Dynamics of Plant Processes and Populations in Semi-arid Australia and the Influences of Drought, Grazing and Fire

A thesis submitted for the degree of
Doctor of Science
of
Massey University

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18 January, 2010

Contents

Abstract

The experimental, analytical and integrative research achievements of the author, relating to the study of plant functioning and dynamics of plant populations and communities in semi-arid landscapes of eastern Australia and the responses to the stresses of drought, fire and grazing, are described. These achievements occurred during a period when scientific knowledge on the functioning and dysfunctioning of ecological communities in arid and semi-arid pastoral lands were required for the development of new managements that sustained natural resources in these water-limited environments. The research described addresses the principle goals of the author, namely to (i) elucidate physiological and demographic responses to climate variability and interactions with the stresses of grazing and fire, and (ii) to use the knowledge to develop new grazing and fire managements for sustaining pastoral businesses and the natural resources on which they depend, in semi-arid pastoral Australia.

In this thesis, the research achievements of the author, the consequent publications, and the recognition of this research, are summarised in the Preface (Section 1). Following the author's *curriculum vitae* (Section 2), and full list of publications (Section 3), a detailed description of the author's research is given in Section 4, which comprises 40 selected publications in refereed journals and books, totalling some 482 pages. These selected publications address the research theme defined by the thesis title *Dynamics of plant processes and populations in semi-arid Australia and the influences of drought, grazing and fire*, and cover the period 1970-2002, during the candidates' research programs with the Commonwealth Scientific and Industrial Research Organisation at Deniliquin and Canberra, Australia.

This work contains no material which has been accepted for the award of any other degree or diploma in any university or other tertiary institution, and no material previously published or written by another person, except where due reference has been made in the text.

Consent is given for loan and photocopying of this copy of the thesis, when deposited in the University Library.

Kenneth C. Hodgkinson
18 January, 2010

Acknowledgements

The research achievements described in this thesis would not have been possible without the collaboration and support of many individuals. First, the author would like to thank the many local, interstate, and international collaborators, who have made valuable contributions to his research. Most of these collaborators are listed specifically, as co-authors on the selection of published work described in Section 4. Within Australia, the author acknowledges valuable ongoing collaborations with Dr R. B. Hacker of Industry and Investment NSW. Of his many international colleagues, the author would particularly like to thank Professor J. A. Quinn, of Rutgers University, for his collaboration; and Professor D. Wang, of Northeast Normal University for his recent intellectual contributions. Second, the author is grateful to those who provided rangeland science leadership in CSIRO, in particular, to Mr Ray Perry who developed a rangeland research unit in CSIRO in 1966 with a shared vision for a systems approach involving ecologists, economists and sociologists, to Dr's A. D. Wilson and G. N. Harrington who provided dynamic group leadership in Deniliquin and to Dr B. H. Walker who contributed inspiring leadership and promoted scientific excellence while the author was in Canberra. Third, the author is grateful to supporting colleagues, in particular B. Dixon, G. Miles and R. Oxley for their technical skills and dedication in contributing to the success of his early experiments, D. Tongway for developing the methods to measure landscape function in Australian rangelands and W. Muller for a continuing role in statistical analyses of data during the author's scientific career. Fourth, the author acknowledges the budgetary and administrative support provided to his research program by CSIRO and the funds provided by the organisations listed in his curriculum vitae. Finally, the author is grateful to his parents, Charles and Betty, for their encouragement and support from New Zealand during his career, and to his wife Lenore, for her support and understanding during many and long absences from home when gathering field data or attending national and international science meetings. Without her enduring sacrificial nature, many of the research achievements would not have been possible.

1. Preface

1.1 Summary

The author has made a sustained, coherent, and significant contribution of high-quality original research which has advanced knowledge in the general fields of plant physiology and ecology and their application in semi-arid Australia. Summaries of this research, the resultant publications and research recognition are given below in Sections 1.2, 1.3, and 1.4, respectively. A selection of 40 refereed publications which encapsulate the main research theme, *Dynamics of plant processes and populations in semi-arid Australia and the influences of drought, grazing and fire,* appears in Section 4, representing the bulk of this thesis.

1.2 Research

The author studied by experimental, analytical and integrative approaches, the functioning of plants and plant communities in semi-arid landscapes disturbed by grazing and fire. The emphasis of his research has been on the interactions of the separately occurring defoliating agents of grazing and fire with co-occuring drought. His twin goals have been to (i) elucidate physiological and demographic responses to climate variability and interactions with the stresses of grazing and fire, and (ii) to use the knowledge for developing new grazing and fire managements for sustaining pastoral businesses and the natural resources on which they depend, in semi-arid pastoral Australia.

While detailed research results are not given here, since they are more properly gleaned from an examination of the published works in Section 4, it is appropriate to summarise some highlights[1] in each section of the authors research.

Section 1: Dynamics of plant processes in 'grazed' Medicago sativa L.

Medicago sativa was used as a model to explore dynamics of physiological processes when plants are partially defoliated. The authors major contribution was to demonstrate reversal in photosynthetic activity of senescing leaves at the base of shoots, and to show that the additional carbon synthesised, partially or wholly replaced the carbohydrates mobilised from the tap root and promoted shoot growth [4]. Rate of functional rejuvenation and the peak photosynthetic rates were found to depend on leaf age and future defoliation; continual removal of shoots raised photosynthetic rates to that of C_4 plants [6]. Shoot yield, irrespective of initial defoliation, was found to be

[1]Numbers in square brackets refer to the authors list of publications (Section 3.1).

determined by numbers of shoots becoming dominant after onset of apical dominance; the supply level of nutrients to shoots was not involved, suggesting hormonal control of regrowth processes [5].

Section 2: Phenotypic and physiologic plasticity in Austrodanthonia caespitosa (Gaudich.) H.P. Linder populations

Austrodanthonia caespitosa was used as a model to explore genetic bases for physiological adaptations in semi-arid zone grasses along environmental gradients. The author's major contribution was to show that floral induction and development in this species is programmed by stimulus of certain day lengths to coincide with predictable growing seasons but in the unpredictable semi-arid environments the controls are relaxed to permit opportunistic reproduction [11]. Populations were found to differ in reproduction; the most northern required 9.5 hour day length and the most southern required 11 hour day lengths for floral induction. In contrast, populations from hot to cool environments showed little or no adaptation to temperature; temperature optima for growth were not different. Relative growth rates however, did decline from hot to cool environments along a latitudinal gradient; the physiological bases for the decline were unique variations in processes in each population [8]. Density stress responses were unique for each population [18], as was plasticity of reproductive characters [19].

Section 3: Adaptive plasticity in semi-arid plants to the agents of grazing and drought

The author has contributed to understanding of how defoliation influences growth and development of plants. Defoliation was shown to impair root growth and function of both the model plants and a semi-arid shrub but the onset and rate of impairment was species dependant [9]. Frequent and severe defoliation of the second model plant significantly reduced shoot growth and raised death rates, especially in summer; irrigation, fertilizer, partial defoliation and less frequent defoliation generally alleviated these responses but there were exceptions [7]. Axial tillers were shown to be a significant adaptation leading to better tolerance of defoliation in a C_4 grass [21]. A review identified attributes of genotypes likely to be associated with population persistence under grazing. The plant/animal interface was identified for further study to improve persistence of populations under grazing [44].

Section 4: Grazing patterns of sheep and critical thresholds for persistence of plant populations subject to the agents of grazing and drought

Grazing patterns of sheep in both shrub and grass dominated rangelands were shown to be generally random but sheep would frequently regraze some shoots [13,29]. At wider spatial and temporal scales it was recognised other dynamics would emerge such as fire, drought and pluvial periods that interact with vegetation attributes [50,58]. The author's major contribution in this field was to identify opportunities to manage composition of semi-arid vegetation by grazing strategies [53] and to develop the case for research on dynamics of grass populations under grazing [96]. Death of grass species

was found to be drought dependant in the absence of herbivore grazing [34]. Importantly he found that grazing, entering a drought, synergistically increased grass death [37]. The fundamental ecological cost of pastoralism was shown to be the breakdown in self maintenance of landscape processes due to excessive grazing pressure at the wrong times and places [32,56]. Grass recruitment was shown to be lower in heavily grazed areas [30]. Wider implications of downwardly adjusting grazing pressures and changing landuse were identified [112].

Section 5: Dynamics of shrub populations and plant processes before and after the agent of fire

The author's review of shrub biology indicated traits that targeted management might exploit to reduce population density and reproduction [12]. Seed in soil beneath degraded woodland was quantified; shrub seed was abundant and previously dominant grasses were absent [14]. Fire was found to stimulate seed germination of *Acacia* and *Cassia* species and spatial and temporal variability in shrub recruitment following fire was quantified [24,25]. The author made a major contribution in demonstrating survival of shrubs after fire was species and height dependant [33]. An interaction between season and frequency of fire effects on mortality of shrubs indicated poor survival outside the fire regimes to which shrub species were adapted [87]. Shrubs sprouting after fire were less water stressed initially but over 10 years they steadily became more stressed [26].

Section 6: Management of plant populations and landscapes by the agent of fire

The author reviewed knowledge and argued how semi-arid woodlands might be managed by certain fire and grazing regimes to reduce shrubs, increase grasses and improve landscape function [45,46,20,54]. A device for integrating soil temperature during fire was developed for management experiments [17]. The effects of fire on soil properties were identified; adverse changes were reversed within five years of a fire [23,27]. Possible effects of fire and grazing regimes in semi-arid Australia on shrub density, landscape processes, function and biodiversity were explored using models [31,59].

1.3 Publications

The author has published widely, with a total of over 115 journal and conference papers and book chapters (see Sections 3.1 and 3.5 respectively). His research, which is of cross-disciplinary significance, has resulted in more than 35 papers published in a wide range of top-quality international refereed journals, including *Australian Journal of Botany*, *Journal of Applied Ecology*, *Oecologia*, and *The Rangeland Journal*. Of his conference papers, ~ 50% have been presented at significant international meetings.

The publications of the author have been cited by a significant number of researchers in a range of ecology, plant science, natural resource management journals. The work of the author has also been well cited in the scientific review literature, e.g., *A*

framework for the ecology of arid Australia, by D.M. Stafford Smith and S.R. Morton (1990) *Journal of Arid Environments* **18**, 255-278 [20,46]; *Event-driven or continuous; which is the better model for managers?* by I.W. Watson, D.G. Burnside and A.McR. Holm (1996) *The Rangeland Journal* **18**, 351-369 [12,20,50,53,101]; *Fire and Plants* by W.J. Bond and B.W. Van Wilgen (Chapman and Hall, London 1996) [25,87]; and *Sprouting ability across diverse disturbances and vegetation types worldwide* by P.A. Vesk and M. Westoby (2004) *Journal of Ecology* **92**, 310-320 [33,46].

A selection of 40 representative publications in refereed journals and books, comprising 482 pages forms the bulk of this thesis (see Section 4). These publications have been marked with asterisks in the full list of publications in Section 3.1. The work described in Section 4 covers the period 1970-2005, following the establishment of the author's first laboratory in Deniliquin. Consistent with the title of this thesis, *Dynamics of plant processes and populations in semi-arid Australia and the influences of drought, grazing and fire,* all of the publications in Section 4 present original research on the influences of grazing and fire: 12 of the selected publications [4,5,6,7,9,13,21,29,30,32,37,96] contain experimental data on responses of plant processes and populations to grazing (or simulated grazing); while 8 of the selected publications [23,24,25,26,27,31,33,87] contain experimental data on responses of plant processes and populations to fire. The author published scholarly work, critically reviewing knowledge: 3 publications contribute to understanding of influences of grazing on plant processes and population dynamics [44,53,112]; 6 publications contribute to understanding of fire on plant processes and population dynamics [12,20,45,46,54,59]; while 4 publications contribute to both [46,50,56,58]. A subset of 11 of the submitted publications [6,11,20,25,26,29,33,34,59,87,112] perhaps best reflects the desire of the author to publish works which deal simultaneously at a high level with the experimental, analytical and theoretical problems in rangeland science.

Since some of the work in Section 4 is of joint authorship, as is quite usual in this field, it is important to list the contributions to each of the author. His estimated contributions to each of the publications in Section 4 are given in the list of refereed publications in Section 3.1. Overall, they amount to ~ 77% of the submitted work, ~ 35% of which has been fully written by him. The general contributions of the author include: the establishment of laboratories, experimental design, many early experimental measurements, most data analysis, and most of the insight. The main exceptions to this assessment include the significant and important technique contributions of colleagues Baas Becking [9], Miles [14], Smith [17], and Ludlow [21]. For the most part, other coauthors had roles which were either minor, and/or limited to suggestions, advice and inspiration. The estimated contributions of the author given in Section 3.1 have taken into account the particular details given in this paragraph of the contributions of others.

1.4 Recognition

International recognition of the author's research achievements is evident from the following broad range of indicators:

(1) Appointment as Member (1996-) and Chair (2004-) of the Editorial Committee for the international journal, The Rangeland Journal;

(2) Election to Fellowship of the Linnean Society (London) in 2003 and Membership of the Royal Society of New Zealand in 2004;

(3) Presentation of solicited addresses at international botanical, grassland, landscape and rangeland conferences/congresses (e.g. Thirtenth International Botanical Congress, Sydney, 1981; Second International Rangeland Congress, Adelaide, 1984; International Conference on Landscape Change and Human Activity, Lanzhou, 2001; XIX International Grassland Congress, Sao Pedro, 2001;
(4) Chairing of sessions at international grassland, landscape and rangeland conference/congresses (e.g. Fifth International Rangeland Congress, Salt Lake City, 1995; XX International Grassland Congress, Dublin, 2005);
(5) Presentation of invited international seminars (e.g. China: Lanzhou University, Northeast Forestry University, Northeast Normal University; NZ: Massey University; UK: Linnean Society; USA: Bringham Young University, Rutgers University, Texas A & M University;
(6) Research with international collaborators, who have been appointed as official visitors to the CSIRO National Rangelands Program and worked in my laboratory. Those appointed include: Professor J. A. Quinn, Rutgers University; Professor V. J. Anderson, Brigham Young University; Professor P. S. Johnson, South Dakota State University; Professor J. Detling, Colorado State University.

National recognition of the author's research achievements is evident from invitations to address national scientific meetings (e.g. National Symposium on Poplar Box Lands, 1979; National Conference on Bushfires, 1998; National Biennial Conference of the Australian Rangeland Society, 2002), invitations to examine PhD theses (Australian National University, Murdock University, University of Adelaide, University of New England, University of New South Wales and University of Queensland) and by the competitive funding of collaborative research on grazing strategies.

2. Curriculum vitae

Kenneth Charles HODGKINSON
Fellow, Agricultural and Forestry Systems Program
CSIRO Sustainable Ecosystems
Canberra, ACT 2601
Australia

Personal

Date of birth	20 June, 1940
Birthplace	Napier, New Zealand
Citizenship	Australia and New Zealand

Academic Qualifications

1967 Ph.D. (Agriculture), University of New England, Australia
Thesis title: *Studies on the Physiology of Regeneration of Lucerne* (Medicago sativa L.)

1963 B.Agric.Sc., Massey College, Victoria University of Wellington, New Zealand

Main Research Interests

Experimental: Field experiments testing models of the short- and long-term responses of individual plants and plant communities to the separate and combined regimes of grazing and fire. Plant water stress measured by Scholander Pressure Bomb and origin of water in trees, shrubs and grasses determined by Stable Isotope Ratio's. Birth and death parameters for grass, forb and shrub plants determined by demographic modelling. Environmental control of reproduction in grasses determined in controlled environments and by voucher specimen examination.
Theoretical: Concepts for landscape-control of water and nutrient supply to plants in water-limited environments and models for grazing and fire regime control of resource supply to plants. Development of predictive models for birth and death of trees, shrubs, grasses and forbs and for plant community responses to fire and grazing regimes. Development of critical thresholds for adaptive management of grassland and wooded grassland landscapes.

Appointments

2007-	Visiting Professor, Institute of Grassland Ecology, Northeast Normal University, China
2002-	Honorary Fellow, CSIRO Sustainable Ecosystems
1990-01	Senior Principal Research Scientist, CSIRO
1999-	Guest Professor, Open Research Laboratory of Forest Plant Ecology, Northeast Forestry University, China
1983	Visiting Principal Research Scientist, CSIRO Tropical Crops and Pastures, Australia
1975	Visiting Associate Professor, Range Science Department, Utah State University, USA
1968-90	Research Scientist to Principal Research Scientist, CSIRO Rangelands Research Centre, Australia
1963-67	Research Assistant, Agronomy Department, University of New England, Australia
1963	Research Assistant, DSIR Plant Physiology Unit, New Zealand

Professional Affiliations

Australian Rangeland Society
Australian Society of Plant Scientists
Ecological Society of Australia
Linnean Society of London (Fellow)
Royal Society of New Zealand

Management experience

1986-97	Program Leader, Ecology and Management of Semi-Arid Lands Group of the National Rangelands Program. Responsible for scientific direction and management of twenty research staff.
1986-90	Officer-In-Charge, CSIRO Rangelands Research Centre. Responsible for organisation and general management of thirty five staff.

Grants

2008	$12,500	ACT Commissioner for Sustainability and the Environment: to assess critical thresholds and stresses in Natural Temperate Grasslands sites in urban and peri-urban Canberra
2004	$10,000	Canberra Urban Parks and Places: to evaluate management of urban corridors of semi-natural vegetation
2000	$9,500	Parks Victoria: to evaluate vegetation monitoring in Mallee National Parks
1999	$3,800	Bureau of Resource Sciences, Agriculture Fisheries and Forestry Australia: for simulating the 4-year forage levels in the Ivanhoe and Cobar districts of NSW
1998	$26,000	Land and Water Resources Research and Development Corporation: to evaluate the ability of SEESAW to predict forage levels from rainfall in wooded rangelands for the Aussie GRASS project
1997	$301,000	Murray-Darling Basin Commission: for indicators to manage total grazing pressure in mulga lands
1992	$350,000	International Wool Secretariat: for evaluating tactical grazing management to maintain/improve wooded sheep-rangelands with NSW Agriculture and Queensland Department of Primary Industries
1990	$544,000	National Soil Conservation Program: to develop restoration managements for degraded rangelands with the Soil Conservation Service of NSW and Australian National University
1988	$76,000	Australian Wool Corporation: for development of grazing strategies to improve rangeland pastures
1987	$160,000	Australian Wool Corporation: for economic research on sheep production in semi-arid sheep lands

Reviewing, steering, editing, lecturing and advising

2006-08	Co-edited a Special Issue of *The Rangeland Journal* on Grasslands and Rangelands of China
2006-08	Lecturer, Lanzhou University, China
2005	Chairman, XX International Grassland Congress, of two sessions on biodiversity, landscape and social issues, Dublin, Ireland and Glasgow, Scotland
2002-08	Lecturer, Institute of Grassland Science, Northeast Normal University, China
2001	Member of an expert panel reporting to the Native Vegetation Advisory Council of NSW on regrowth and soil erosion in the semi-arid woodlands of New South Wales
2001-03	Guest Professor and lecturer, Open Research Laboratory of Forest Plant Ecology, Northeast Forestry University, China

2000-01	Consultant to Gannan Prefecture, Gansu Province, China, on grazing management of alpine grasslands
2000	Consultant to Parks Victoria on monitoring of vegetation in Mallee National Parks
1999	Guest Professor and research reviewer, Open Research Laboratory of Forest Plant Ecology, Northeast Forestry University, Harbin, China
	CSIRO member on the National Rangelands Monitoring Coordinating Committee for the National Land and Water Resources Audit
1997-00	CSIRO member of the Steering Committee for a MDBC project on Tactical Management of Total Grazing Pressure in the Mulgalands
1996-99	Wildlife and Ecology representative on the CSIRO Textile Clothing and Footwear Sector and co-coordinator for the sustainable fibre and leather production sub-sector
1996	Chairman of Organising Committee for a MDBC workshop on managing total grazing pressure in mulgalands
1996	Member of the Steering Committee for the Sheep and Wool Institute of Queensland Department of Primary Industries
1996-	Member of the Editorial Committee of the Australian Rangeland Society and Chairman (2004-)
1995-	Supervisor of Post-Graduate Students (Honours and PhD programs) from Australian National University, University of New South Wales and Northeast Forestry University (China)
1995-00	Member of the Organising Committee of the 6th International Rangeland Congress and Co-organiser of the Scientific Program
1991-95	Member of the Advisory Committee to Department of Environmental Science and Rangeland Management, University of Adelaide
1991	Guest lecturer on Ecological Systems, The University of New South Wales, Canberra
1989-	Reviewer for senior promotions in Colorado State University, Foundation for Research Development, King Saud University, NSW Agriculture, Queensland Department of Primary Industries, Rutgers University, University of New England, University of Queensland, Utah State University and Texas A&M University
1988	Co-organiser of a workshop on Rangeland Restoration Ecology
1989-98	Member and Chairman (1992) of the Rangelands Research and Development Group, a multi-agency body developing cooperative proposals for research in NSW and Queensland rangelands
1988-	Reviewer of research proposals for the Australian Wool Corporation, Australian Research Council Research Grants Committee, and the Israel/USA Bilateral Agreement on Research and Development
1988-	Member of Woody Weed Task Force, a multi-agency and grazier group to co-ordinate woody weed control in western NSW
1987-89	Adviser to NSW Government Insurance Office on the effects of wildfire on semi-arid wooded rangelands
1986-97	Program Leaders Meeting, CSIRO Division of Wildlife and Ecology
1985-86	President, Australian Rangeland Society
1983-89	Council, Australian Rangeland Society (Chairman 1985-86)
1979-	Examiner of Ph.D. theses for the Australian National University, Curtin University of Technology, Murdock University, University of Adelaide,

University of New England (2), University of New South Wales and University of Queensland and of Masters (2) and Honours (1) theses for the Australian National University

1975- Reviewer for *Acta Oecologica, Australian Journal of Agricultural Research, Australian Journal of Botany, Australian Journal of Ecology, Australian Journal of Plant Physiology, Australian Journal of Soil Research, Conservation Ecology, Ecology, Ecosystems, Journal of Applied Ecology, Journal of Arid Environments, Journal of Ecology, Journal of the Royal Society of New Zealand, New Phytologist, New Zealand Journal of Agricultural Research, New Zealand Journal of Botany, The Rangeland Journal, Oecologia, Rangeland Ecology and Management,* and *South African Journal of Range and Forage Science*

1968-70 International Biological Program, Plant Physiology Working Group

3. List of publications[1]

3.1 Publications in refereed journals

[1] Hodgkinson, K. C. and Veale, J. A. (1966). The distribution of photosynthate within lucerne as influenced by illumination. *Australian Journal of Biological Science* **19,** 15-21.

[2] Hodgkinson, K. C. and Nicol, G. R. (1967). A multi-channel gas switch. *Australian Journal of Instrument Control* **23,** 37-38.

[3] Hodgkinson, K. C. (1969). The utilisation of root organic compounds during the regeneration of lucerne. *Australian Journal of Biological Science* **22,** 1113-1123.

*[4] Hodgkinson, K. C. (90%), Smith, N. G. and Miles, G. E. (1972). The photosynthetic capacity of stubble leaves and their contribution to growth of the lucerne plant after high level cutting. *Australian Journal of Agricultural Research* **23,** 225-238.

*[5] Hodgkinson, K. C. (1973). Establishment and growth of shoots following low and high level cutting of lucerne in relation to the pattern of nutrient uptake. *Australian Journal of Agricultural Research* **24,** 497- 510.

*[6] Hodgkinson, K. C. (1974). Influence of partial defoliation on photosynthesis, photorespiration and transpiration by lucerne leaves of different ages. *Australian Journal of Plant Physiology* **1,** 561-578.

*[7] Hodgkinson, K. C. (1976). The effects of frequency and extent of defoliation, summer irrigation and fertiliser on the production and survival of the grass *Danthonia caespitosa* Gaud. *Australian Journal of Agricultural Research* **27,** 755-767.

*[8] Hodgkinson, K. C. (60%) and Quinn, J. A. (1976). Adaptive variability in growth of *Danthonia caespitosa* Gaud. populations at different temperatures. *Australian Journal of Botany* **24,** 381-396.

*[9] Hodgkinson, K. C. (90%) and Baas Becking, H. G. (1977). Effect of defoliation on root growth of some arid zone perennial plants. *Australian Journal of Agricultural Research* **29,** 31-42.

[1]Those publications appearing in Section 4 are marked with an asterisk. The estimated contributions of the author are given as percentages within the parentheses following his name.

*[10] Hodgkinson, K. C. (70%), Johnson, P. S., and Norton, B. E. (1978). Influence of summer rainfall on root and shoot growth of a cold winter desert shrub, *Atriplex confertifolia*. *Oecologia* **34,** 353-362.

*[11] Hodgkinson, K. C. (70%) and Quinn, J. A. (1978). Environmental and genetic control of reproduction in *Danthonia caespitosa* populations. *Australian Journal of Botany* **26,** 351-364.

*[12] Hodgkinson, K. C. (1979). The shrubs of poplar box (*Eucalyptus populnea*) lands and their biology. *Australian Rangeland Journal* **1,** 280- 293.

*[13] Hodgkinson, K. C. (1980). Frequency and extent of defoliation of plants by sheep in a foothill range community in northern Utah. *Journal of Range Management* **33,** 164-169.

*[14] Hodgkinson, K. C. (70%), Harrington, G. N. and Miles, G. E. (1980). Composition, spatial and temporal variability of the soil seed pool in a *Eucalyptus populnea* shrub woodland in central New South Wales. *Australian Journal of Ecology* **5,** 23-29.

[15] Walker, J., Condon, R. W., Hodgkinson, K. C., and Harrington, G. N. (1981). Fire in pastoral areas of poplar box (*Eucalyptus populnea*) lands. *Australian Rangeland Journal* **3,** 12-23.

[16] Hodgkinson, K. C. and Beeston, G. R. (1982). The biology of Australian weeds - *Eremophila mitchellii* Benth. *Journal of the Australian Institute Agricultural Science* **48,** 200-208.

*[17] Hodgkinson, K. C. (60%), Gordon, W. T. and Smith, D. L. (1982). A field device for integrating temperature sensed in grass or forest fires. *Australian Journal of Ecology* **7,** 403-409.

*[18] Quinn, J. A. and Hodgkinson, K. C. (50%) (1983). Population variability in *Danthonia caespitosa* (Gramineae) in responses to increasing density under three temperature regimes. *American Journal of Botany* **70,** 1425-1431.

*[19] Quinn, J. A. and Hodgkinson, K. C. (50%) (1984). Plasticity and population differences in reproductive characters and resource allocation in *Danthonia caespitosa* (Gramineae). *Bulletin of the Torrey Botanical Club* **111,** 19-27.

*[20] Hodgkinson, K. C. (60%) and Harrington, G. N. (1985). The case for prescribed burning to control shrubs in eastern semi-arid woodlands. *Australian Rangeland Journal* **7,** 64-74.

*[21] Hodgkinson, K. C. (60%), Ludlow, M. M., Mott, J. J. and Baruch, Z. (1989). Comparative responses of the savanna grasses *Cenchrus ciliaris* and *Themeda triandra* to defoliation. *Oecologia* **79,** 45-52.

[22] Ludwig, J. A. and Hodgkinson, K. C. and Macadam, R. D. (1989). Principles, problems and priorities for restoring degraded rangelands. *Australian Rangeland Journal* **12,** 30-33.

*[23] Greene, R. S. B., Chartres, C. J. and Hodgkinson, K. C. (40%) (1990). The effect of fire on the soil in a degraded semi-arid woodland. I. Physical and micro morphological properties. *Australian Journal of Soil Research* **28,** 755-777.

*[24] Hodgkinson, K. C. (80%) and Oxley, R. E., (1990). Influence of fire and edaphic factors on germination of the arid zone shrubs *Acacia aneura, Cassia nemophila and Dodonaea viscosa. Australian Journal of Botany* **38,** 269-279.

*[25] Hodgkinson, K. C. (1991). Shrub recruitment response to intensity and season of fire in a semi-arid woodland. *Journal of Applied Ecology* **28,** 60-70.

*[26] Hodgkinson, K. C. (1992). Water relations and growth of shrubs before and after fire in a semi-arid woodland. *Oecologia* **90,** 467-473.

*[27] Tongway, D. J. and Hodgkinson, K. C. (50%) (1992). The effect of fire on the soil in a degraded semi-arid woodland. III. Nutrient pool sizes, biological activity and herbage response. *Australian Journal of Soil Research* **30,** 17-26.

[28] Anderson, V. J., Hacker, R. B. and Hodgkinson, K. C. (1994). Photographic utilisation standards for three perennial grasses. *The Rangeland Journal* **16,** 135-140.

*[29] Hodgkinson, K. C. (60%), Terpstra J. W. and Muller, W. J. (1995). Spatial and temporal pattern in the grazing of grasses by sheep within a semi-arid wooded landscape. *The Rangeland Journal* **17,** 154-165.

*[30] Anderson, V. J., Hodgkinson, K. C. (40%) and Grice, A. C. (1996). The influence of recent grazing pressure and landscape position on grass recruitment in a semi-arid woodland of eastern Australia. *The Rangeland Journal* **18,** 3-9.

*[31] Daly, R. L. and Hodgkinson, K. C. (60%) (1996). Relationships between grass, shrub and tree cover on four landforms of semi-arid eastern Australia, and prospects for change by burning. *The Rangeland Journal* **18,** 104-117.

*[32] Anderson, V. J. and Hodgkinson, K. C. (60%) (1997). Grass-mediated capture of resource flows and the maintenance of banded mulga in a semi-arid woodland. *Australian Journal of Botany* **45,** 331-342.

*[33] Hodgkinson, K. C. (1998). Sprouting success of shrubs after fire: height dependent relationships for different strategies. *Oecologia* **115,** 64-72.

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