revealed that the distribution of about 220 of these Indian species were widespread in wetlands (freshwater and coastal) and dune vegetation from India, through Malesia into Australia. Some 64 woody species had a disjunct distribution on the sandstone and lateritic soils of India and northern Australia [36].

Most of the C4-photosynthetic grasses, that dominate the savanna understorey of the Eucalyptus open forests and woodlands on the medium-nutrient lateritic earths, belong to the Gondwanan element (37 genera) and Old World Tropical element (30 genera) [37]. At least two species of these ancient grasses—*Heteropogon contortus* and *Themeda triandra*—are still widespread in Australia.

The nutrient-poor sandstone soils and medium-nutrient lateritic earths of northern Australia were formed in the Late Cretaceous over 50–100 million years ago. The Gondwanan plant communities—rainforest, eucalypt open-forest with a grassy (savanna) understorey, and sandstone edaphic complex (containing heathy elements)—appear to have survived with little modification in their original species composition.

4. UNESCO Arid Zone Research Program (1950s)

Early in the 1950s, UNESCO focussed on the problem of desertification throughout the world. The Executive of C.S.I.R.O. (under Sir Ian Clunies-Ross) accepted the challenge and coopted Prof. Wood to chair a planning committee in the Adelaide University. As was to be expected, Prof. Wood fostered long-range studies of Arid Zone vegetation similar to that initiated in 1925 by Prof. Osborn on Koonamore Vegetation Reserve in north-eastern South Australia [38, 39]

and on Gilruth Plains, Cunnamulla, Queensland by Dick Roe in 1939 [40–42].

Wood also promoted the water-balance studies that I had initiated on Dark Island heathland to try to understand how enough soil water could be conserved to support foliage growth (and flower initiation) of overstorey plants (*Eucalyptus*, *Banksia*, etc.) during summer—the driest season of a Mediterranean-type climate [43, 44].

Shortly afterwards (1953–1954), Fulbright Fellow, Prof. Walt Phillips from Tucson, Arizona, and Fulbright Scholar Dorothy Taylor from Duke University, North Carolina, spent a year in the Botany Department of the University of Adelaide to study Arid Zone vegetation. I was encouraged to survey Arid Zone research in the United States from Idaho, to Nevada and Utah, to southern California, Arizona, New Mexico, to Texas—which I undertook on a Carnegie Fellowship for two months during 1956. The balance of foliage cover in overstorey and understorey strata had been clearly demonstrated in the USDA mesquite thinning-experiment near Tucson, Arizona [45], and in the seasonal-grazing trial on sagebrush at the Sheep Experiment Station, Dubois, Idaho.

The balance of foliage cover between overstorey and understorey plants had also been recorded in our studies on postfire succession in Dark Island heathland in the 1950s [46].

Before I left Adelaide for the United States and France in 1956, Prof. Prescott and Prof. Wood asked me to contribute an article on the water-balance studies that I had initiated on Dark Island heathland and on Koonamore Vegetation Reserve for the UNESCO-C.S.I.R.O. Symposium on “*Climatology and Microclimatology*” [47] to be held in Canberra during October 1956—before the Melbourne Olympic Games. Apparently, my paper [48], presented in absentia, stirred leading international bioclimatologists—C. W. Thornthwaite of the Laboratory of Climatology, Centerton, New Jersey, USA; Dr. John L. Monteith, Physics Department, Rothamsted Experimental Station, Harpenden, Herts, UK; Prof. R. Geiger, Ludwig Maximilians Universität, Munich, Germany (and later Prof. Heinrich Walter); Prof. Louis Emberger, Institut de Botanique de l’Université de Montpellier, France; Prof. F. S. Bodenheimer (and later Prof. Michael Evanari), University of Jerusalem, Israel.

During the Symposium, Prof. Emberger of Montpellier presented his Pluviometric Quotient (Q) for the classification of Mediterranean-type climates in North Africa and southern Australia [49, 50]

$$Q = \frac{2000P}{(M^2m^2)}, \quad (1)$$

where P is the mean annual precipitation, M is the mean maximum temperature of the hottest month, and m is the mean minimum temperature of the coldest month.

Shortly afterwards, he was invited to contribute an article on his Pluviometric Quotient for the “*Biogeography and Ecology in Australia*” [51]—“*La place de l’Australie méditerranéenne dans l’ensemble des pays méditerranéens du Vieux Monde*” [52].

As I was studying the postfire biomass production [53, 54] in garrigue and maquis vegetation in the Mediterranean-type climate of southern France during September to November 1956 (based in Prof. J. Braun-Blanquet's Laboratory), I was privileged to discuss the symposium with Prof. Emberger when he returned to the University of Montpellier. Thus began the cooperative research between Montpellier and Australia and the establishment of the C.S.I.R.O. Laboratory in Montpellier (1966–2008) to research biological control of weeds (such as skeleton weed, *Chondrilla juncea*) introduced from the Mediterranean-type climate into Australia (Richard Groves, pers. comm. 2010).

Arid Zone research on Koonamore Station was activated after my return from sabbatical leave in 1956. Anne Hall, Con Eardley, and myself collated the annual records on the “*Regeneration of the vegetation on Koonamore Vegetation Reserve, 1926–1962*” [39]. An ecological survey was made of the vegetation of Koonamore Station by Bailey Carrodus, Margaret Jackman, and myself [55]. Bailey Carrodus embarked on a two-year study of the monthly water relations of saltbush and bluebush plant communities—on plots irrigated with a range of “rainfalls.” Carrodus and I also designed a glasshouse experiment to examine how long droughted saltbush plants could survive by absorbing water (into their leaves) from an atmosphere that was very humid at night [56]. Helene Martin studied the monthly water balance in the vegetation gradient from subhumid to humid climates in the Mt Lofty Ranges [57].

Australia became the driving force in the UNESCO Arid Zone Research Program and, under Ray Perry's leadership, was responsible for initiating the International Rangeland Ecology Society. In July 1970, Dr. Gilbert Long invited me to attend a conference on “*Ecological Studies in the Arid Zone of North Africa*” at C.N.R.S. Montpellier, France. During the last week in 1970, I was invited to survey Arid Zone research in Israel by Michael Evanari, Kofish Tadmor, and Gideon Orshan of the Botany Department, University of Jerusalem; one of their postgraduate students, Ruhama Berliner, spent a year in the University of Queensland modelling water balance of the vegetation of Israel [58]. Both Ray Perry and I were invited to the 1972 conference on “*Eco-physiological Foundation of Ecosystem Productivity in the Arid Zone*” [59] in Samarkand by Prof. Louis Rodin of Leningrad University, USSR.

Dr. Ph. Daget of the Institut de Botanique and Dr F. di Castri of the C.N.R.S. Centre Louis Emberger, in Montpellier, were part of the team in the production of “*Mediterranean-type Ecosystems. A Data Source Book*” [60]. Daget, Ahdali, and P. David contributed “*Mediterranean bioclimate and its variation in the palaearctic region*” [61, pages 117–124, 139–148]—from the Atlantic Ocean to the Middle East.

5. Ecological Biogeography of Australia

Most of the present-day soils and ecosystems in Australian landscapes—from the tropical north to the temperate south of the continent—have been developed on the degradation products of nutrient-poor, Gondwanan lateritic soils during

the climatic oscillations that have occurred over the last fifty million years [11, 23, 62–64].

In the Early Tertiary when the Australian continent separated from Antarctica, temperate rainforest vegetation, dominated by *Nothofagus*, was widespread over the southern and south-eastern part of the continent [65–67]; in drier habitats, sclerophyllous heathy elements existed [68]. Tropical rainforest flora existed in the wettest areas of the north and north east [69, 70]. Gondwanan C4 grasses and associated flora must have been widespread in the warmer north of the continent [37, 71–74], while some 14% of the present-day sandstone flora contains woody species in common with the sandstone flora of India—and no where in between [35, 69, 75, 76]. Although the southern part of the Australasian Tectonic Plate was located at latitude 60–65°S during the Late Cretaceous, palaeo-oxygen analyses of the sediments in the South Tasman Sea indicate a mean annual temperature of 19.5°C [77]. At this latitude, the sun would shine throughout the year, with no long winter [78]; the temperature differed by only a few degrees from winter to summer [68], thus favouring tall open-forest vegetation, similar to the structure of the vegetation inland from the coast of northern New South Wales.

As the climate became drier in the Early Tertiary, the genus *Eucalyptus* (including the bloodwood now known as *Corymbia*) appears to have evolved as an overstorey to the Gondwanan heathland and grassland vegetation [79]. The original rainforest vegetation of the tropical north—which is linked with New Guinea [80]—and the temperate south survived in only a few perhumid sites. Some taxa of the Early Tertiary flora became separated by thousands of kilometres on either side of the continent [75]; the present-day floras of south-western and south-eastern Australia overlapped on Kangaroo Island and adjacent Peninsulas of South Australia [81].

The mid-Tertiary marine inundations in southern Australia, that submerged the Eucla Basin and the Murray Basin, and so forth, resulted in the deposition of a great depth of calcareous material, composed of foraminifera and molluscs, and so forth [23, 82]. After the seas retreated, the soils that developed on this calcareous substrate experienced a low, but continual, accession of sea spray (cyclic salt). Depending on the degree of leaching, varying amounts of sodium ions became associated with the clay cations of these soils, thus producing a solonchic B horizon. Both coastal and inland sand-dunes became mobile following devegetation during the arid cycles of the Quaternary. Vast sand-dune systems developed in southern Australia—on Eyre Peninsula, the Ninety-Mile Plain in the Upper South East District, and the Murray Mallee District—and extended eastward into Victoria as the Little and Big Deserts and the Sunset Country [83]. The arid Centre of the continent became a dust bowl in which extensive dune systems resulted [7]. The impacts of these geological events on southern Australian soils and vegetation were summarised by Dr Crocker of the Waite Agricultural Research Institute and Prof. Wood of the Botany Department of the University of Adelaide [3, 4].

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 time and space [5, 84]. The various ecophysiological facets of the ecosystem

Vegetation

= Function (climate, parent material, relief, organisms, time)
(2)

were explored and integrated by one scientist. Crocker’s colleague, Dr Stephens of the C.S.I.R.O. Division of Soils, promoted the integrated studies of chronosequences as a basis for the management of soils and associated ecosystems—in his Presidential Address (October 1956) to the Royal Society of South Australia [85] and at the ANZAAS meeting in Adelaide during August 1958 [86]. Quaternary studies of the development of landscapes in Australia resulted in geomorphology of the landscape [87] and palynological studies of the changing pollen content of peat deposits in Lynch’s Crater, Atherton Tableland, over the last 150 000 years [88].

The development of the Gondwanan vegetation in the Late Cretaceous through the Cainozoic—palynological studies initiated by Isabel Cookson in the University of Melbourne in the 1940s [65]—was traced by Helene Martin in the University of New South Wales and by Mary Dettmann in the University of Queensland [66, 68, 89–97]. These and other palynological studies showed that, from the mid-Miocene, the aridity of the continent increased progressively from north-western Australia, across inland Australia into south-eastern Australia [92–95, 98].

During the 1950s, The Netherlands’ publisher Dr W. Junk embarked on the series “*Monographiae Biologicae*” to compile studies on the biogeography of the flora and fauna on the continents of the world. The volume “*Biogeography and Ecology in Australia*” [51] was compiled by Australian ecologists, botanists, and zoologists, with editors—Alan Keast (ornithologist in the Australian Museum), Bob Crocker (plant ecologist and soil scientist in Sydney University), and Chris Christian (Chief of C.S.I.R.O. Land Research and Regional Surveys). The papers by Crocker [84], Emberger [52], and Wood [99] summarized the effects of changing climate and soils during the Cainozoic on the distribution of major plant communities in Australia. As this volume became a best seller, the publisher urged Alan Keast, then teaching in Queen’s University, Canada, to prepare an update of Australian biogeographic studies. While Alan was on sabbatical at Griffith University, he coopted Ray Specht to coordinate contributions on the biogeography of the Australian flora, Barbara Y. Main for invertebrates, W. D. Williams for limnology, Murray J. Littlejohn for cold-blooded vertebrates, and Norman B. Tindale on Aborigines. Many scientists participated in the production of a three-volume edition, entitled “*Ecological Biogeography of Australia*” [100].

6. International Biological Program: Conservation (1960s)

The intellectual climate in which the first Conservation Survey of Australia was undertaken for the International Biological Program (IBP) was very different from that pertaining today. Conservation was not seen by one’s peers as a valid scientific exercise, and so the IBP Conservation Survey was undertaken totally without funding. Its completion was a tribute to the participants, of whom there were many, for the concept of conservation of natural resources had been a philosophical ideal in Australia since the 19th Century.

In 1960, Miss Minard F. Crommelin left a sum of \$7,000 to the Australian Academy of Science to further the cause of conservation in Australia. This bequest stimulated the establishment of a steering committee under the chairmanship of Dr Max Day that fostered studies on the conservation status of each State and Territory in Australia [101].

The South Australian subcommittee included Prof. Cleland (a naturalist and conservationist of long experience), Dr Geoff Sharman (marsupial expert), and Dr Ray Specht (plant ecologist). As much of South Australia had already been covered by plant ecological surveys, it was decided to assess the conservation status of plant formations and associations within the State. The resulting survey was published in the *Transactions of the Royal Society of South Australia* [102]. A survey of the conservation status of all plant species recorded in South Australia was published two years later [103].

The objective of this work was the conservation of all living organisms. It was reasoned that if all major plant communities in South Australia were conserved, most plant species would be conserved for posterity. It was assumed that because all animal species are dependent on vegetation either for food or shelter or both, most of the resident invertebrates and vertebrates would be included in these reserves.

The emphasis of the conservation survey was on the majority of the plant and animal species that are found in the major ecosystems of the State, not on the minor number of rare and endangered species.

This approach to the conservation of major plant communities in South Australia was followed by the Frankenberg Report [104] for the State of Victoria, sponsored by the Victorian National Parks Association. The appraisal of the “gaps” in the conservation network was adopted as the basis for the Conservation Section for the International Biological Program [105, 106] and was applied to the “*Conservation of Major Plant Communities in Australia and Papua New Guinea*” [107].

After the development of large computers in the 1970s, the subjective definition of major plant communities, used in the IBP Conservation Survey, was replaced by an objective classification. With financial support from the Australian Heritage Commission, floristic components in almost 5000 ecological surveys, covering all the continent, were sorted into 338 TWINSPAN Floristic Groups, with a further 60 understorey Floristic Groups. The conservation status of these objectively defined Floristic Groups was analysed in the “*Conservation Atlas of Plant Communities in Australia*” [108].

Only a few nations, however, were able to undertake IBP conservation surveys covering the whole extent of their territory—let alone the whole of the continent. Decades later, conservationists of the Idaho Cooperative Fish and Wildlife Research Unit, who had been concentrating research on “Endangered Species,” embarked on a program termed “Gap Analysis,” similar to the Australian IBP Conservation Survey [109].

7. International Union for the Conservation of Nature (1970s)

Towards the end of the IBP conservation survey of major plant communities, Dr Ron Melville of Kew Herbarium visited Australia for the Pan Pacific Science Conference held in Canberra in 1971. In his retirement, Melville had accepted the challenge of IUCN (International Union for the Conservation of Nature) to prepare a “*Red Data Book of Endangered Plants*.” Staff of the major Australian herbaria readily cooperated with the IBP Conservation Committee to list (with their distributions) the primitive seed plants in the Australian flora possessing: (1) primitive floral characters [110]; (2) primitive morphological characters [111]. The species considered to be rare and endangered in each State/Territory were listed in the same publication. The presence of only a few plants of a species, however, enabled that species to be nominated as “rare and endangered” in one State, although it was common over the State border in an adjacent State. This national problem was painstakingly solved over the next decades [112–115].

8. International Biological Program: Production Processes (1960s)

The UNESCO–C.S.I.R.O. Symposium [47] on “*Climatology and Micro-climatology*” (October 1956) stressed the need for research on the field measurement of evapotranspiration from reservoirs, wetlands, agricultural systems, and plant communities from the arid to the humid climatic zones. During the next decade, the World Meteorological Organisation (WMO) promoted such integrated research worldwide. Following the success of the International Geophysical Year (IGY), the International Council of Scientific Unions (ICSU) decided to initiate the International Biological Program (IBP)—an integrated study of terrestrial, freshwater, and marine ecosystems of the world.

After a great deal of discussion and argument, a program emerged under the title “*The Biological Basis of Productivity and Human Welfare*.” Its objective was “to promote a world-wide study of organic production on the land, in fresh water, and in the seas, and of human adaptability to changing conditions.” The program “should be limited to basic biological studies related to productivity and human welfare, which will benefit from international collaboration, and are urgent because of the rapid rate of change taking place throughout the world.” The First Assembly of the International Biological Program (IBP) was held in Paris in July 1964—Turner, a proxy for Robertson who had

attended the ICSU-IBP planning committee in Prague in 1963, represented the Australian Academy of Science. Six sections of IBP were to be organized.

Productivity of Terrestrial Communities (Section PT).

Production Processes in Terrestrial Communities (Section PP):

Subsection—Photosynthesis in terrestrial communities;

Subsection—Nitrogen metabolism in terrestrial communities;

Subsection—Community physiology of terrestrial communities.

Conservation of Terrestrial Communities (Section CT).

Productivity of Freshwater Communities (Section PF).

Productivity of Marine Communities (Section PM).

Human Adaptability (Section HA).

During the 1950s and 1960s, my research (in the Universities of Adelaide, Melbourne, California and Oxford) had concentrated on the community-physiology of phosphorus nutrition in native plant communities—to discover how heathland and grassland plant communities are able to survive on soils extremely low in available nutrients. In the 1960s, I was encouraged to change my direction into the aerodynamic processes involved in the development of structure and growth of complex, native plant communities. During a six-month sabbatical as Royal Society—Nuffield Foundation Fellow in the Department of Agriculture in the University of Oxford in 1964—I was coopted by Prof. Geoffrey Blackman on behalf of the Royal Society to act as convenor of the community physiology subcommittee for the International Biological Program (IBP), Section PP, Production Processes of Terrestrial Ecosystems.

After the death of Sir Ian Clunies Ross in 1959, radio-physicist Fred White became Chairman of C.S.I.R.O. and food biochemist Robertson was coopted onto the C.S.I.R.O. Executive. Although Robertson had been introduced to research in plant ecology in a survey of Myall Lakes, N.S.W. [116] by his Sydney Professor of Botany, Osborn, his career had concentrated on the transport of plant nutrients across cytoplasmic membranes in plant cells. He quickly briefed himself of environmental problems facing the nation in discussions with Professor Turner of Melbourne University whenever he had the opportunity. Robertson’s appointment to the Executive at that time was of short duration when the University of Adelaide invited him to take the Chair of Botany after the death of Prof. Wood. During his brief period on the C.S.I.R.O. Executive, however, a research proposal to investigate the aerodynamic fluxes of evapotranspiration from plant communities—mostly smooth-structured agricultural crops—was initiated by C.S.I.R.O. Division of Meteorological Physics.

In May 1965 when I arrived in Paris for the first meeting of the Planning Committee for IBP Section PP (Production Processes), I was amazed at the disciplines of scientists who had been invited to serve on my Sub-Section (Community-Physiological Processes)—Specht (convenor), J. P. Cooper (plant breeder, Wales), P. Gaastra (eco-physiologist, Netherlands), J. Kvet (grassland ecologist, Czechoslovakia), E. Lemon (micro-meteorologist, U.S.A.), M. Monsi (crop physiologist, Japan); J. L. Monteith (agricultural physicist, Britain), I. C. M. Place (Petawawa Forest, Canada); Rodin (plant ecologist, U.S.S.R.), Z. Sesták (plant biochemist, Czechoslovakia) and C. T. de Wit (ecosystem modeller, Netherlands).

On my return to Melbourne after the first Planning Committee, I assembled an interdisciplinary team to develop the research objectives of IBP Section PP (Community-Physiological Processes)—D. E. Angus (C.S.I.R.O. Division of Meteorological Physics), T. F. Neales (eco-physiologist, University of Melbourne) and Specht (community-physiologist, University of Melbourne). The effect of aerodynamic fluxes (above and within a plant community) on the structure, growth and biodiversity of complex native plant community (and associated consumers and decomposers) was proposed. In January 1967, these objectives were accepted, with little modification, by the IBP-PP planning committee [117].

I was then coopted by the Australian Academy of Science to promote three Sections of the Australian International Biological Program—Section PT (Productivity), Section PP (Production Processes) and CT (Conservation) of Terrestrial Ecosystems—a task that I had to undertake with no financial support.

The aim of this IBP research proposal was to establish the community-physiological processes that determine the annual foliage growth of the multitude of foliage shoots—in all strata of a native plant community, from ground level to overstorey canopy—and, with time, result in the structure of these plant communities (closed forest, open forest, woodland, tall shrubland, low shrubland, tussock grassland, etc.). Annual foliage growth (both vertical and horizontal) is under the influence of the aerodynamic fluxes (frictional, thermal, evaporative, and atmospheric salinity) in the atmosphere as it flows turbulently over and through a plant community. Available soil water and nutrients at the time of annual shoot growth determine the number of leaves produced on vertically oriented foliage shoots. The photosynthetic potentials of foliage shoots in both overstorey and understorey strata determine the primary production (per hectare) of a plant community and support the non-photosynthetic sections (stems and roots) of the producers as well as associated consumers and decomposers. It was thus

proposed to monitor (by microinstrumentation) the balance between influx (photosynthesis) and efflux (respiration) of carbon dioxide in representative ecosystems (not enclosed in constant-environment chambers) and evapotranspiration from the ecosystem throughout the whole day, over a period of at least a year. The basic principles of community-physiology (thus derived) could then be integrated in ecosystem models to enable the scientific management of ecosystems.

It is essential to study community-physiological processes in root systems and associated rhizosphere organisms as well as in the aboveground section of an ecosystem. The USSR Academy of Sciences, Soviet National Committee for the IBP, organized an international symposium on this subject, August 28th–September 12th 1968 [59].

A number of nations (UK, Canada, Australia, USSR, Japan) were keen to study community-physiological processes in aerodynamically smooth plant communities—using a meteorological tower to measure the gradient of temperature, water vapour, and carbon dioxide above a dense plant community with an aerodynamically smooth canopy.

In order to assess (1) the amount of water evapotranspired from an ecosystem and (2) the balance of carbon dioxide influx and efflux in an ecosystem, *continuous recordings* of the profiles of wind, temperature, water vapour, and carbon dioxide above and within “smooth-surfaced” plant communities (crops, reed swamps, etc.) were initiated in Britain, Canada, United States, Japan, and Australia. This research into aerodynamic fluxes within and above a plant community—lasting over an entire year or more—was pioneering in the days before reliable microinstrumentation and high-speed computers with large memory that did not depend on a 240-volt power generator had been developed. As well, very few plant scientists had the expertise to cooperate with the micro-meteorologists in the structural analysis of the plant community. It was only in Australia, however, that a small group of scientists were prepared to study the growth of foliage shoots (both vertical and horizontal) in the many life forms that composed complex-structured plant communities.

As I was already familiar with the monsoonal vegetation of Arnhem Land and the subtropical vegetation of south-eastern Queensland, I was coerced to leave the sophisticated scientific centres in southern Australia to pioneer my interdisciplinary IBP-PP proposal in the classical Botany Department of the University of Queensland. My prime task was to introduce interdisciplinary teaching on the study of ecosystems into secondary and tertiary education (at both undergraduate and postgraduate levels). At the same time, I wished to initiate interdisciplinary research in a complex native plant community near Brisbane. I was strongly supported in this endeavour by the Physics, Biochemistry, and Agriculture Departments (and later by the Zoology Department) of the University of Queensland, the Cunningham Laboratory of C.S.I.R.O., and by the Education Department of Queensland.

Financial support for such an interdisciplinary venture in the field was very expensive—four-wheel drive vehicles, electronic microenvironmental and biological field measuring

equipment, a caravan to house a computer (very large and expensive in those pioneering days), a generator to provide power, travel, and camping costs, plus insurance off the campus, and so forth. Expensive research laboratories and equipment with technical staff were essential for laboratory studies and teaching. The newly formed Australian Research Grants Commission, established by Professor Robertson in 1966, supported this interdisciplinary research—but under my name, not including other team members. Experts in the field of plant physiology, plant biochemistry, plant biophysics, community-physiology, and micrometeorology formed essential members of the team both for teaching and research.

The key member of the team, a micro-meteorologist, was the most difficult to find. Finally Dr David Angus was seconded from C.S.I.R.O. Division of Meteorological Physics—provided he could work on a low, smooth-structured plant community, not on a complex native plant community. Financial arrangements were made for David to study the Mitchell Grass tussock grassland on the Wilson Plain, north of Charleville—but this plant community was in the Arid Zone where aerodynamic fluxes were unpredictable, so David tried to develop his aerodynamic studies alongside Archerfield Aerodrome. Dave Doley, Neill Trivett, and Catherine Mittelheuser, however, studied the remarkable ability of chloroplasts in apparently dead leaves of Mitchell grass to resurrect rapidly after a shower of rain [118, 119].

9. International Biological Program: Biome Studies (1970s)

In the United States, finances needed to implement the six independent Sections of IBP were combined under IBP Biome Studies; in the scramble for finances, descriptive studies tended to dominate over the study of ecophysiological and community-physiological processes. As well, ecosystem modellers could not wait until basic concepts of community-physiological processes had been developed. Instead, most ecosystem models were based on eco-physiological processes that had already been developed for single plants and animals in well-watered Northern Hemisphere ecosystems—ecosystems that are quite unlike the complex, open-structured plant communities on the infertile Gondwanan soils in the drier Southern Hemisphere.

Many scientists were involved in the development of these concepts. During the following decades, community-physiology processes were investigated in Australia and promoted abroad. Australian ecologists prepared articles on the major plant formations in *Australian Vegetation* [120, 121] for the International Botanical Congress, Sydney. Research on each major ecosystem was pursued.

(i) For the Arid Zone Ecosystem Program—a survey from the “cold desert” in Idaho to the “warm desert” in Texas, United States [122], together with the long-term records on Koonamore Vegetation Reserve [38, 39, 123], plus Winkworth’s survey [124] of the spinifex grasslands of Central Australia, enabled the development of the IBP Arid Zone Program in Northern Africa (Montpellier, France,

Oct. 1970); in Israel (December 1970); in the U.S.S.R. (Samarkand, May 1972) [59]. Canopy dynamics of overstorey strata and associated subshrubs were investigated in *Acacia* communities in the arid zone of South and Central Australia [125, 126]. A thinning experiment to encourage the growth of the grassy understorey by reducing the density of mulga trees was established at Charleville in south-western Queensland [127, 128]. The ability of C4 grasses, such as *Astrebla* spp., to survive desiccation in the arid zone—and to resurrect after rain—was explored [118, 119]. Resurrection plants—extremely desiccation tolerant—in the Australian flora were investigated by Don Gaff and associates at Monash University [129–133].

(ii) For the Grassland Ecosystem Program—an extensive point quadrat survey of the structure of grassland vegetation in the South East of South Australia [134, 135] and of the *Themeda* grassland in Victoria [136] formed the basis of the Grassland Ecosystem Program. This research was promoted in New Zealand (Massey University, January 1967); in the United States (Fort Collins, Colorado, July 1970); in Canada (Saskatchewan, July 1970). The C.S.I.R.O. Pastoral Laboratory, Armidale, NSW, became affiliated with the Grassland Biome Program in the United States. D. J. Connor of the University of Queensland joined the ecosystem modelling team in Fort Collins while on sabbatical leave in 1972.

(iii) For the Mediterranean-Climate Ecosystem Program—the Botany Department of the University of Adelaide investigated the structural and biomass changes in both the heathland and mallee-broombush vegetation in the Upper South East of South Australia in stands aged over 25 years postfire [46, 137]. Osborn, the first Professor of Botany in the University of Adelaide, had a long-time interest in the similarities between the structure of southern Australian and the vegetation in the Mediterranean Basin [138, 139]. Osborn, who had recently retired to Adelaide from the Chair of Botany in Oxford University, encouraged Specht, on his sabbatical leave in 1956, to compare the postfire changes in structure and growth of treeless vegetation in three Mediterranean-type climates—southern California, southern France, and southern Australia [53, 54]. Twenty years later, similar studies were made on the structure and growth of fynbos vegetation in the Mediterranean-type climate of Cape Province, South Africa [140, 141]. These studies formed the basis for the IBP Mediterranean-Climate Biome Program in California and Central Chile [142–145]. Other nations soon extended these studies to Mediterranean-type ecosystems in their region.

Mediterranean-climate conferences were held in

- (a) Valdivia, Chile (August 1971) on “*Mediterranean-Type Ecosystems. Origin and Structure*” [142];
- (b) Palo Alto, California (August 1975) on “*Environmental Consequences of Fire in Mediterranean Ecosystems*” [146];
- (c) Stellenbosch, South Africa (September 1980) on the “*Role of Nutrients in Mediterranean-type Ecosystems*” [147];

- (d) San Diego, California (June 1981) on “*Dynamics and Management of Mediterranean-Type Ecosystems*” [148];
- (e) Montpellier, France (May 1983) on “*Bioclimatologie Méditerranéenne*” [149];
- (f) Perth, Western Australia (August 1984) on “*Resilience in Mediterranean-type Ecosystems*” [150];
- (g) Sesimbra, Portugal (October 1985)—“*Plant Response to Stress*” [151];
- (h) Barcelona and Zaragoza in Spain (October 1985)—(Carles Gracia & HeimeTerradas unpubl.);
- (i) Woods Hole, Mass., U.S.A. (October 1986)—“*Patterns and Processes in Biotic Impoverishment*” [152];
- (j) Montpellier, France (August 1987) on “*Time Scales of Biological Responses to Water Constraints*” [153];
- (k) Thessaloniki, Greece (August 1988)—(Margarita Arianoutsou unpubl.);
- (l) Alicante and Barcelona, Spain (1990)—(Carles Gracia unpubl.);
- (m) Israel (1990)—Memorial Volume 39 of *Israel Journal of Botany* on death of Professor Michael Evanari, Botany Department, University of Jerusalem [58];
- (n) Aix-en-Provence, France (1991)—Festschrift Volume 16 for Professor Pierre Quézel, *Ecologia Mediterranea* [154];
- (o) Crete, Greece (September 1991) on “*Plant-Animal Interactions in Mediterranean-type Ecosystems*” [155];
- (p) Reñaca near Santiago, Chile (October 1994) on “*Landscape Degradation in Mediterranean-Type Ecosystems*” [156];
- (q) San Diego, California (1997)—(Walt Oechel unpubl.);
- (r) Stellenbosch, South Africa (2000)—(William Bond, Richard Cowling and Glaudin Kruger unpubl.);
- (s) Greece (2004)—(Margarita Arianoutsou & Costas Thanos unpubl.);
- (t) Perth, Western Australia (2007)—(Kingsley Dixon unpubl.)

In Australia, the MEDECOS program stimulated research into “*Kwongan*,” the vegetation of the sand plains north of Perth [157], and in “*Mallee Ecosystems*” in the semiarid region of south-eastern Australia [158, 159]. Research on the eucalypt forests of southern Australia was summarised in “*The Jarrah Forest*” [160] of south-western Australia and in “*Nutrition of Eucalypts*” [161]. Under the auspices of the International Society for Mediterranean Ecosystems (ICSU-ISOMED), initiated in 1984 by Francesco di Castri, the Ecological Director of UNESCO, scientists from all Mediterranean-climate countries cooperated to produce “*A Data Source Book for Mediterranean-Type Ecosystems*” [162, Table 17] and a survey of “*Biogeography of Mediterranean Invasions*” [163].

(iv) For the Heathland Ecosystem Program:—Dark Island heathland, South Aust. (1950–1960) [20, 46]; Frankston and Wilsons Promontory, Victoria (1961–1966); Beerwah and North Stradbroke Island, Queensland (1966–1975); Brisbane, Canberra, and Perth, Australia (1975); Western and Eastern Cape, South Africa (1975 and 1979); Cathedral Peak, South Africa (1975); Cambridge and Leeds, England (1975); Aberdeen and Edinburgh, Scotland (1975). IBP investigations were fostered across the Arctic, in Malesia (especially Borneo and New Guinea), in New Zealand, in South America (lowlands and highlands across the north and in the extreme south of the continent), and in the United States (Appalachian Balds, coastal California, and coastal New Jersey to south-eastern USA). Studies on the heathlands of Costa Rica, Japan, Micronesia, New Caledonia, and in countries to the north of the Mediterranean Basin were also included [164, 165]. The growth rhythms in the foliage of Australian heathlands from southwest Western Australia to south-east Queensland were related to seasonal climatic factors [166].

(v) For the Coastal Wetland Program—the distribution of the flora and fauna of mangrove and salt-marsh ecosystems around the coastline of Australia were collated [167]. The phenology of mangroves from the subtropics to the tropics was studied [168–176]. The zonation of mangrove and salt-marsh vegetation from mean sea level to extreme high water springs was recorded [167–169, 177–179]. From Cape York to Tasmania, the species richness of mangrove vegetation was found to decrease while the species richness of salt-marsh vegetation increases [180]. Northeastern Australia and New Guinea show the greatest biodiversity of mangrove species anywhere in the world [180, 181]. The peak of species richness of lichens epiphytic on mangrove trees is found in the subtropics, declining in the near-vertical solar radiation experienced in the tropics and in the lower-intensity, oblique rays in temperate Australia [182, 183].

(vi) For the Subalpine-Alpine Ecosystem Program—decreasing air temperature with altitude affects leaf lengths and tree heights of snow gum (*Eucalyptus pauciflora*) in the Snowy Mountains area of south-eastern Australia [184, 185]. The photosynthetic relationship of leaves to temperature in this cline was investigated in the field and phytotron by Ralph Slatyer and postgraduates [186–190].

(vii) For the Forest Ecosystem Program—*Acacia harpophylla* (Brigalow) open-forest at Meandarra, Queensland [191]; *Eucalyptus signata* open-forest on North Stradbroke Island, Queensland [192, 193]; *Eucalyptus obliqua* open-forest at Mt Disappointment, Victoria [194]. The seasonal growth rhythms in the foliage of overstorey eucalypts were collated in tropical, subtropical, and temperate eastern Australia [195–202]. Tree density was estimated from mid-1800s survey maps for eucalypt open forests that grew, presettlement, on the shallow Brisbane metamorphic, and the hard Brisbane tuff [203].

(viii) Ecological studies on serpentine vegetation began in San Benito Mountains, California in the 1950s [204]. In 1989, ecologists in Queensland were encouraged by Roger

Reeves of Massey University, N.Z., to investigate the serpentine vegetation in the Rockhampton-Marlborough area of Central Queensland, in the Widgee Mountain-Kilkivan area of south-eastern Queensland, and in the Baryulgil area of north-eastern N.S.W. [205]. In the 1990s, international symposia on the ecosystems of ultramafic (serpentinite) soils were initiated; community-physiological studies on the eucalypt forests on serpentinite in Central Queensland and north-eastern New South Wales were presented in Davis, California (1991), in New Caledonia (1995), and in Kruger National Park, South Africa (1999) [206–208].

(ix) For the Rainforest Ecosystem Program—a floristic framework for Australian rainforests from Tasmania to the Kimberleys [209–211]; the floristics of monsoonal rainforests in the Northern Territory [212]; the floristics of dry vine forests in south-eastern Queensland [213]; the maintenance of species diversity in tropical rainforests of North Queensland [214, 215]; the dynamics of a rainforest at Mt Glorious, in perhumid south-eastern [216–218]; the species richness of the remnants of the Big Scrub in perhumid to humid north-eastern N.S.W. [219]; the species richness of disjunct stands of dry vine forests in Central Queensland [220]; the dynamics of a rainforest pocket at Gambubal, in humid south-eastern Queensland [221–224].

(x) For the Tropical Savanna Ecosystem Program—research on “*Australian Grasslands*” [225] was summarised for the International Grasslands Congress held in Surfer’s Paradise in 1969. A. N. Gillison and H. A. Nix of C.S.I.R.O. Division of Land Use Research and A. E. Newsome of C.S.I.R.O. Wildlife Research reviewed the intensive investigations being conducted in the north of Australia. An International Savanna Symposium was held in the C.S.I.R.O. Cunningham Laboratories in 1984 [226]. This international symposium was followed by a working group on “*Tropical Plant Communities. Their Resilience, Functioning and Management in Northern Australia*” [227]. Studies on the variation in composition and structure in tropical savannas were undertaken at Weipa in Northern Queensland [228] and in the Northern Territory [202, 229–231]. The species richness of plants and resident vertebrates in monsoonal ecosystems was found to be closely correlated [232]—a relationship demonstrated for the rest of Australia [219, 233, 234].

10. Ecosystems of the World (Elsevier, Amsterdam, 1977–2006)

The “Australian” ecosystem modeller, David W. Goodall, was appointed as Professor of Range Science in the U.S. Arid Zone Ecosystem Program at Logan, Utah, between 1968 and 1974. In 1975, David was invited, by Elsevier Publishing, Amsterdam, to be the General Editor of a 30-volume series to summarise the IBP Biome Studies of “*Ecosystems of the World*”. This project occupied Goodall for the next 40 years, well into his 90s.

10.1. Terrestrial Ecosystems

10.1.1. Natural Terrestrial Ecosystems

Vol. 1 Wet Coastal Ecosystems [235].

Vol. 2 Dry Coastal Ecosystems [236–238]:

Part A. Polar Regions and Europe;
Part B. Africa, America, Asia and Oceania;
Part C. General Aspects.

Vol. 3 Polar and Alpine Tundra [239].

Vol. 4 Mires: Swamp, Bog, Fen and Moor [240]:

Part A. General Studies;
Part B. Regional Studies.

Vol. 5 Temperate Deserts and Semi-Deserts [241].

Vol. 6 Coniferous Forests [242].

Vol. 7 Temperate Deciduous Forests [243].

Vol. 8 Natural Grasslands [244, 245]:

Part A. Introduction and Western Hemisphere;
Part B. Eastern Hemisphere and Résumé.

Vol. 9 Heathlands and Related Shrublands:

Part A. Descriptive Studies [164];
Part B. Analytical Studies [165].

Vol. 10 Temperate Broad-Leaved Evergreen Forests [246].

Vol. 11 Mediterranean-Type Shrublands [145].

Vol. 12 Hot Deserts and Arid Shrublands, Part A. [247], Part B. [248].

Vol. 13 Tropical Savanna [249].

Vol. 14 Tropical Rain Forest Ecosystems:

Part A. Biographical and Ecological Studies [250];
Part B. Structure and Function [251].

Vol. 15 Forested Wetlands [252].

Vol. 16 Ecosystems of Disturbed Ground [253].

10.1.2. Managed Terrestrial Ecosystems

Vol. 17 Managed Grasslands:

Part A Regional Studies [254];
Part B Analytical Studies [255].

Vol. 18 Field Crop Ecosystems [256].

Vol. 19 Tree Crop Ecosystems [257].

Vol. 20 Greenhouse Ecosystems [258].

Vol. 21 Bioindustrial Ecosystems [259].

10.2. Aquatic Ecosystems

10.2.1. Inland Aquatic Ecosystems

Vol. 22 Rivers and Stream Ecosystems [260].

Vol. 23 Lakes and Reservoirs [261].

10.2.2. Marine Ecosystems

Vol. 24 Intertidal and Littoral Ecosystems [262].

Vol. 25 Coral Reefs [263].

Vol. 26 Estuaries and Enclosed Seas [264].

Vol. 27 Continental Shelves [265].

Vol. 28 Ecosystems of the Deep Ocean [266].

10.2.3. Managed Aquatic Ecosystems

Vol. 29 Managed Aquatic Ecosystems [267].

10.2.4. Underground Ecosystems

Vol. 30 Subterranean Ecosystems [268].

11. International Geosphere-Biosphere Program (Late 1980s)

Since the Industrial Revolution, the level of carbon dioxide in the atmosphere has steadily increased to about 450 ppm due to the burning of fossil fuels. Much of the black-body radiation reradiated from the surface of the Earth is trapped by these gases, thus gradually increasing the temperature in the atmosphere—the “greenhouse effect” [23, page 197, 261]. The level of carbon dioxide in the atmosphere is now so high that global warming is inevitable—as had occurred during the Late Cretaceous and the mid-Tertiary.

When this high value of carbon dioxide was reported by the observatory on the summit of Hawaii, the Systems Ecology Research Group (SERG), in San Diego State University, turned their attention from the MEDECOS investigation of Californian chaparral to Alaskan ecosystems—downwind from Hawaii. Shortly afterwards, the International Council of Scientific Unions (ICSU) fostered the International Geosphere-Biosphere Program (IGBP).

An article on “*Global warming: Predicted effects on structure and species richness of Mediterranean-climate ecosystems in southern Australia*” [269] was presented at the 1987 MEDECOS Conference in Montpellier on “*Time Scales of Biological Responses to Water Constraints: The Case of Mediterranean Biota*” [153]. The Australian Academy of Science held a conference on “*Global Change*” [270] at which I was invited to present a paper on “*Geosphere-biosphere interaction in terrestrial ecosystems*” [271]. Shortly afterwards, an international meeting of IGBP was held in Canberra.

In 1989 as part of the Queensland Government greenhouse gas inventory, the Queensland Department of Environment and Resource Management initiated the Statewide Land Cover and Trees Study (SLATS) to monitor wooded

vegetation cover throughout the State—a program that has continued for almost twenty years [272]. In conjunction with SLATS, the Queensland Herbarium has monitored the survival of remnant vegetation throughout the State from 1996 to 2008 [273]. When the savanna understorey is dry and brown at the driest time of the year, the Foliage Projective Cover (FPC) of the overstorey in the vegetation of Queensland is mapped by satellite imagery using the Normalised Difference Vegetation Index (NDVI) to estimate changes in cover (by clearing) of the remaining native vegetation [272, 274]. Tree cover in the State of Queensland has thus been followed for over twenty years and has provided a scientific basis for the control of future land clearing and the effects of climate change.

Community-physiological studies on ecosystems from the tropical north to the temperate south of the continent were summarized in “*Australian Plant Communities, Dynamics of Structure, Growth and Biodiversity*” [23]. During the short period of annual foliage growth in evergreen plant communities, aerodynamic fluxes (frictional, thermal, evaporative) in the atmosphere as it flows over and through a plant community determine the foliage projective covers (FPCs) and leaf attributes (leaf area, leaf specific weight, the ratio of foliar nitrogen to foliar phosphorus, the ratio of chlorophyll a to chlorophyll b, the carbon isotope ratio, nitrate reductase enzyme activity) in overstorey and understorey strata [275–281]. In regions that experience seasonal drought, the combined foliage projective covers in overstorey and understorey strata determine monthly evapotranspiration (per hectare) so that the ratio of actual to potential evapotranspiration is correlated with available soil water during every month of the year—a community-physiological constant termed the evaporative coefficient [282]. In climates such as Australia that experience seasonal drought, an increase in air temperature of 2°C during this period of annual foliage growth will affect the structure of the plant community [283], so that tall open forests (FPC 60–70%) → open forests (FPC 45–65%) → woodlands (FPC 35–45%) → open scrub (FPC 25–35%) → low open shrubland (FPC < 25%) → desert communities [269]. The interception of solar radiation (per hectare per annum) by the plant community will be reduced and affect the balance in species richness (the number of species per hectare) of vascular plants and associated vertebrates in the ecosystem [22, 154, 232–234, 284–290]. Variation in available soil water and nutrients during this short period of annual foliage growth will influence vertical shoot growth (and stand height at maturity) but not foliage projective covers and leaf attributes produced in the overstorey and understorey strata [23].

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