

**Relative importance of fire interval and environmental
gradients for rainforest distribution in the Sydney region:
Littoral rainforest communities**

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Abstract

In New South Wales, inappropriate fire regimes have been identified as a key threatening process, defined as one that negatively affects the survival, abundance or evolutionary ability of a species or ecological community. Rainforests are considered by some to be fire-intolerant communities, but fires do occur in these communities. Many rainforest species are known to recover following a fire. However, it appears that with relatively short fire intervals, rainforests can be eliminated from the landscape. Hence, land management agencies often exclude fires from rainforest communities in order to increase the fire interval and to ensure rainforest conservation.

The ability of rainforest species to recover after a fire is related to resource availability and fire regimes. Consequently, the distribution of rainforest in the landscape can be hypothesised to be the result of the interaction of different environmental and fire gradients. This study quantifies the relative importance of fire interval and other environmental gradients including thermal, moisture, solar radiation and nutrient regimes for the occurrence of rainforest communities in the Sydney region. Generalised Linear Models and Geographical Information System datasets of fire interval and numerous environmental gradients are used for this purpose. Such information can be used to identify which rainforest areas are more likely to be negatively affected by short fire intervals and may require management intervention.

Key words: Rainforests; fire; environmental gradients; relative importance

Introduction

In Australia, rainforests are considered to be fire-intolerant vegetation communities, which could be eliminated from landscapes following frequent and intense fires. Conversely, it is also expected that rainforests can potentially increase their distribution and outcompete sclerophyll vegetation in the absence of fires (Gilbert, 1958; Bowman, 2000). However, it has been reported that some rainforest species are as resilient to fires as sclerophyllous species (Campbell & Clarke, 2006; Williams *et al.*, 2006), suggesting that factors other than fire may be determining the distribution of rainforests in landscapes.

Whether the distribution of rainforests is affected by fire is an issue that requires further clarification, particularly from a land management viewpoint. Management activities include fire exclusion for rainforest conservation (DECC, 2008) because inappropriate

fire regimes have been identified as a threatening process for some rainforest communities.

If we adhere to the view that fires can eliminate rainforest from landscapes, the Sydney region would be an area where the relative high incidence of both natural and anthropogenic fires would be in direct conflict with rainforest persistence. Fire management practices in this area aim to protect people and property, while simultaneously maintaining biodiversity values (Morrison *et al.*, 1996). However, these objectives are often in conflict as prescribed burning for fuel reduction can eliminate species that require long periods to reach maturity, such as rainforest species (Adam, 1992).

It is reasonable to expect that the distribution of rainforests will be the result of the interaction between environmental gradients and disturbance regimes and plant vital attributes. The primary environmental gradients, namely moisture, thermal, solar radiation and fertility gradients, are the most likely candidates controlling the distribution of rainforests and other vegetation in landscapes (Nix, 1978). The vital attributes, defined as the species characteristics that have an important role in determining the direction of succession (Noble & Slatyer, 1980), will determine the outcome of the interactions between environmental gradients and disturbance regimes. The effects of fires on rainforest distribution need to be explored in preference to other disturbance regimes given their apparent importance for rainforest distribution.

The fire regime describes the pyric conditions experienced at a point in the landscape using four fire metrics: intensity, interval, seasonality and type of fire (Gill, 1975). When the occurrence of fire is observed at the landscape scale, the fire regime can be conceptualised as a gradient, based on the fire metric used to describe it. For example, a landscape can be classified as having areas that experience shorter or longer fire intervals.

This study ranks the relative importance of fire regimes and environmental gradients using landscape-scale information on a range of indices of primary environmental gradients and presence/absence of rainforest communities. Because the quantification of fire regimes at a scale that is relevant for long lived rainforest species is difficult with the information available, only indices of fire interval were used for this study. Specifically, this study addresses the following hypothesis:

Fire interval, or an associated metric such as the number of fires per study period or time since fire, is the main environmental control of rainforest distribution.

This paper focuses on Temperate Littoral rainforests (Littoral rainforests herein) in the Sydney region as an example of a larger study being conducted at multiple scales in a variety of rainforest types.

Methods

The study area covers parts of the landscape deemed to have reliable fire history records within a region ranging from Port Macquarie in the North to Bega in the South, and from Lithgow in the West to the eastern coast of New South Wales. Fire histories post 1977-1978 were considered to be reliable following de Ligt (2005) and Davidson (2006) (Figure 1). Within the study area, Littoral rainforests occupy 473 ha. Littoral rainforests are defined on a floristic basis, as mapped by Tozer *et al.* (2006). The dominant overstorey species include *Acmena smithii* (Lilly Pilly), *Casine australis* (Red Olive-berry) and *Eucalyptus botryoides* (Bangalay); *Livistona australis* (Cabbage Tree Palm), *Pittosporum undulatum* (Sweet Pittosporum), and *Synoum glandulosum* (Scentless Rosewood) (Tozer *et al.*, 2006).

Presence of rainforest communities was determined at the map-scale by randomly sampling the vegetation map created by Tozer *et al.* (2006). An equal number of sampling points were randomly selected for rainforest absences using areas of similar environmental domains located outside the mapped rainforest patches. The primary environmental gradients, namely solar radiation, moisture, mineral nutrients and thermal, were used to identify the environmental variables most likely to be influential for the distribution of rainforests. These variables were derived at a landscape-scale using Geographical Information System (GIS) datasets created for the purpose of this project (Kuramoto *et al.*, 2007) (Table 1).

General Additive Models (GAM) were used to identify the environmental response of the continuous variables. Where possible, the shape of the response curve was included in the subsequent modelling stages. The second step included sampling all the available environmental gradients and conducting a correlation analysis to reduce the number of variables. Where two or more variables were correlated, the variables representing resource or direct gradients (*sensu* Austin (1980)) were selected in preference to indirect gradients.

Because of the large number of variables, a Generalised Linear Model (GLM) was constructed using backwards elimination to select the combination of variables that created the most parsimonious model based on the Akaike Information Criterion (AIC). Finally, the most important environmental controls of Littoral rainforest were ranked using a GLM, the variables making the most parsimonious model identified with the AIC, and forward stepwise selection as described by Nicholls (1991).



Figure 1. The study area (grey) and the Sydney region (white) are shown in relation to Littoral rainforests patches as mapped by Tozer *et al.*(2006) (black) and selected localities in New South Wales.

Table 1. Summary of environmental gradients used as independent variables for modelling.

Variable	Units	Definition	Description	Regime					Gradient Type
				Fire	Nutrient	Solar Radiation	Thermal	Moisture	
Soil fertility	N/A	Fertility from low to high	Derived from 1:250,000 scale surface geology maps using Turvey (1987) soil classification scheme.		X				Resource
Number of fires	N/A	Number over 29 years	Calculated using fire histories compiled by the NSW Department of Environment and Climate Change. The years used are from 1977-78 to 2006.	X					Direct
Time since fire	Years	Number of years since the last fire		X					Direct
Slope	%		Derived using a 25 metre DEM provided by the NSW Department of Environment and Climate Change, and ArcMap spatial analyst tools.	X	X				Indirect
Southness	N/A	Index of aspect, with 0 = southern oriented areas and 1 = northern oriented areas		X		X	X	X	Indirect
Westness	N/A	Index of aspect, with 0 = western oriented areas and 1 = eastern oriented areas		X		X	X	X	Indirect
Solar radiation	Mj m ⁻² y ⁻¹	June solar radiation on slopping surface	Derived using the 25 metre DEM and the program SRAD (Gallant, 1997).	X*		X		X*	Resource

*Denotes variables that can be considered to be indirect gradients for the primary environmental gradients selected, otherwise the variable is classified as indicated in the gradient type column.

Table 1. Summary of environmental gradients used as independent variables for modelling. (Continued).

Variable	Units	Definition	Description	Regime					Gradient Type
				Fire	Nutrient	Solar Radiation	Thermal	Moisture	
Landscape Position	N/A	Landform classification	Derived using the 25 metre DEM and Summerell <i>et al.</i> (2005) landscape classification.	x	x			x	Indirect
Topographic Wetness Index	N/A	Identifies the areas of higher topographic soil moisture, where lower values are drier areas and higher values are wetter areas	Derived using the 25 m DEM and the Compound Topographic Wetness Index as described by Wilson and Gallant (2000).					x	Indirect
Mean annual Temperature	°C		Derived using the 25 metre DEM and BIOCLIM (Houlder <i>et al.</i> , 2000)				x		Direct
Mean annual precipitation	mm y ⁻¹						x		Direct
Land Tenure	N/A	Land Tenure	Derived using the Meshblock dataset (Harper, 2005)						N/A

*Denotes variables that can be considered to be indirect gradients for the primary environmental gradients selected, otherwise the variable is classified as indicated in the gradient type column.

Results

Precipitation was found to be the most important variable explaining the distribution of Littoral rainforests (Table 2). Position in the landscape, June solar radiation, soil fertility, time since fire (TSF), and land tenure were also found to be significant in explaining the distribution of Littoral rainforests, but all were of much lesser importance than precipitation.

Table 2. Results for the Generalised Linear Model for Littoral rainforest occurrence.

Model	DF	Deviance	Res. DF	Res. Deviance	Probability (Chi)	Corrected explained deviance
Null			345	479.66		
+ Fertility	4	12.98	341	466.68	0.01	2.71
+ Number of fires	1	5.34	334	474.32	0.02	1.11
+ TSF	1	0.02	344	479.64	0.89	0.00
+ Land Tenure	3	26.86	342	452.80	<0.01	5.60
+ Precipitation	1	188.94	344	287.81	0.00	39.39
+ June Solar Radiation	1	58.85	344	420.81	<0.01	12.27
+ Temperature	1	1.14	344	478.51	0.28	0.24
+ Landscape Position	6	95.27	339	384.39	0.00	19.86
+ Westness	1	13.66	344	466.00	<0.01	2.85
Precipitation						
+ Fertility	4	11.71	340	276.10	0.02	1.48
+ Number of fires	1	0.22	343	287.59	0.64	0.03
+ TSF	1	2.06	343	285.75	0.15	0.26
+ Land Tenure	3	22.89	341	264.92	<0.01	2.89
+ June Solar Radiation	1	33.25	343	254.55	<0.01	4.20
+ Temperature	1	1.47	343	286.34	0.23	0.19
+ Landscape Position	6	37.55	338	250.25	<0.01	4.74
+ Westness	1	6.98	343	280.83	<0.01	0.88
Precipitation + Landscape Position						
+ Fertility	4	15.41	334	234.85	<0.01	2.10
+ Number of fires	1	3.16	337	247.10	0.08	0.43
+ TSF	1	19.30	337	230.96	<0.01	2.63
+ Land Tenure	3	10.35	335	239.91	0.02	1.41
+ June Solar Radiation	1	34.27	337	215.99	<0.01	4.67
+ Temperature	1	10.00	337	240.25	<0.01	1.36
+ Westness	1	1.88	337	248.37	0.17	0.26
Precipitation + Landscape Position + June Solar Radiation						
+ Fertility	4	17.08	333	198.91	<0.01	2.49
+ Number of fires	1	0.35	336	215.64	0.06	0.05
+ TSF	1	9.97	336	206.02	<0.01	1.46
+ Land Tenure	3	6.89	334	209.10	0.08	1.01
+ Temperature	1	4.38	336	211.61	0.04	0.64
+ Westness	1	2.68	336	213.31	0.10	0.39

Table 2. Results for the Generalised Linear Model for Littoral rainforest occurrence. (Continued).

Model	DF	Deviance	Res. DF	Res. Deviance	Probability (Chi)	Corrected explained deviance
Precipitation + Landscape Position + June Solar Radiation + Fertility						
+ Number of fires	1	1.24	332	197.67	0.27	0.18
+ TSF	1	12.27	332	186.65	<0.01	1.79
+ Land Tenure	3	6.35	330	192.56	0.10	0.93
+ Temperature	1	5.47	332	193.44	0.02	0.80
+ Westness	1	2.79	332	196.12	0.09	0.41
Precipitation + Landscape Position + June Solar Radiation + Fertility + TSF						
+ Number of fires	1	3.45	331	183.19	0.06	0.52
+ Land Tenure	3	13.59	329	173.06	<0.01	2.05
+ Temperature	1	0.89	331	185.76	0.35	0.13
+ Westness	1	1.67	331	184.98	0.20	0.25
Precipitation + Landscape Position + June Solar Radiation + Fertility + TSF + Land Tenure						
+ Number of fires	1	2.8071	328	170.248	0.09	0.44
+ Temperature	1	1.3396	328	171.7155	0.25	0.21
+ Westness	1	0.2847	328	172.7704	0.59	0.04

The model suggests that Littoral rainforest are distributed in areas of relatively high precipitation, increasing their distribution as precipitation increases and reaching its maximum distribution at approximately 1150 mm of precipitation per year (Figure 2a).

The following characteristics are also suggested:

- The forests occur on lower slopes (Class 4), low rises in low sloped valley flats (Class 6) and a small proportion occurs on ridge tops (Class 1) (Figure 2b), probably as a result of classification methodology artefacts.
- Rainforest distribution increases as solar radiation decreases (Figure 2c).
- The forests occur in areas of low to medium fertility (compared to the rest of the landscape) (Classes 3 and 4) (Figure 2d).
- The occurrence of Littoral rainforests requires at least 15 years absence of fires (Figure 2e).
- National Parks are more likely to contain Littoral rainforests than other land tenures (Figure 2f).

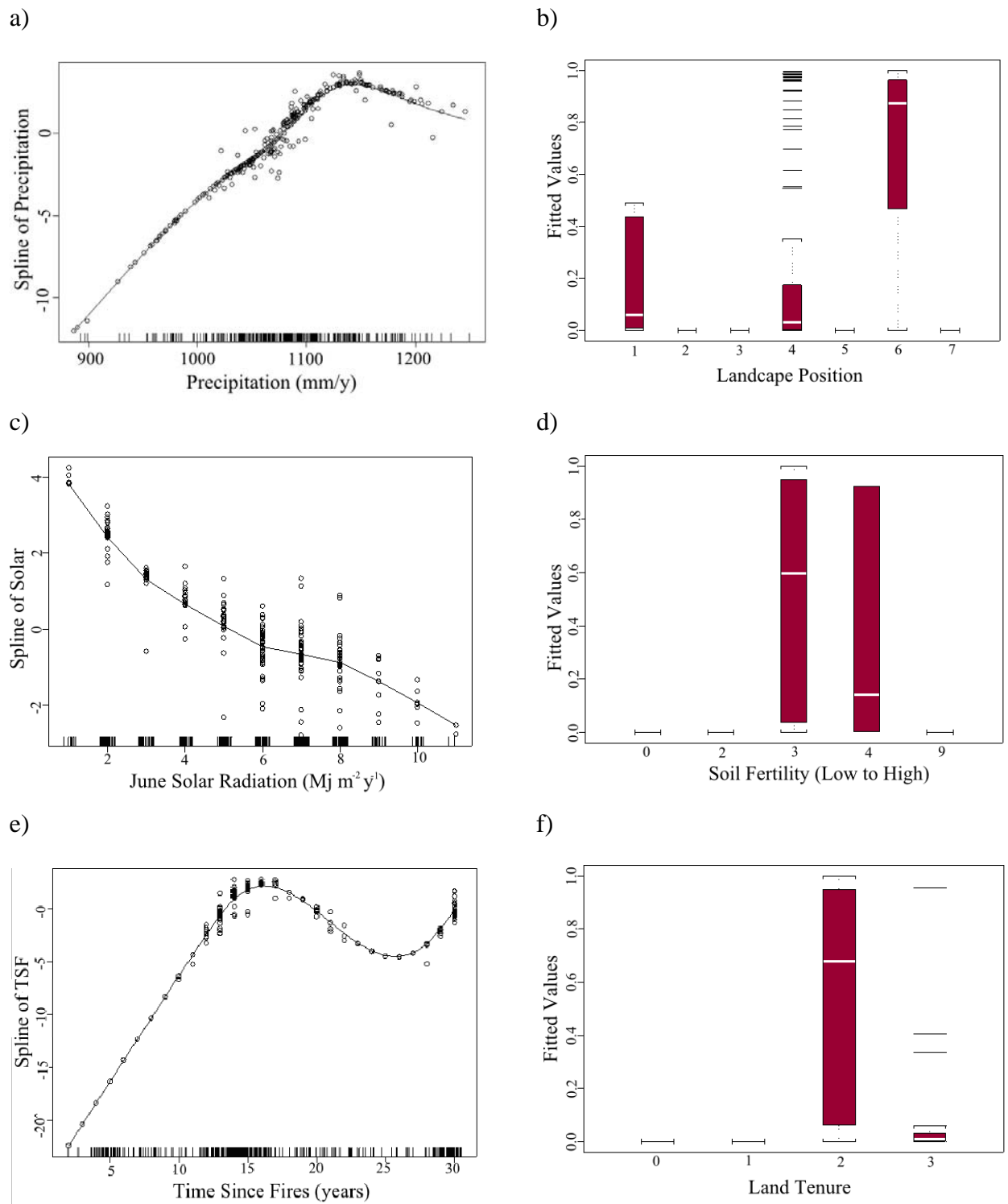


Figure 2. Graphical representation of the responses of rainforests in relation to environmental gradients. **a.** Spline of precipitation (described using a GAM). **b.** Box plot for landscape position, where class 1 are ridge tops, class 4 are low valley flats and class 6 are low rises in low sloped valley flats. **c.** Spline for June solar radiation (described using a GAM). **d.** Box plot for soil fertility, with ranges in order of increasing fertility from values of 0 to 13 for the entire landscape. **e.** Spline of Time Since Fire (TSF) (described using a GAM). **f.** Box plot for Land Tenure, where class 2 are National Parks and reserves and 3 are agricultural areas.

Discussion

The proposed hypothesis, namely that fire interval or a related fire metric was the main environmental control of the distribution of Littoral rainforests was rejected. The results support the view that precipitation is the main determinant of rainforest distribution as this variable alone explains almost 40% of the model's deviance. In general, precipitation has been found to be important for rainforests in the region (Floyd, 1990). After precipitation, the other variables found to be significant for Littoral rainforest occurrence include, in decreasing order of significance, the position in the landscape, June solar radiation and soil fertility; time since fire and land tenure.

The fact that the position in the landscape was found to be second in significance further suggests that moisture regimes are critical for this rainforest type, particularly since the majority of rainforest patches included in the analysis occur in areas that can retain moisture such as valley flats (Figure 2b). However, given that this is an indirect variable, position in the landscape may also indicate that Littoral rainforests occur in areas protected from disturbances such as wind and fire, with the exception of a small proportion of patches that are located on ridge tops.

The relationship between the solar radiation and littoral rainforest occurrence suggests that this variable is not a limiting factor (Figure 2c). Studies conducted in rainforest in coastal New South Wales found that the rainforest species had a competitive advantage in low light conditions as they were more efficient in increasing biomass (Barret & Ash, 1992). Although the ability to establish in low light conditions has not been explicitly found for Littoral rainforest species, this is considered to be typical of rainforest species and has been proposed for discriminating between rainforest and other species (Lynch & Nelder, 2000).

Nutrients regimes were also found to be significant for Littoral rainforests which were found to occur in areas of relatively low to medium fertility compared to the rest of the landscape (Figure 2d). Nutrients have been proposed to be important for rainforest occurrence in general (Florence, 1996) and specifically for rainforests in the Sydney region (Beadle, 1953, 1954).

This analysis suggests that areas usually with more than 15 years time since fire, which are an indication of a longer fire interval, are required to maintain Littoral rainforests in this landscape (Figure 2e). Time since fire and the number of fires are metrics that describe aspects of the fire interval and were found to be highly correlated ($R^2 = 0.85$).

Together, they represent the only component of the fire regime that could be quantified for the study area, namely fire interval. Information on vital attributes was available for all the reported dominant overstorey species of this community (DEC 2002), which were observed to resprout following fires. However, conflicting information exists for *Pittosporum undulatum*, which has been reported to respond to fire by dying or by resprouting (Gleadow & Ashton, 1981). The need for the suggested minimum fire interval of 15 years may reflect the time required to reach reproductive maturity for these species, which ranges from a minimum of 2 to 5 years. However, it can take up to a maximum of 30 years for *Acmena smithii*, which was found to be eliminated when two fires occur over 20 years (Chesterfield *et al.*, 1990).

Finally, land tenure was found to be important, probably because the majority of Littoral rainforest patches studied were found inside National Parks and reserves, with some exceptions found on agricultural land (Figure 2f). Historically, rainforests have been cleared for agriculture in preference to sclerophyll vegetation as they were believed to occur on areas of higher fertility (Adam, 1992). The extant rainforests may be located in areas of steep topography that were not suitable for agriculture or in areas that have been protected in parks and reserves for a long time.

The interpretation of the results have to be conducted considering: i) the accuracy of the mapped rainforests, ii) the accuracy of the dependent variables; and iii) the general uncertainty of environmental modelling because of current knowledge of environmental processes. Firstly, the rainforest map was deemed to be accurate, particularly because the boundaries of rainforest patches were mapped using aerial imagery. However, there is uncertainty about the species composition of each patch, thus limiting extent to which the interpretation is relevant to all patches studied. Secondly, because the input variables are themselves modelled, it is possible that errors acquired during the creation of these surfaces are carried to the modelling of rainforests. For example, some of the Littoral rainforest patches were found to occur on ridge tops; however, this is more likely to be an artefact of the landscape classification. Thirdly, static models are only a “snapshot” in time and do not take into account the changing nature of the environment. It is possible that factors such as landscape position have become important recently if they became refuges from disturbances such as wind, clearing for agriculture and bushfires. This problem can only be overcome using landscape-scale experiments that involve burning rainforest patches multiple times, an exercise that is not viable when studying

endangered ecological communities such as Littoral rainforests. It may be possible that variables such as fire may have been important in the past when rainforests were widespread but less in current conditions.

This study ascertains that precipitation is the most important environmental control for Littoral rainforest distribution. Other environmental gradients were found to be significant but much less important as they collectively explained only 13.20% of the model deviance (Table 2). It can be concluded that the distribution of Littoral rainforests is the result of a combination of variables.

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References

- Adam, P. (1992) *Australian Rainforests* Oxford University Press, Oxford.
- Austin, M.P. (1980) Searching for a model for use in vegetation analysis. *Vegetatio*, **42**, 11-21.
- Barret, D.J. & Ash, J. (1992) Growth and carbon partitioning in rainforest and eucalypt forest species of south coastal New South Wales, Australia. *Australian Journal of Botany*, **40**, 13-25.
- Beadle, N.C.W. (1953) The edaphic factor in plant ecology with a special note on soil phosphates. *Ecology*, **34**, 426-428.
- Beadle, N.C.W. (1954) Soil phosphate and the delimitation of plant communities in Eastern Australia. *Ecology*, **35**, 370-375.
- Bowman, D.M.J.S. (2000a) *Australian Rainforests: Islands of Green in a Land of Fire* Cambridge University Press, Cambridge.
- Campbell, M.L. & Clarke, P.J. (2006) Response of montane wet sclerophyll forest understorey species to fire: evidence from high and low intensity fires. *Proceedings of the Linnaean Society of NSW*, **127**, 63-73.
- Chesterfield, E.A., Taylor, S.J., & Molnar, C.D. (1990). Recovery after wildfire: Warm temperate rainforest at Jones Creek. Technical Report Series No. 101. Arthur Rylah Institute for Environmental Research, Melbourne.
- Davidson, A.M. (2006) Key determinants of fire frequency in the Sydney region. Honours Thesis, The Australian National University, Canberra.
- DECC - New South Wales Department of Environment and Climate Change (2008). Littoral Rainforests in the NSW North Coast, Sydney Basin and South East Corner Bioregions Profile. Online resource. Last accessed on August 8th, 2008. <http://www.threatenedspecies.environment.nsw.gov.au/tsprofile/profile.aspx?id=10867>.
- DEC - New South Wales Department of Environment and Climate Change (2002). NSW Flora Fire Response Database. Version 3.1. (ed. Cohn, J). Digital Database.
- de Ligt, R. (2005) Probability of burning with time-since-fire in the Sydney region. Honours Thesis, The Australian National University, Canberra.

- Florence, R.G. (1996) *Ecology and silviculture of eucalypt forests* CSIRO Publishing, Collingwood.
- Floyd, A.G. (1990) *Australian rainforest in New South Wales* Surrey Beatty and Sons Pty Ltd, Chipping Norton, NSW.
- Gallant, J.C. (1997) Modelling Solar radiation in Southern Australia. In *Modsim 97: International Congress on Modelling and Simulation* (eds A.D. McDonald & M. McAleer), Vol. 1, pp. 456-463. Modelling and Simulation Society of Australia, Hobart, Tasmania.
- Gilbert, J.M. (1958) Forest succession in the Florentine Valley, Tasmania. *Paper and Proceedings of the Royal Society of Tasmania*, **93**, 129-151.
- Gill, A.M. (1975) Fire and the Australian flora: A review. *Australian Forestry*, **38**, 4-25.
- Gleadow, R.M. & Ashton, D.H. (1981) Invasion by *Pittosporum undulatum* of the Forests of Central Victoria. I: Invasion Patterns and Plant Morphology. *Australian Journal of Botany*, **29**, 705-720.
- Harper, P. (2005). Information paper, Draft Mesh Blocks Australia. Australian Bureau of Statistics, Canberra.
- Houlder, D., Hutchinson, M., Nix, H., & McMahon, J. (2000) ANUCLIM version 5.1. Centre for Resource and Environmental Studies, The Australian national University, Canberra.
- Kuramoto, C.I., Cary, G.J., Bradstock, R.A., Gill, A.M., King, K.J., & Austin, M.P. (2007) Are fire regimes crucial for rainforest distribution in the Sydney Region? In Joint AFAC/ Bushfire CRC Conference 2007. Australian Fire Authorities and Bushfire CRC, Hobart, Tasmania.
- Lynch, A.J.J. & Nelder, V.J. (2000) Problems of placing boundaries on ecological continua - options for a workable national rainforest definition in Australia. *Australian Journal of Botany*, **48**, 511-530.
- Morrison, D.A., Buckney, R.T., Bewick, B.J., & Cary, G.J. (1996) Conservation conflicts over burning bush in south-eastern Australia. *Biological Conservation*, **76**, 167-175.
- Nicholls, A.O. (1991). Examples of the use of generalised linear models in analysis of survey data for conservation evaluation. In *Nature conservation : cost effective biological surveys and data analysis* (eds C.A. Margules & M.P. Austin), pp. vii, 207. Commonwealth Scientific and Industrial Research Organization, Melbourne.
- Nix, H.A. (1978). Determinants of environmental tolerance limits in plants. In *Biology and quaternary environments* (eds D. Walker & J.C. Guppy). Australian Academy of Science, Canberra.
- Noble, I.R. & Slatyer, R.O. (1980) The use of vital attributes to predict successional changes in plant communities subject to recurrent disturbance. *Vegetatio*, **43**, 5-21.
- Summerell, G.K., Vaze, J., Tuteja, N.K., Grayson, R.B., Beale, G., & Dowling, T.I. (2005) Delineating the major landforms of catchments using an objective hydrological terrain analysis method. *Water Resources Research*, **41**, W12416.
- Tozer, M.G., Turner, K., Simpson, C., Keith, D.A., Beukers, P., MacKenzie, B., Tindall, D., & Pennay, C. (2006). Native vegetation of southeast NSW: a revised classification and map for the coast and eastern tableland. Version 1.0. NSW Department of Environment and Conservation and NSW Department of Natural Resources, Hurstville.
- Turvey, N.D. (1987). A technical classification for soils of *Pinus* plantations in Australia: Field Manual. The School of Forestry. The University of Melbourne, Melbourne.
- Williams, P., Parsons, M., & Devlin, T. (2006) Rainforest recruitment and mortality in eucalypt forests of the wet tropics - refining the model for better management. In Bushfire Conference 2006. Life in a fire prone environment: Translating science into practice., Brisbane.
- Wilson, J.P. & Gallant, J.C. (2000) *Terrain analysis: Principles and applications* John Wiley and Sons, Inc., New York.