An Assessment of Fuel Characteristics and Fuel Loads in the Dry Sclerophyll Forests of South-East Tasmania

by

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Declaration

This thesis contains no material that has been accepted for the award of any other degree or diploma in any University. This thesis contains no copy or paraphrase of material previously published or written by another person, except where due reference is made in the text.

Portions of the work presented here have been published in the following reports:

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Statement of Authority of Access

Frontispiece

The author wishes to acknowledge the Tasmania Fire Service for the long-term use of one of the finest Indian-built four wheel drives available.

Abstract

The amount of available wildfire fuel is one of the critical factors for determining fire behaviour and is the only factor that can be easily managed. Knowledge of the rates and patterns of fuel buildup is therefore essential to effective fire management, both for wildfire incident management and on-going land management. Fifty-nine sites throughout south-eastern Tasmania were sampled for fuel loads, floristic and environmental data. A curve-fitting process was applied to the field data to produce fuel accumulation curves for the major dry sclerophyll vegetation types in the study area. Once developed, the fuel accumulation curves can be used to underpin other tools, such as GIS systems and field guides.

A range of ordering schemes were applied to the data to determine whether the traditional classification of sites by canopy dominant species yielded the best results. Sites were categorised by phytosociological association, by geological substrate, by average rainfall and by the density of the canopy trees. These orderings were chosen as they conform to known major environmental determinant factors in dry sclerophyll bushland and were shown to have statistically reliable relationships to fuel loads.

The potential for developing a field guide for land managers and field officers based on the modelled fuel curves was recognised, and a system developed for trialling. This method for rapidly assessing fuel weight in the field relies entirely on simple field measurements and provides an acceptable estimate in a mere fraction of the time required using more traditional methods.

The results of these studies provide new tools for managing fire in the south-eastern Tasmanian region and an appropriate methodology for further studies. The possibility of using other fuel classifications is demonstrated and indicates new avenues of investigations.

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1. Introduction

Wildfire

Anno Domini 1077. This year was London burned, one night before the Assumption of St. Mary, so terribly as it never was before, since it was built... This year also was the dry summer; and wild fire came upon many shires, and burned many towns; and also many cities were ruined thereby.

This quotation from the Anglo-Saxon Chronicle (written between 890 AD and the mid-12th century) shows the problems of managing wildfire and protecting assets is by no means a recent phenomenon. Throughout the world, anywhere with forests or woodlands is a candidate for a wildfire given the right conditions and a source of ignition. A fire has the potential for damage and tragedy anywhere a forest or woodland abuts human habitation.

Fire management at the urban-bushland fringe, sometimes termed the WUI, or Wildland-Urban Interface (Fried *et al*. 1999) is a major focal point for fire research across the globe. This research, in all its forms, has as its ultimate goal the understanding of fire and the factors contributing to fire behaviour, to protect lives as well as to protect assets or ecosystems from damage or destruction.

Fire science has grown as a discipline over the last thirty-five years, moving from what was essentially a purely asset-protection philosophy to a broader and more academic stance. Today, the field incorporates a wide range of established disciplines. Elements of botany, zoology, geography, meteorology, ecology and the newer technological disciplines of remote sensing and Geographic Information Systems are all incorporated into modern fire research. The rise of cheap, powerful computers and the development of statistical and modelling software have contributed to the advance of fire science a great deal, permitting greater and more varied amounts of data to be processed quickly and accurately.

Today, there still remains an echo of the original fire-fighter's philosophy in the science, with much of the literature in circulation over the last three decades being easily categorised into either 'operational' or 'academic'. Increasingly the operational works can be seen to be incorporating the findings of previous academic studies, and the academic studies are mostly bent toward a practical land management outcome. The last fifteen years has seen a convergence of the two camps and the emergence of a new philosophy, one of providing research with both scientific integrity and practical usefulness.

Wildfire research

Wildfire research appears to arise from areas of the world with large forested tracts of land and universities or government bodies with an interest or responsibility for these lands. Predictably enough, the United States, Canada and Australia feature highly as the country of origin for the bulk of recent research work. These countries have a considerable need for this research and have made available the necessary resources to develop the expertise. Fire research from the rest of the world, while lesser in quantity, is not less in quality or intent. Work is being produced in countries such as New Zealand, Africa, South America and in the Mediterranean, all places where fire is an issue for land management. While these works are usually addressing specific management problems unique to these places, the development of methodologies, tools and procedures is globally useful.

In recent years, fire science has seen its own dedicated publication, *The International Journal of Wildland Fire* (now into its 12th volume), as well as a noticeable increase in the size and quality of fire science conferences, such as the biennial *Bushfire* series in Australia and New Zealand.

Wildfire in Tasmania

Early in the morning on the 7th of February 1967, a fire was spotted in the hills behind the Hobart suburb of New Town. It was considered to be no immediate threat and no actions were taken to contain the fire (Ahern and Chladil 1999). Between 11am and 4pm that day, 62 people lost their lives and approximately 264 000 hectares of Tasmanian bush and agricultural land was burned by this and 109 other fires burning that morning (McArthur 1969). In the Hobart municipality alone, 20 people were killed and 433 houses destroyed (Ahern and Chladil 1999).

The 1967 wildfire event marked a turning point in wildfire management in Tasmania. The need to develop both better disaster response systems and to equip emergency services with the appropriate technology and training became patently obvious. Among the emergency services and those responsible for the management of bushlands around built-up areas, the recognition of the need for research into fires for both natural resource management and asset protection increased enormously. A rural fire brigade was organised and control burns were instituted, initially on an *ad hoc* basis, with guidelines being drawn up later in the mid-1970s (Gledhill 1993).

Many of the areas burned in South-Eastern Tasmania in 1967 now support a much larger population and in some cases have become major suburbs in their own right. The new suburbs have grown with a diffuse urban-bushland boundary characterised by houses built well into the bushland, to provide a 'natural' setting and surroundings for the occupants. The desire to live in a natural setting is much more prevalent in the Australian urban community compared to pre- 1967 times. This increased area of mixed suburbia and bushlands has increased the importance of managing the fringing bushland to reduce fire risk and protect life and property (Gledhill 1993, Bradstock, Gill, Kenny and Scott 1998). It is also salient to remember the words of McArthur, in his 1969 report on the 1967 fires:

"Human memory is notoriously short lived and it is disturbing to find that many people consider the conditions of 7th February are unique…"

The complacency of the general public when faced with the possibility of major wildfires entering the urban areas remains one of the major hurdles in planning for wildfire events.

The relevance of fuel modeling

Fire behaviour is a product of the interplay of a number of factors, such as air temperature, air humidity, fuel moisture levels, wind speed, wind direction and available fuel (Cheney 1981). These factors can be considered to be either environmental or meteorological in origin.

Meteorological factors influencing fire behaviour are capable of changing very quickly and in many cases in an unpredictable manner. A sufficiently large hot fire is capable of altering many of these factors by itself, through its own radiant heat and thermal convection. These meteorological factors cannot be modified effectively by human intervention to assist in fire threat minimisation or wildfire fighting.

Available fuel is the only fire behaviour factor to exhibit a sufficiently stable pattern of variability to permit the development of accurate predictive tools capable of projecting potential fire hazard years into the future. Fuel loads are linked to site productivity and are controlled by biomass growth and decomposition rates, so statistical models taking these factors into account should be able to predict the accumulation of fuel through time, and are often shown graphically as a curve plotted on axes representing fuel weight and time. Such models and suitable fuel curve graphs will allow the development of an appropriate timetable for the application of fuel reduction procedures.

Wildfires and land management

A fire does not remove all biomass as it passes. Large items, such as trunks and branches are charred but remain largely intact after the fire front has passed. The hottest and most active area of a wildfire is the leading edge, or fire front. This front burns the smaller, finer proportion of the vegetation: leaves, twigs, grasses and low shrubs.

The fine fuel component is termed 'flash fuels' by many researchers. Flash fuels are generally considered to be in the order of 2 mm or less along their narrowest axis (Dickinson and Kirkpatrick 1987) although some authors consider this fuel category to be 6 mm or less along the narrowest axis (Cheney 1990). Materials of a larger diameter require more energy to kindle and do not actively support the fire front (Burrows and McCaw 1990).

Fuel accumulation modelling is concerned solely with the accumulation of the fine fuel biomass, as it is this fuel component that supports the front - the most dangerous and difficult to manage part of a wildfire. The actual size of the fine fuels consumed in the fire front is variable. The size of fuel particles consumed in the fire front is determined primarily by fuel moisture levels, fuel pre-heating and fire intensity (Burrows 2001) and the size of fuel residue left behind the fire front gives an indication of fire intensity (Cheney 1981).

Fuel reduction for risk management

Fuel loads can be managed quite easily by using biomass removal processes that traditionally include fire itself. Controlled fuel reduction fires are an important management tool for fire risk minimisation in dry sclerophyll forests, particularly on the urban fringe where asset protection might be categorised as more important than protecting ecosystem values. These fires are planned for spring and autumn, when climatic conditions will support a low intensity or 'cool' fire with little risk of the fire escalating into an uncontrollable state (Gledhill 1993) and an acceptable reduction in fuel loads. Cheney (1981) gives an average intensity of a fuel control fire in open eucalypt forest at 500 kWm^{-2} or less and average flame heights of 1.5 metres. High intensity wildfires have intensities in the order of 3000 kW/m^{-2} or greater, and flame heights above 15 metres.

The decision to apply a fuel reduction fire is essentially a process of risk assessment. For any particular sites' fuel load to be considered 'manageable' in case of a wildfire, a decision is made based on incorporating the current fuel load (measured or modelled) with known climatological data (Gill *et al.* 1987). It is possible to calculate the expected number of days per year where the weather conditions and fuel load will combine to make for a potentially uncontrollable fire should one occur, using an established tool such as the Forest Fire Danger Meter, Mark 5 (McArthur 1973). By lowering the available fuel, the number of days per year when a potential wildfire could not be controlled by emergency services is reduced.

A fuel reduction fire lowers the available fuel to an acceptable level from a management perspective, but leaves considerably more unburnt fuel behind than hotter summer fires. The amount of moisture held in the fuel particles and the cooler ambient temperatures at optimum controlled burning conditions (Conroy 1993) result in less pre-heating of fuels, diminishing the fire intensity and rate of spread (Hatton and Viney 1991). The lower heat intensities result in relatively less damage to understorey vegetation than after wildfire, and this in turn leads to a quicker post-fire recovery time, potentially returning to significant fuel loads within two to four years (Tolhurst 1996a). Jasper (1999) notes that this combination of cool fire and fast recovery leads to short-term fuel reduction but long term ecological change. Tolhurst (1996b) attributes this ecological change likely to result from a fire interval of too short a duration to allow plant species to recover from one fire and establish sufficient reserves to permit the survival of the next.

Fuel accumulation studies

Fuel accumulation in Australian forests has received considerable scientific attention over the last fifteen years. Studies have been either management-oriented while covering a limited range of vegetation types, or theoretical re-appraisals of the statistical method and modelling procedures used for the management oriented studies.

Studies of the former type provide management tools for the target vegetation types, such as Jarrah and Karri forests in Western Australia (Peet 1971, McCaw *et al*. 1992) and Silver-top Ash (*Eucalyptus sieberi*) forests (Gould 1993, Neyland and Askey-Doran 1994). The results of these studies have little direct applicability outside the chosen vegetation types, but are capable of indicating broad trends or patterns that might be expected in similar vegetation types elsewhere. Once the fuel curves have been generated for the vegetation community or communities being studied, the curves themselves can be used as predictive tools.

Statistical and methodological investigations provide key insights for the development of appropriate methodologies and the incorporation of appropriate measurement techniques (McCaw 1991), canopy and understorey litter variability (Birk 1979) and decay rates across seasons (Mercer *et al*. 1996, Birk 1979) or for different litter components (O'Connell 1991).

Fensham (1991) used a statistical model that has been widely employed in fuel accumulation studies in Australia, such as Fox *et al.* (1979), Birk and Simpson (1980) and Neyland & Askey-Doran (1994). This model, while having some debatable assumptions, is both robust and logical and is accepted by many as appropriate. The assumption of the model that is a matter of concern is the use of single coefficients for litter accumulation and decay, when studies of litter accumulation show considerable seasonal variability in dry sclerophyll forest litter resulting from differences in accession and decomposition rates (Mercer *et al*. 1996).

Alternative litter accession models require long-term site-specific litter collection as part of the data acquisition process and will produce an accurate picture of the litter processes for the duration of the sampling period, but not necessarily beyond that. Should the sampling period have unusual weather patterns or another uncommon event, the data will not be representative of average conditions. For studies involving a wide field area or a narrow timespan for field sampling, the process used must by necessity contain some form of averaging in the modelling process. The single-value accession and decomposition coefficients in the model used by Fensham (1991) and others functions well as a means of averaging across time or space, and are therefore unlikely to disrupt the accuracy of the results.

The increased availability of computer processing power has allowed for new ways of managing fire and fuel load data. Specialised software packages such as FIREPLAN have been developed as tools for wildfire threat analysis (Malcolm *et al*. 1995) and include fuel accumulation models as part of the software's predictive structure. Output from FIREPLAN as depicted in Malcolm *et al*. (1995) indicates a simple model of fuel accumulation that does not appear to take immediate post-fire effects into account.

Incorporating fuel accumulation curves into a Geographic Information System (GIS) software system gives land managers a highly effective means of handling spatial data and provides a tool to support management decisions. The rapid rise of GIS as an inexpensive and relatively easy to use land management tool has seen a proliferation of studies incorporating predictive models for wildfire fuel accumulation and potential fire behaviour throughout the world. Systems are being developed and refined throughout much of the Western world across a range of scales and resolutions depending on purpose and data availability (Hardy *et al*. 2001).

The Hobart bushfire danger mapping work by Smith (1999) typifies the use GIS systems can make of existing or current fire research. Smith's study used the fuel accumulation model and accumulation curves from Bresnehan (1998) and topographic Digital Elevation Models to develop a fire hazard map for the greater Hobart area. This information has the potential to provide a reliable desktop tool for land management.

Studies and tools based on state-of-the-art computer software packages for predicting fuel accumulation will always have at their cores a model or equation that has been developed beforehand. The model can be considered to be the critical element of a software package or GIS system- an inappropriate or overly simple model will not produce high quality output for management purposes regardless of the complexity of the system built upon it. This is echoed by Gollberg *et al*. (2001), who recommend "Management tools including databases, maps and models should be grounded in ecological research and principles." Despite the importance of accuracy and appropriate use of research, not all fire management worldwide employs this philosophy when it comes to fuel accumulation (Keane *et al*. 2001).

Aims

This study intends to meet the need for accurate predictive models of fuel accumulation for land management, based on easily and cheaply obtainable data. The three major components of the study are:

1- to develop a model for fuel accumulation in dry sclerophyll forests in south-eastern Tasmania

This study will examine the nature of fuel accumulation in South Eastern Tasmania and develop a standard set of techniques for data acquisition. The current practice of classifying sites according to dominant canopy species will be used to permit comparisons with previous studies. The use of dominant canopy species classification schemes will be examined for relevance and reliability, and alternative classifications suggested by recent literature will be tested and compared.

The statistical model currently used to prepare the fuel curves currently in use for the study area has a demonstrable flaw in the use of a single constant value for post-fire fuel residue. It is intended to develop and refine a more powerful and logical model while keeping the basic structure of the process model equation structure. This new model will be used to develop an array of new fuel accumulation curves for the common dry sclerophyll vegetation types within the study area.

2- to test a range of easily-determined predictors of fuel loads and fuel components

Other factors likely to impact on fuel accumulation will be investigated to determine their importance in fuel modelling. The value of the current practice of assigning site classifications by the dominant canopy species will be investigated, using both environmental determinants and phytosociological data to derive alternative site classifications that can be compared to the canopy species based classifications. These alternative classifications can then be compared to the fuel curves from aim 1 above, to determine if there are more appropriate means of classifying vegetation types for fuel accumulation studies.

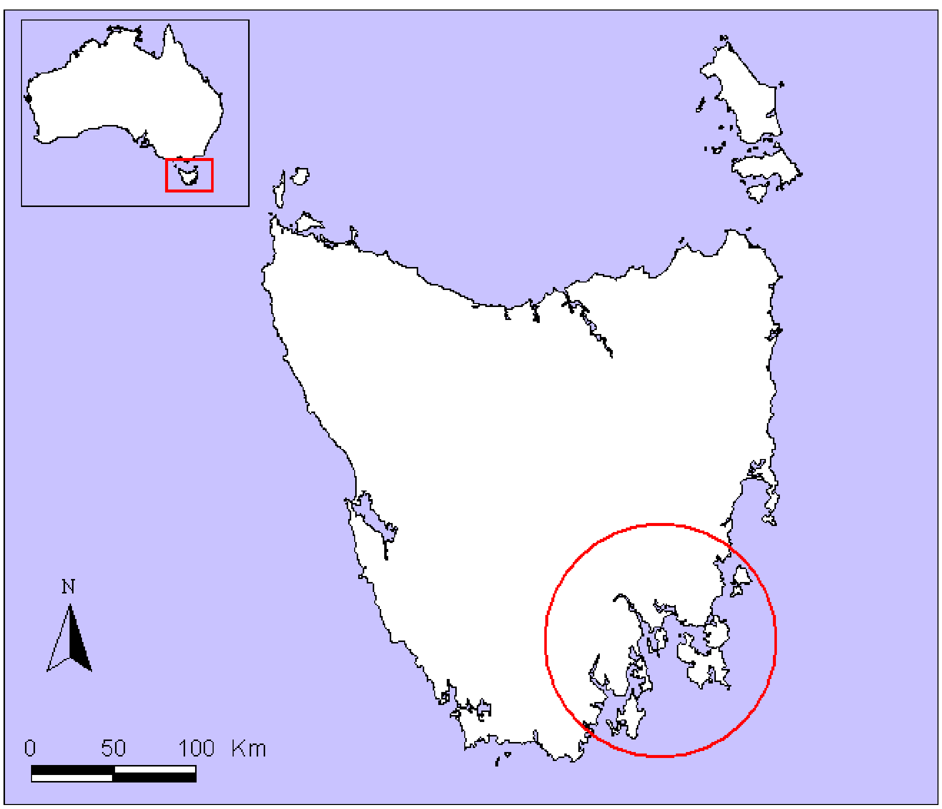
Studies investigating this possibility are often concerned with classification systems that permit remote sensing, such as Oswald *et al*. (1999), through the use of recognisable features such as tree basal area or crown closure estimation, and incorporating existing fuel models. The production of fuel curves from aim 1 above are likely to indicate if remotely-sensed environmental factors can be used in fuel accumulation prediction in south eastern Tasmanian dry sclerophyll vegetation communities.

3- to develop a simple field technique for determining fuel loads in south-eastern Tasmania

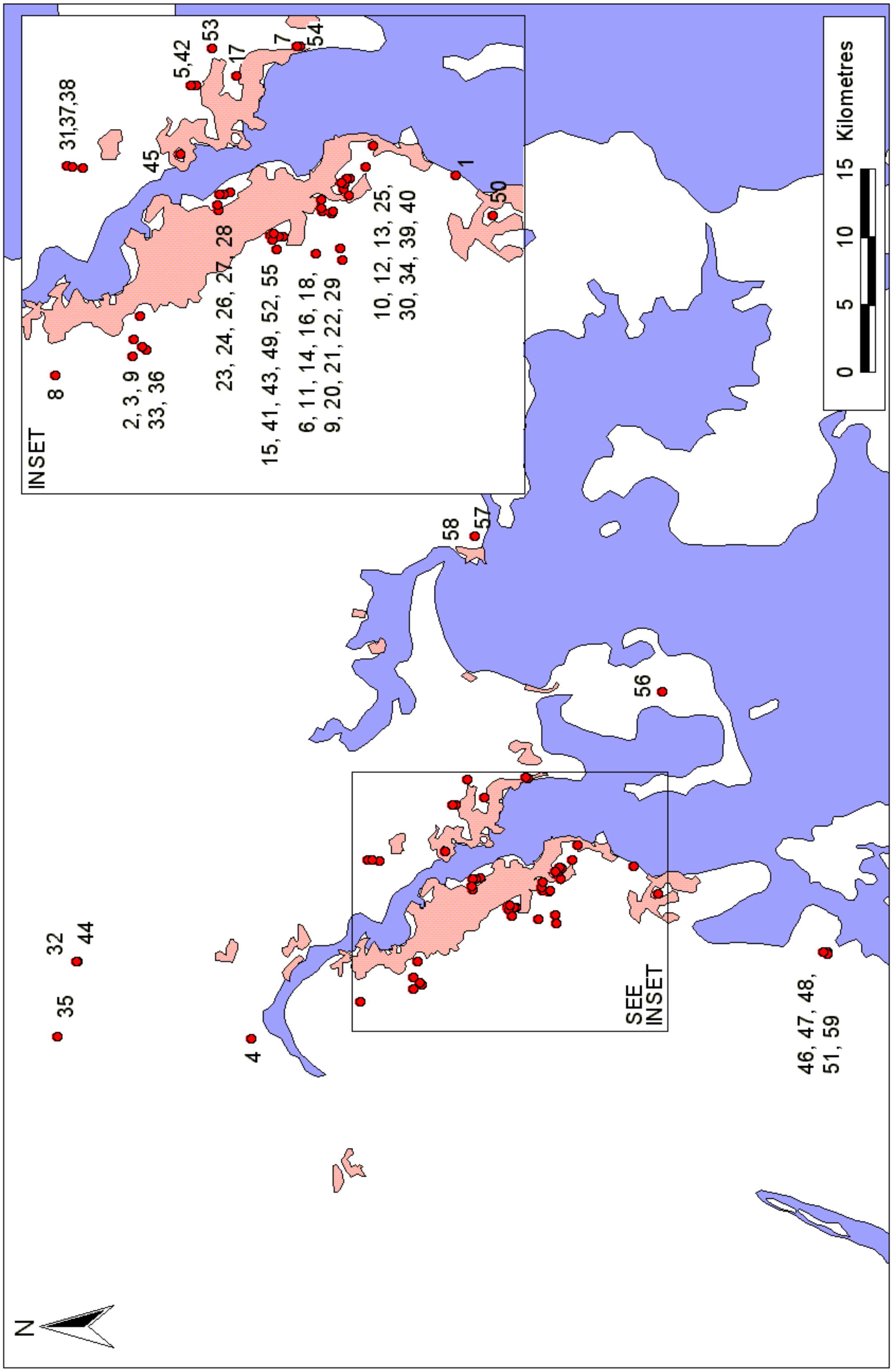
There is a recognised need amongst land managers for rapid, simple and reliable field assessment techniques for fuel loads. The fuel accumulation data will be re-examined for the possibility of such a field technique and if possible, an appropriate method will be developed. The potential for a simple field technique to be derived from aims 1 and 2 above will be investigated along the lines of existing successful field guidebooks and techniques. This is considered a practical approach as it builds on the advances in layout and readability made by previous field guides.

2. Study Area

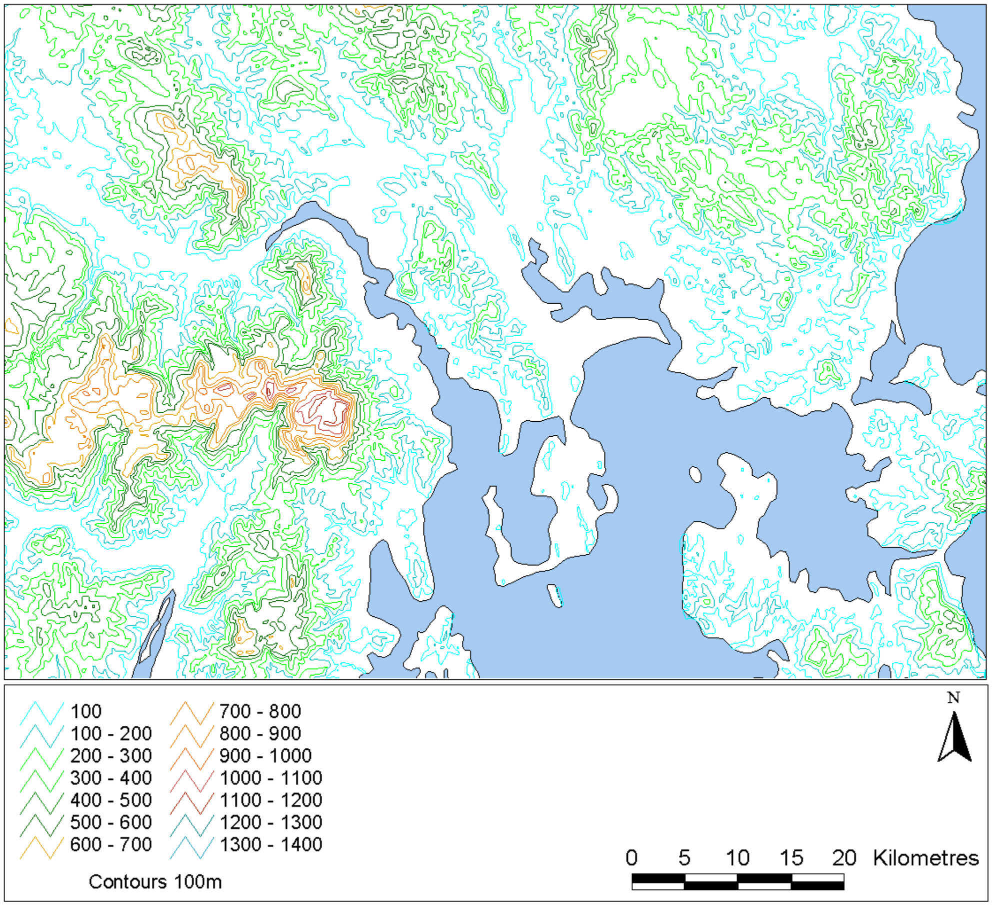
The area covered by this study comprises the dry forests and woodlands of South Eastern Tasmania within the general area shown in Map 1. Including cleared land and built-up areas, the study covers approximately 246 000 hectares. This includes all of the Greater Hobart area and the bushland reserves maintained by the Hobart, Glenorchy and Clarence City Councils, as well as bushland areas managed by the Department of Primary Industry, Water and Environment (DPIWE), Hobart Water and private landowners. The study sites are distributed throughout the area, primarily within the urban-bushland fringe areas (see Map 2). For the exact location of the study sites, the grid reference coordinates, derived from the 1:25000 Tasmanian Map Series, are contained in appendix 1.



Map 1: Tasmania, showing south eastern region



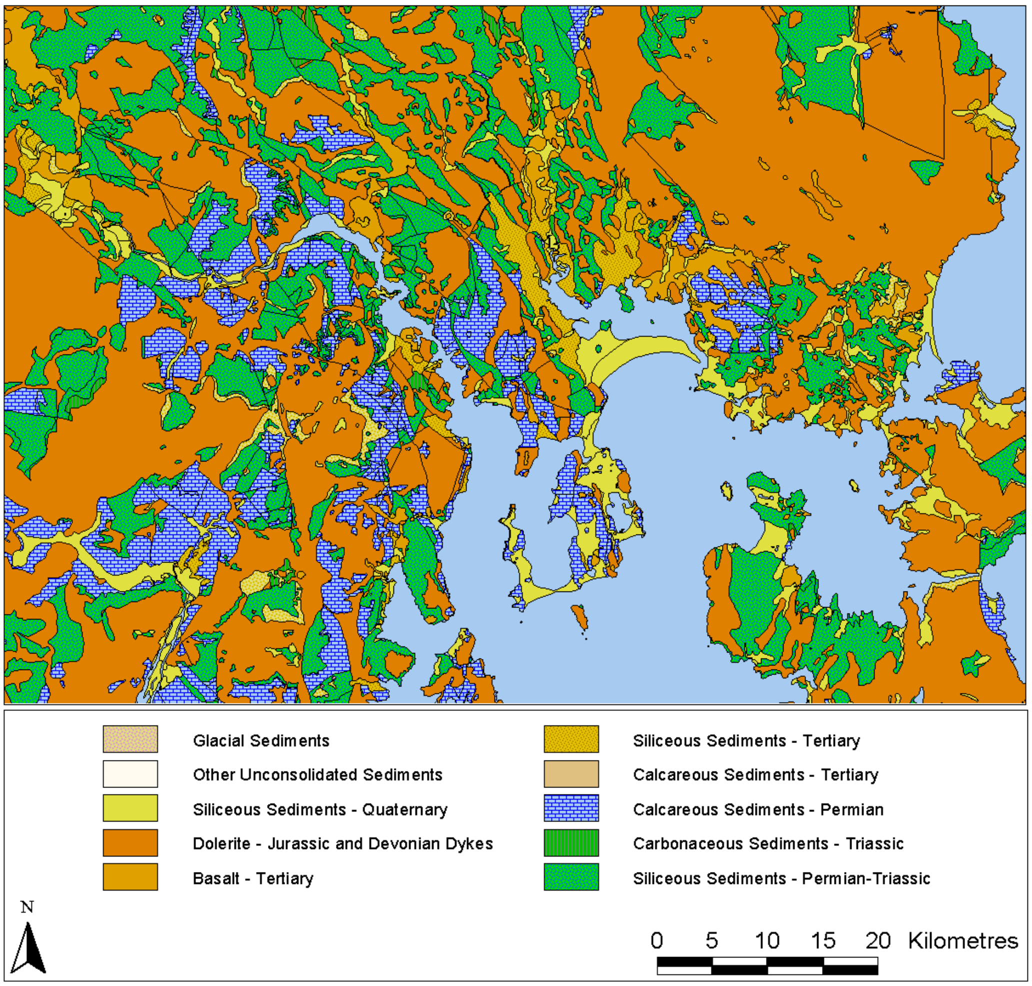
Map 2: South-eastern Tasmania, showing built up areas and location of sampling sites



Map 3: Topography of the study area

The study area is located along the southern extremity of the Midlands 'Rift Valley' (Scanlon 1990), which has the typical stepped appearance of a dissected *horst*-and-*graben* landscape. Given the steep-sided hill-slopes (see Map 3), rising from sea level to over 1200 metres in a very short distance and Tasmania's relatively high latitude of 42° south, the combination of solar angle of incidence and slope aspect governs the arrangement of wetter and drier vegetation communities (Nunez 1983). Many of the sites sampled were on northerly or northeasterly facing slopes.

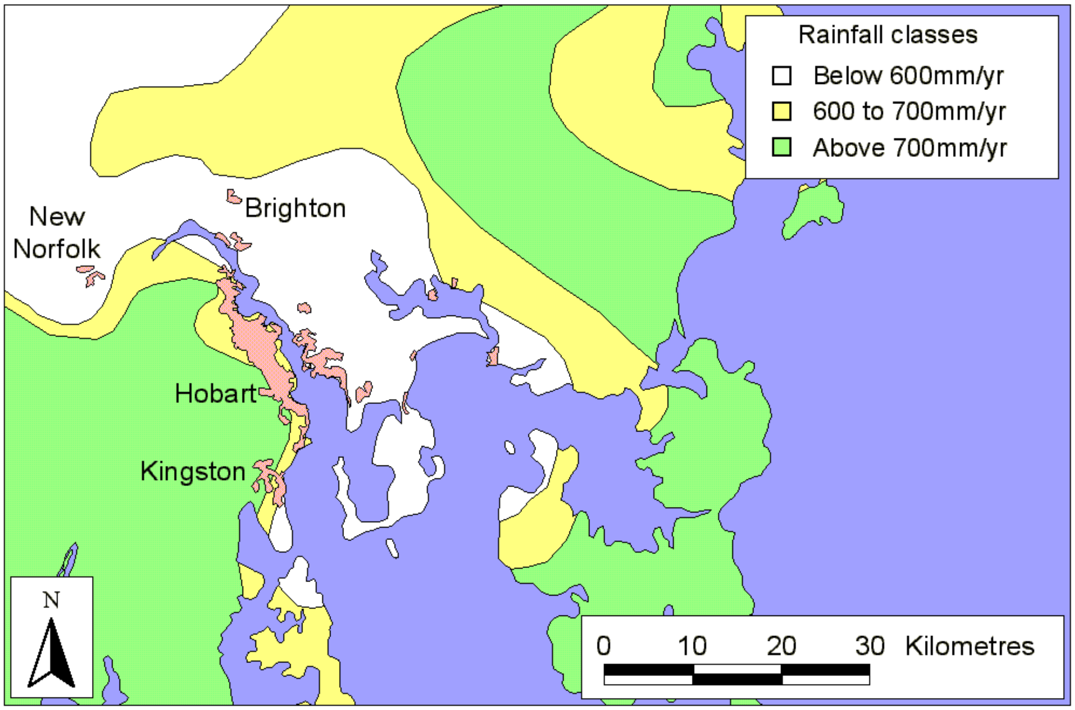
There are three main geological units throughout the study area: dolerite, the Parmeener Supergroup sedimentary units and basalt, as shown on Map 4. The dolerite is Jurassic in age and forms virtually all the hilltops and high ground. It is the most prevalent geological type of the southeastern region of Tasmania. The Permian to Triassic Parmeener sediments range from coarse yellow sandstone to very fine grey mudstone. This sediment underlies much of the dolerite and is often found on hillsides and valley bottoms. The basalt is Tertiary in age and has a very limited distribution, outcropping in occasional hilltop peaks and hillside lobes.



Map 4: Geology of study area

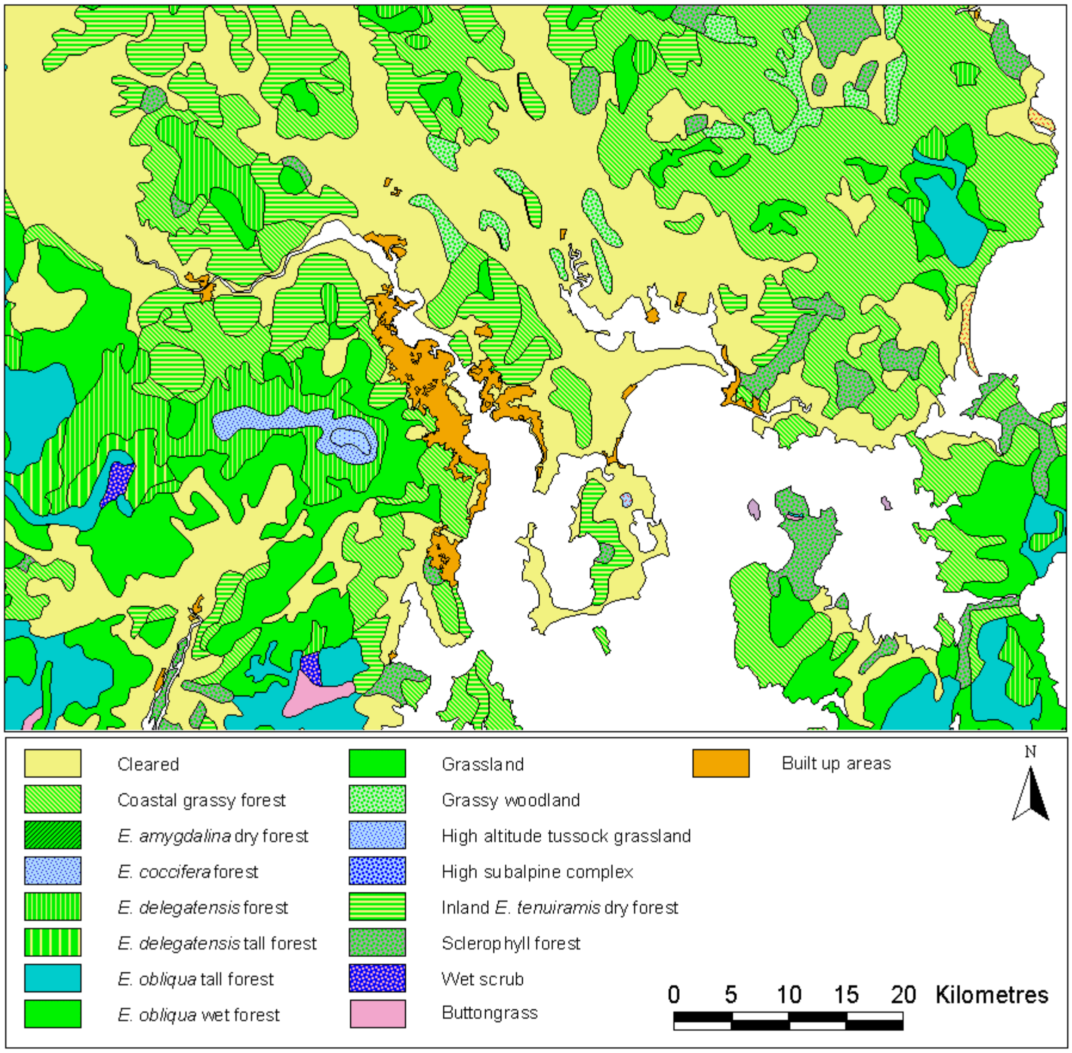
Davies (1988) Land Systems classifications for the study area groups all the sampling sites into substrate and rainfall based zones. Study sites fell into the classification zones D1, D2, S1, S2, M1 and B.

Zones D1 and D2 are low rainfall dolerite hilly country and high rainfall dolerite hilly country respectively. Similarly, zones S1 and S2 are low rainfall sandstone hilly country and high rainfall sandstone hilly country respectively. Zone M1 is low rainfall mudstone hilly country, and Zone B is deep sand of marine origin (Davies 1988).



Map 5: Rainfall classes, modified from Davies (1988)

Map 5 shows the distribution of rainfall across southeastern Tasmania as divided into three classes- under 600 mm per year, 600 to 700 mm per year and over 700 mm per year. These division points were chosen to broadly divide the dry sclerophyll communities into classes based on available moisture. The upper limit for dry sclerophyll forest is considered to be approximately 1000 mm annually (Laffan *et al*. 1998).



Map 6: Vegetation communities of the study area (from Kirkpatrick and Dickinson 1984)

The vegetation of the study area is very diverse (see Map 6), reflecting the wide range of substrates, topography and rainfall found throughout southeastern Tasmania. Much of the land is cleared and built up, particularly along the wider valley floors and the coastal and estuarine shores. The dry sclerophyll vegetation types are classified in Map 6 into an array of generalised communities.

The vegetation communities chosen for this study do not align directly with the communities outlined in Map 6 above as some of those mapping units were seen to be too broad, encompassing too wide a range of community sub-types. The more precisely defined communities of Duncan and Brown (1985), which were based on canopy dominant species and understorey type, were adopted in the present study.

The dry sclerophyll vegetation communities are mostly found on north-facing slopes and in most lower altitude areas. Much of the dry sclerophyll vegetation has been cleared or is in some way impacted upon by human habitation. Many of the hillside suburbs of Hobart have a diffuse interface with dry sclerophyll communities, particularly in the foothills of Mount Wellington.

3. General Methods

Introduction

The raw data are the basis for all further investigations, so logically it follows that the quality of the data acquisition and statistical processes underpin the quality of the entire set of results. This chapter discusses the methods by which the data set was built and the basis for the use of these methods. Fensham (1991) used an essentially robust and proven method, and so this was used as a starting-point.

Data Acquisition

The concept of using 'space' as an analogue for 'time' was adopted to allow the fuel accumulation data to be based on sites with as broad a range of fire ages as could be found within the study area. The use of a data set derived from a number of similar sites of differing age rather than one single site studied over a long period has both advantages and disadvantages. The advantages are primarily practical and logistical, with the potential to develop a data set containing as wide a range of fire ages as practicable.

The greatest disadvantage with the use of space-for-time is that each site is fundamentally a different place to the other sites. Factors such as altitude, local moisture dynamics, slope, aspect, soil depth and type, and species compositions differ from one site to the next. This variation is in part diminished by the use of a site classification scheme that incorporates environmental or vegetation community variables in the decision-making process.

Field techniques

Site selection

The primary aim in site selection was to gain a suitable number of sampling sites from each of the major forest and woodland communities in South-eastern Tasmania, with a particular reference to the urban/bushland interface. Sites were initially grouped according to the community descriptions described in Duncan and Brown (1985). This was intended to provide an initial classification scheme for the study, as fuel accumulation characteristics were already demonstrated to be different across vegetation community groupings in the study area (Fensham 1991).

A small number of control burns and wildfires occurred within the study area during the preliminary and fieldwork stages of this study, permitting close scrutiny of immediate post-fire fuel levels and behaviour on these sites. Effectively the entire study area was burnt in the fires of 1967, making the greatest possible time-since-fire for any site in the study area something in the order of thirty years. The remaining sites were chosen to fill in the intervening fuel ages.

Sampling sites were selected using five criteria. These criteria were ordered in importance and each potential sampling site was assessed for suitability. The criteria were, in order:

Primarily, the site had to display minimal levels of disturbance. Sites that displayed evidence of disturbance, and particularly of firewood gathering, were not sampled. This evidence was usually in the form of wheel tracks from four-wheel drive vehicles, tree stumps and sawn branches. The sites with recognisable signs of firewood gathering invariably had noticeable levels of discarded twig and leaf material, often termed 'slash material'. Areas undergoing commercial logging are known to have vastly increased fuel loads (Marsden-Smedley, Slijepcevic, Hickey and Chuter 1999) from the slash material left behind. It follows that sites undergoing firewood gathering have a similar impact, albeit on a lesser magnitude. The presence of an artificial source of litter accession in addition to the natural processes leads to the assumption that sites undergoing firewood gathering were not representative of natural fuel accumulation rates.

Secondly, the site had to have minimal levels of weed infestation. Sites with high levels of weed infestation have visibly different vegetation structures and floristics. They are therefore likely to have altered fuel loads and spatial arrangements of this fuel load (van Etten 1995). Many potential sites in the study area, particularly along the urban-bush interface, were found to carry high weed loads. A wide range of weed species was encountered, with South African Boneseed (*Chrysanthemoides monilifera* ssp. *monilifera*) and Gorse (*Ulex europaeus*) being the most prevalent in terms of both extent and degree of infestation. Weed-dominated sites showed marked fuel differences in the near-surface layer, as well as considerably more live flash-fuel biomass when compared to non-infested sites. The fire management regimes of many urban fringe sites leads to a persistence of weeds on infested sites (Downey 1999). The invasive habit of weeds in the immediate post-fire recovery stage can lead to marked alteration in community structure and therefore fuel structure (van Etten 1995). Thus, any potential sampling site found to contain more than occasional individuals of a weed species was not included in the study.

Thirdly, where possible, sites of known fire age were selected. Sites of known fire age were sampled in preference to sites of unknown fire age, to provide a means of comparing the accuracy of field-based fire age indicators. This also provided greater data reliability for the statistical procedures and fuel curve fitting process. Most sites throughout the Greater Hobart Area have good records of fire history, although in some cases this record is not a written one. Recollections of fire age by researchers and land managers were corroborated or checked against field-based methods before being accepted.

Fourthly, the sites had to be within a recognisable canopy dominance class. Sites that did not clearly belong to any of the six canopy categories (see chapter 4), or were intermediate between two categories, were not sampled. The primary cause of sites exhibiting features intermediate between two classes was the presence of sharp change in a major environmental variable, such as slope or geology.

Fifthly, the site had to be accessible by safe and simple means. Site accessibility was considered in the selection procedure, both for speed and safety of collection and for any subsequent re-sampling. Many locations with easy access were also those with the greatest amount of disturbance, and as such this selection criteria was given the least weighting of the five.

Site descriptions

Once selected, each site was described in terms of its basic physical, spatial and vegetation characteristics. A survey of vascular plants was made, along with details of the major environmental characteristics.

Eucalypt identification followed Duncan (1996). Tasmania has a high degree of endemism in its eucalypt species, and hybridising in eucalypts is common and well documented (Williams and Potts 1996), leading to difficulty in identifying canopy dominant species. The 'half-barked' *Eucalyptus amygdalina* studied by Kirkpatrick and Potts (1987) exhibits characteristics intermediate between *E. amygdalina* and *E. pulchella*, and is found in the eastern portion of the study area. For the purposes of this study, a decision was made to treat the half-barked population as *E. amygdalina*. Community identification was based on Duncan and Brown (1985).

Tree basal area was calculated using the Bitterlich Variable Radius Method, or 'Bitterlich Wedge', as described in Mueller-Dombois and Ellenberg (1974). This method uses a sighting block to select trees to be added to a count. This count can be geometrically transformed to give an estimate of tree basal area in m^2 per hectare. For this study, a sighting block was constructed in the 1:50 width to length ratio suggested in Mueller-Dombois and Ellenberg (1974), which produced a field measure that required no geometric transformation. For details of the measuring tool see appendix 2.

Geology was determined in the field from surface float rock or outcropping bedrock and crosschecked with geological maps. Details of site elevation, slope and aspect were taken from 1:25 000 map data, an estimation of average rainfall was derived from Davies (1988) and an estimate of yearly total solar radiation was calculated from slope and aspect measurements using the method of Nunez (1983).

Dating methods

The time since last fire for each site was determined from written records and reliable recollections and, where possible, assessed using simple field methods.

Ring counts were taken from individuals of *Leptospermum* species (Marsden-Smedley, Rudman, Pyrke and Catchpole 1999) when present. Cross-sections were sawn from the base of the *Leptospermum*, smoothed using coarse and fine grade sandpaper and the rings counted under a magnifying lens. At least five individuals were counted on sites where this method was available.

Node counts were made for individuals of *Banksia marginata* when individuals of this species were found at a sampling site. *Banksia marginata* usually produces one new whorl of branches per year on each branch (Brown and Podger 1982). A careful count from the top of the oldest branch to the tree base will give an accurate estimation of the minimum age of the tree and provide an estimate of time since the last fire. For sites where this method was being used, at least five individuals were counted per site.

Corollary evidence from eucalypts was also examined. The signs of recovery from fire, such as regrowth around scorch scars and the presence and condition of sprouted epicormic or lignotuber buds can be used to infer fire intensity and vegetation recovery (Strasser *et al*. 1996).

Fuel weight sampling

Field and laboratory techniques were modified from Cheney *et al.* (1990) and McCaw (1991). The technique was based on collecting all fine fuels from ten quadrats of 1 m^2 at each site. The quadrat was extended as a rectangular column to 2.5 m above the ground, to include the understorey shrubs and small trees. This method differs from transect-based fuel load estimation techniques, such as that outlined in Nalder *et al*. (1999), which require the use of a formula to transform the field measurements into a weight estimate.

The protocol for distributing the quadrats within each site began by determining the extent of the site. The edges of each site were considered to be the places where slope, aspect, fire age, vegetation community type or substrate type changed. The first sampling point was chosen by hurling the wooden quadrat frame from the perimeter towards the centre to start a run of random quadrat locations. Subsequent quadrats were determined by a random over-the-shoulder hurl from the previous quadrat.

The fuel collected was limited to the flash fuels, which were 6 mm or less across the narrowest axis (Cheney 1990). For each quadrat sampled, the fuel load was partitioned into three height-based categories. Each quadrat was then further divided into live *versus* dead fuel, giving six separate sample categories as follows:

surface fuels, below 10 cm height, including litter and low grass,

near surface fuels to approximately 60 cm, or low shrub and bracken height,

elevated fuels to approximately 2.5 m, or understorey canopy height.

Most fuel divisions consider litter as surface fuel and all low vegetation as near-surface. For ease of collection everything less than roughly 10 cm in height was considered 'surface'. When sorted into live and dead fractions, the grasses and other low vegetation are in the surface live category and the litter and low cured grasses fall into the surface dead category.

The samples were collected in a 'top down' approach using hand pruners, starting with elevated fuel and progressing to the near-surface and finally the surface fuel layers. A hand-held gardening fork was used to rake the loose litter into piles and ensure the fine late-stage decomposition material, often termed the 'leaf duff', was collected in its entirety. Materials collected were placed into labelled plastic bags for later sorting.

Point cover measurement

At each quadrat, a metre rule was used to determine the height of the fuel layers. The point to be measured was chosen by tossing the rule over the shoulder into the quadrat to be sampled. A series of measurements from within each quadrat was then taken for the litter depth, near-surface vegetation height and elevated vegetation height.

Litter depth was measured using a rule, with ten measurements taken- one from each quadrat. If there was no litter at any one measurement point (i.e., the ruler was sitting on bare soil or rock), a zero depth was recorded. From these ten measurements, an estimation of the quadrat litter cover in square metres per hectare, and litter depth in millimetres, was derived.

Vegetation strata heights were determined at the litter depth measurement points, using a metre rule. Heights were recorded for all strata present within each quadrat. These measures were then averaged to provide an estimate of fuel strata height and continuity across the entire site.

Laboratory techniques

Sorting, drying and weighing

The sampled material was hand-sorted into the six fuel categories and placed into paper bags. These were then oven-dried at 105°C for 24 hours. This temperature and duration is considered hot enough to drive off free moisture but not sufficiently hot to drive off the volatile oils contained within the fuel samples (Fox *et al*. 1979, Fensham 1991).

Strong brown paper bags were used to contain the drying samples as the paper allows passage of water vapour through the walls of a sealed bag, whereas trays and plastic bags must remain open to allow vapour loss. Open containers are vulnerable to spillage and contamination and were therefore avoided.

After drying, the samples were weighed immediately upon removal from the oven. It was found to be essential that the samples were weighed as they were removed from the oven, as the sample material was observed to take up atmospheric moisture at a rate of up to 0.02 g sec^{-1} (pers. obs.). Samples were weighed to an accuracy of 0.05 g.

Each bag containing sample material was weighed first, the bag emptied and the empty bag weighed to derive the net dry fuel sample weight. For each of the fifty-nine sites sampled, an average of 45 bags of approximately 250 grams weight of material was processed.

Site sheets

Fuel dry weight data were collated on Microsoft Excel™ spreadsheets, one per canopy class. For each site, mean weights were derived for all six of the fuel categories. These were then combined to form:

total fuel load, composed of all six fuel categories,

total dead fuel load, combining the three dead fuel categories, total live fuel load, combining the three live fuel categories,

litter fuel load, solely made up of the surface dead fuel category, and

non-litter fuel load, comprising all categories except surface dead fuel.

Curve Fitting

Conceptual model

The expected theoretical pattern for a fuel accumulation curve is set out below in Figure 1. The form of this curve was derived from raw data presented in published fuel accumulation studies.

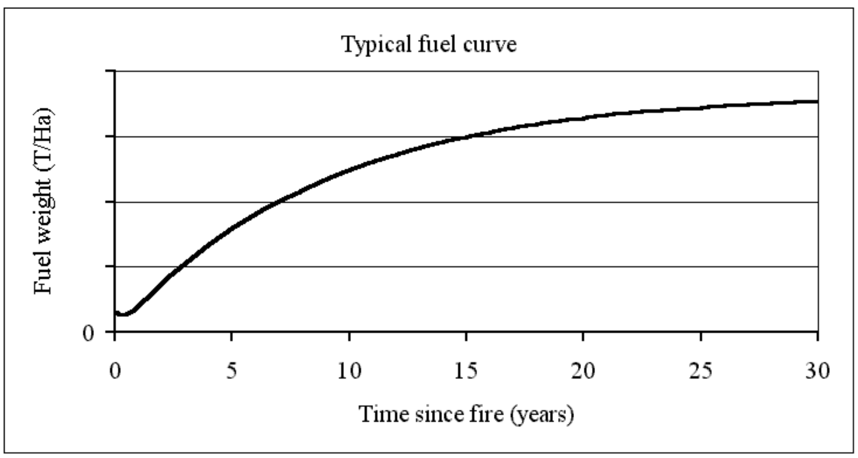


Figure 1: Idealised fuel curve for dry sclerophyll forests

The accumulation pattern is based on the following fire recovery sequence:

Time zero- occurrence of fire. Not all of the available fuel is removed; the size of the residue is dependent on fire intensity and flame residence time.

The few months immediately following the fire usually sees the scorched and dead leaves, bark and twigs fall from the canopy. This 'leaf drop' forms a thin, patchy surface litter layer that slowly decays as the low vegetation recovers and litter organisms recolonise the site. Decay rates are low, as the soil and litter invertebrate populations are still likely to be recovering from the fire (Norris and Conroy 1999).

Between three and six months will elapse in dry sclerophyll forest communities before the regrowth of low vegetation becomes properly established. This time span can vary according to species present, fire intensity and season of fire occurrence (Noble 1989). Canopy trees will be sprouting new growth, often from epicormic buds on the trunks. Soil nutrients freed by the fire permit faster than normal growth of the surviving individuals of some plant species and the activation of dormant seeds in the soil of plant species that may have been killed outright by the fire (Odgers 1996). This return of the plant community in turn supports a returning invertebrate community (Radho-Toly *et al*. 2001). The litter layer deepens, providing more habitat for the return of decomposer organisms. Also during this period the vertebrate fauna begins to recolonise (Sutherland and Dickman 1999) through immigration and natural increase. The fuel curve is now onto the 'main sequence', as from this point litter accession outstrips litter decomposition and fuel loads begin increasing in weight.

After the first six months to a year, the recovery of taller understorey vegetation is well progressed. The regrowth of the understorey communities will continue for the next ten to twenty years.

A point will be reached where litter accession and litter decomposition are approaching equilibrium; the maximum fuel load a site is likely to exhibit. The stage at which this occurs is not connected to the recovery of the pre-fire vegetation community, but a significant understorey community must build up to provide the solar protection for ground layer moisture levels and habitat for decomposer organisms before the accession /decomposition equilibrium point is reached.

It is worth noting at this point that the accession/decomposition equilibrium point is not fixed, but is rather a likely average maximum fuel load. Accession and decomposition rates will vary seasonally and from year to year (Fox *et al*. 1979, Mercer *et al*. 1996), responding to medium and longer-term temporal differences in rainfall and solar energy. Many other factors influence fuel accession, such as storm damage, canopy tree disease or infestation, or physical disturbance (Birk 1979, Birk and Simpson 1980, Pook *et al*. 1997).

Non-linear curve fitting

Accumulation curves were fitted using Systat™ to an equation form based on that presented by Olson (1963) and Landsberg (1977). Modified forms of this basic equation (Equation 1 below) have been presented by Birk and Simpson (1980), Walker (1981), O'Connell (1991) and Fensham (1992):

$$y = y_{\max}\,(1\text{-exp}^{-kx})$$

Equation 1: Basic equation form

The variable x is the elapsed time since the site was last burnt. The $y_{\max}$ component of the equation is the point at which the values for y have reached a steady state. The k component indicates the rate of litter decomposition. At $y_{\max}$ the litter accession (A) is equal to litter decomposition (k) (Olson, 1963).

The variable y can represent total fuel weight or a separate component of the total, such as bark fuel or leaf fuel (O'Connell 1991). For this study, the intention was to treat the fine fuel material in its totality, to look for the broad-scale patterns in accession and decomposition. Separate fuel components exhibit a variable accession pattern across time, particularly across the seasons (Pook *et al*. 1997). Given the design of the fuel sampling procedure involved fuel sampling during all seasons of several years, the incorporation of fuel component data collected during different seasons across a number of years introduces a new, uncorrectable source of data variability which has the potential to diminish the overall reliability of the output and may violate the basic assumptions of the statistical method.

When y_{max} is reached, the litter accession rate *A* can be determined from the decay constant *k* previously determined from Equation 1, as shown in Equation 2 (Birk and Simpson 1980):

$$k = {}^{A}/y_{max} \quad \textit{therefore} \quad k * y_{max} = A$$

Equation 2: Accession, decomposition and decay constant

Not all fuel accumulation studies have used a model which accounts for the fuel residue left behind following a fire, but rather simply starts at time = 0, weight = 0, such as the model used by Fox *et al*. (1979). As the after-fire residue in a control burn can be several tonnes per hectare, this can be seen as a serious limitation. Fensham (1992) estimated the average after-fire residue at 1.92 tonnes per hectare for southeastern Tasmanian dry sclerophyll bushland. The after-fire residue is represented as a fixed average coefficient that then diminishes over time to a point where the accession of fuel begins to outstrip the decay rates. At this point, the curve form moves onto the main sequence. Equation 3 shows the model used by Fensham (1992) and Neyland and Askey-Doran (1994).

$$y = y_{max}\,(1\text{-}\exp^{-kx}) + 1.92(\exp^{-kx})$$

Equation 3: Equation with after-fire residue (after Fensham 1991)

The after-fire residue is highly variable on both meso- and micro- scales, depending on the fuel and fire behaviour conditions at burning (Robichaud and Miller 1999). It follows that the use of a constant residue coefficient across a range of vegetation classes is not representative of observed conditions and may be likely to force the regression into inaccuracies.

In addition to this, it is unlikely that a single average post-fire residue constant will be representative of a set of sites with a mix of both controlled and uncontrolled burns in their fire histories. By allowing the regression procedure the capacity to predict the best-fit post-fire residue for that particular data set, the resultant curve will theoretically return a higher level of explanatory power. The equation then becomes:

$$y = y_{\max} (1\text{-exp}^{-kx}) + a(\text{exp}^{-cx})$$

Equation 4: Final model form

In this equation, the litter decomposition variable *k* is divided into two separate decomposition variables: *c* for the immediate after-fire fuel dynamics and *k* for the build-up of fuel after the initial post-fire effects have passed. The variable a is an estimate of the likely after-fire residue for the category as a whole.

The after-fire fuel residue was observed to occur only within the surface dead fuel category during sampling of recently burnt sites. As such, the equation component $a(e^{-cx})$ was added to the accumulation model only for data sets containing the surface dead fuel category.

Equation 4 provides the form of the curve suggested in the conceptual model, and was accepted as an appropriate statistical model. It should be noted there are two assumptions of the model that are not representative of natural conditions - an assumption that the decay rates are constant and the assumption the community will reach a steady-state point where accession equals decomposition.

Studies into litterfall (Attiwill *et al*. 1978, Birk 1979a, Birk 1979b, Birk and Simpson 1980, Mercer *et al*. 1996, Clarke and Allaway 1996) all indicate that litter accession is not a steady process. Litter accumulates at different rates through the seasons and decomposition rates vary according to temperature and moisture availability. Storm or wind events, disease in the crown or understorey species or invertebrate infestations all produce pulses of higher litter fall. Significant long-term litterfall studies are required to determine the processes and patterns of variability (Mercer *et al*. 1995).

Similarly, environmental and climatological variability produces a situation where the theoretical 'steady-state' point of accession-equals-decomposition is not a constant. Wetter times may see greater decomposition rates; drier times may result in greater litter fall and less decomposition activity. Any single forest community will have litter accession and decomposition rates that vary according to prevailing environmental conditions.

The fuel accumulation model is not able to take this variability into account, relying on a single decomposition coefficient for the post-fire litter accumulation and an estimate of the likely point at which accession rates equals decomposition rates. For the purposes of the production of community-wide fuel curves indicating general patterns across a wide range of environmental variables, the model is not limited in its usefulness by these assumptions.

Data Normality and Heteroscedasticity

The data sets were examined for statistical normality to determine the types of statistical procedures that could be applied. The regression process, goodness of fit measures (r^2) and other statistical methods employed are all parametric procedures, which require data exhibiting a normal distribution as a precondition. If the data are not normally distributed, it is not valid to apply parametric statistical methods and less powerful non-parametric methods must be substituted.

Normality Tests

An initial examination of the fuel accumulation data set normality was made to ensure the validity of the statistical tests used. A series of XY plots comparing the field data in all classifications to normally distributed random number sequences using Microsoft Excel™ 7. Any sign of data non-normality in classification data sets was investigated. Following this, the more rigorous Anderson-Darling test (MINITAB™ version 12.23) was applied to confirm the results of the initial tests.

Residual Tests for Data Homoscedasticity

Graphing the regression residuals (observed minus predicted) against time for each site in each category gives an insight into two critical areas: data heteroscedasticity and goodness of data/model fit throughout the time series. According to Ratkowsky (pers. comm.), a consistent increase in the magnitude of residuals with the increase of the magnitude of the predicted fuel load itself indicates the data set is exhibiting a heteroscedastic distribution and the regression procedure employed cannot be relied upon in a statistical sense. Using this post-hoc heteroscedasticity test procedure in addition to the normality checks applied prior to the regression process permits a greater reliance on the explanatory power of the resultant fuel curves.

Residual plot graphing also gives a clear indication if the model is consistently over-predicting or under-predicting fuel weight in any section of the accumulation curve. Should such patterns appear consistently in the residuals, it would indicate a process or accumulation pattern for which the model has failed to account (Hamburg 1983, Ratkowsky pers. comm.). The presence of these patterns would prompt further refinement of the model equation, the possible need for a transformation of the data or the abandonment of the original model and development of a new equation form. Residual plots from all regression curves developed are contained in Appendix 3.

4. Fuel Accumulation as Predicted by Forest Community Type

Introduction

The sclerophyllous habit of Australian dry vegetation is a result of adaptation to drought conditions and low nutrient availability (Williams 1991) and is considered to enhance the flammability of both the living plants and the litter they shed. Six dry sclerophyll vegetation communities were found in the study area. Five of the communities correspond to those outlined in Duncan and Brown (1985), with the sixth community being a type commonly encountered in the study area. These vegetation types were identified by the dominant tree species in the canopy layer and the understorey type.

These types were used to order the fifty-nine sites into groups in preparation for generating the fuel accumulation curves.

The vegetation communities

Allocasuarina verticillata forest and woodland [Ave]

Allocasuarina verticillata dominated forest and woodland was found on dolerite slopes and ridges, generally with a northerly aspect. Canopy height was generally below eight metres. A sparse shrub and small tree assemblage, with a mixed heathy and grassy ground layer typify the understorey. The shed needles of *A. verticillata*, which forms a characteristic thick, unbroken carpet capable of suppressing most understorey species, dominated the litter layer.

Understorey trees were commonly *Bursaria spinosa* and *Dodonaea viscosa*, and a medium to high density of tussock graminoids such as *Lomandra longifolia* occupied the lower fuel layers. Species of *Olearia* and *Ozothamnus* were common low shrubs.

Agrostis spp., *Poa* spp., *Themeda triandra* and *Austrostipa* spp. dominated the grasses, often in the inter-canopy spaces where light penetration to the ground layer was high and needle fall from *A. verticillata* was relatively minor. *Astroloma humifusum* was a common heath species in the low fuel layer and herbs such as *Chrysocephalum* spp. were also found.

Eucalyptus pulchella forest [Epu]

Largely found on soils derived from dolerite-based substrates, *Eucalyptus pulchella* dominated vegetation ranged from medium density forest to open grassy or heathy woodlands. *Eucalyptus viminalis, E. ovata* and *E. globulus* were common canopy sub-dominant species. Understoreys ranged from dominantly heath species to grasslands, with most sites exhibiting a mix of grass and heath species.

Understorey trees were commonly only slightly shorter than the canopy height. *Exocarpos cupressiformis, Acacia dealbata, A. verticillata, A. mearnsii* and *Banksia marginata* were typical of the understorey tree and tall shrub layer.

Heathy shrubs and tussock graminoids dominated the lower vegetation layers. *Lomandra longifolia, Pteridium esculentum* and *Epacris impressa* were typical species in this layer.

Grasses included Ehrharta spp., Dichelachne spp., Themeda triandra, Austrostipa spp., Poa spp. and Danthonia spp.

Eucalyptus amygdalina heathy forest [Eamh]

Dry sclerophyll communities with *Eucalyptus amygdalina* dominating the canopy layer were found solely on sandstone, sandstone-derived or deep sand substrates. Throughout the study area, there was a clear delineation between *E. amygdalina* communities with a grassy understorey and communities with heath dominated understoreys. Fensham and Kirkpatrick (1992) suggest the differences may be based in soil moisture and organic content, fire history and past land use. Data checking showed marked differences in the fuel accumulation patterns between the heathy understoreys and grassy understoreys. These differences were sufficient to cause data heteroscedasticity problems. When separated into the two separate communities, as in Duncan and Brown (1985), the new data subsets conformed to the preconditions for the curve fitting and were adopted as separate canopy classes.

In addition to the dominant E. amygdalina, the canopy often included E. obliqua and E. viminalis. Acacia dealbata, Exocarpos cupressiformis, Leptospermum lanigerum, L. scoparium and Banksia marginata most commonly form the tall shrub layer. Bursaria spinosa and Allocasuarina littoralis are also found in this layer.

A low heathy layer, ranging in height from approximately 20 centimetres up to 1.2 metres above the litter surface was made up mostly by *Lomandra longifolia*, *Pteridium esculentum*, several species of *Leucopogon*, *Diplarrena moraea*, *Epacris impressa* and *Ozothamnus obcordatus*.

Heath-dominated understorey communities differed markedly in the relative prominence of bracken fern, *Pteridium esculentum*. Sites were either thickly blanketed in the low to medium heath layer by *P. esculentum,* or were dominated by a diverse community of other shrub species. While in floristic terms the difference between the fern-dominated and non-fern-dominated sites is minor, in terms of fuel structure the sites were appreciably different.

Eucalyptus amygdalina woodland [Eamg]

Eucalyptus amygdalina sites with a grass-dominated understorey generally showed an open structure, with grasslands containing wide-spaced small tree and shrub species and tussock graminoids. Canopy tree density was generally lower than heath-dominated *E. amygdalina* sites, leading to much higher light penetration to the low vegetation levels.

Canopy sub-dominant species typically included Eucalyptus viminalis, E. globulus and E. obliqua. Understorey trees were mostly Acacia dealbata, A. mearnsii, Exocarpos cupressiformis, Dodonaea viscosa and Allocasuarina littoralis.

Lomandra longifolia, Diplarrena moraea, Dianella revoluta and *D. tasmanica* were commonly found in the low heath layer, sparsely dispersed throughout a typically thick sward of grasses, including *Themeda triandra*, *Austrostipa* spp., *Poa* spp. and *Austrodanthonia* spp.

Eucalyptus tenuiramis & *E. risdonii* forest and woodland [Etr]

Occurring solely on mudstone-derived soils, this community category is characterised by a sparse heathy understorey and significant areas of bare ground. Typically found on dry locations and mostly on north-facing slopes, these communities generally had very low species numbers and low vegetation densities on all structural levels.

Eucalyptus tenuiramis and *E. risdonii* generally formed monotypic canopies, but occasional individuals of *E. viminalis* and, on higher altitude sites, *E. obliqua* were found to occur.

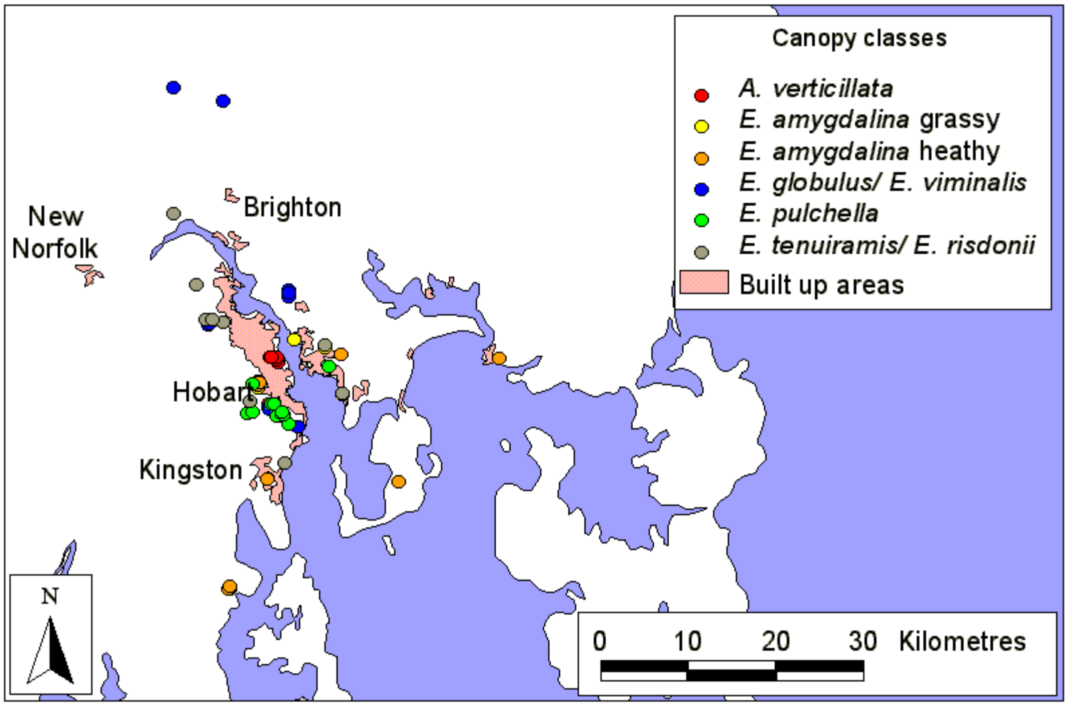
Exocarpos cupressiformis, Acacia dealbata and *Banksia marginata* were present but sparsely distributed in the understorey tree layer, although it should be noted that the generally low canopy height of the dominant eucalypts meant the canopy and understorey trees were often of very similar heights. *A. dealbata* in some cases was a canopy sub-dominant rather than understorey tree.

Understoreys were typically sparse shrub and heath species, with few grasses and heath species present. Tussock graminoids were very rare, but low or prostrate heath species such as *Pultenaea* spp. and *Daviesia* spp. were often found.

Eucalyptus globulus & *E. viminalis* forest [Egv]

This community type does not correspond directly with Duncan and Brown (1985). This community occurs on dolerite and sandstone based substrate types found throughout the study area. Canopies dominated by *Eucalyptus globulus* and *E. viminalis* were found most often in the wetter areas and more southerly-facing slopes. *Eucalyptus amygdalina, E. obliqua, E. ovata* and *E. pulchella* form canopy sub-dominants. Understorey trees included *Acacia verticillata, Dodonaea viscosa, Exocarpos cupressiformis* and *Bursaria spinosa.*

Many sites dominated by *Eucalyptus globulus* and *E. viminalis* exhibit an open, mixed heathy and grassy species assemblage. The low fuel stratum was largely dominated by tussock graminoids, particularly *Lomandra longifolia* and *Diplarrena moraea*. Heathy shrubs included *Epacris impressa*, *Astroloma humifusum* and species of *Olearia*. The low graminoid *Dianella revoluta* is found at some sites. A thick frond layer of *Pteridium esculentum* often dominated other sites. Grasses ranged in dominance of the ground layers from very minor to approaching 30% cover. *Austrodanthonia* spp., *Austrostipa* spp., *Poa* spp., *Themeda triandra*, *Ehrharta stipoides* and *E. distichophylla* were all commonly found.



Map 7: Sites coded according to canopy dominant species.

The 59 sampling sites were classified as shown in Table 1, with between 8 and 13 sites in each category. The raw data are contained in Appendix 1.

Category	Site numbers
Ave *Allocasuarina verticillata*	23, 24, 25, 26, 27, 28, 29, 30
Epu *Eucalyptus pulchella*	10, 11, 12, 13, 14, 15, 16, 17, 18, 19, 20, 21, 22
Eamh Heathy *Eucalyptus amygdalina*	49, 50, 51, 52, 53, 54, 55, 56, 57, 58, 59
Etr *Eucalyptus tenuiramis/ E. risdonii*	1, 2, 3, 4, 5, 6, 7, 8, 9
Egv *Eucalyptus globulus/ E. viminalis*	31, 32, 33, 34, 35, 36, 37, 38, 39
Eamg Grassy *Eucalyptus amygdalina*	41, 42, 43, 44, 45, 46, 47, 48

Table 1: Sites in canopy ordering classification

Fuel Accumulation Curves

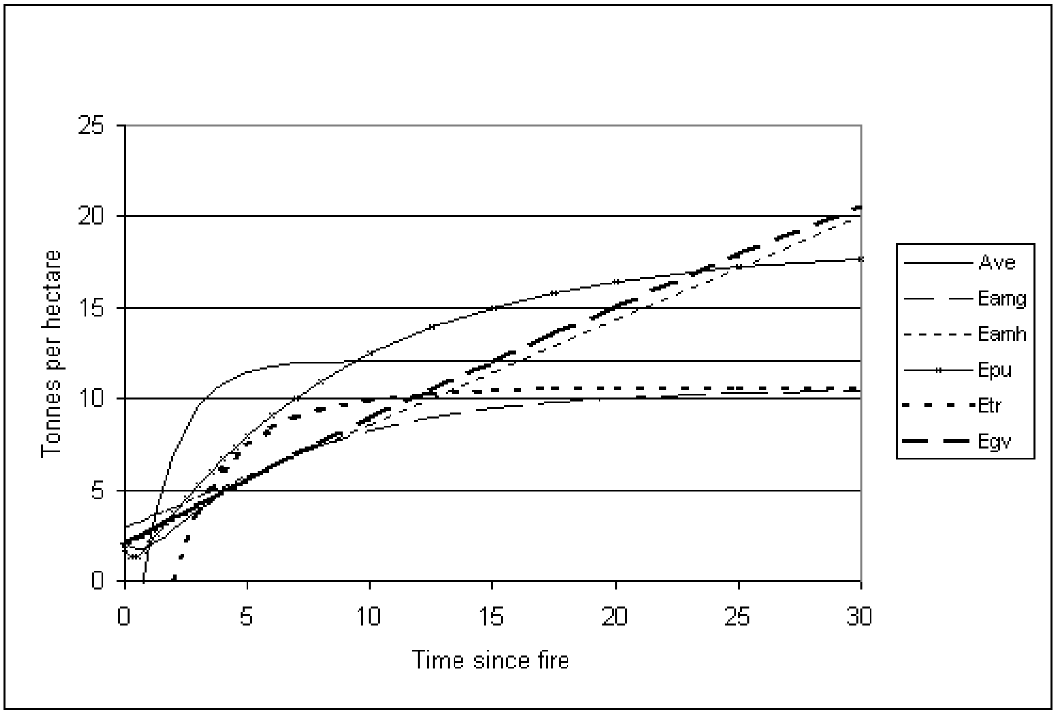


Figure 2: Fuel accumulation- total fuel

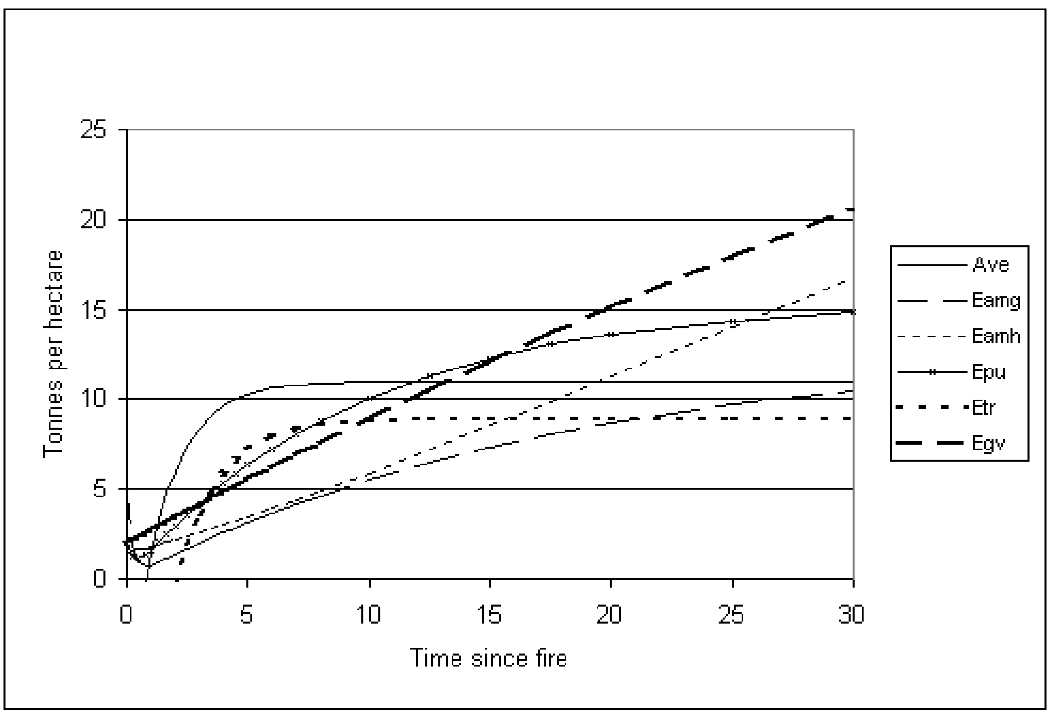


Figure 3: Fuel accumulation- total dead fuel

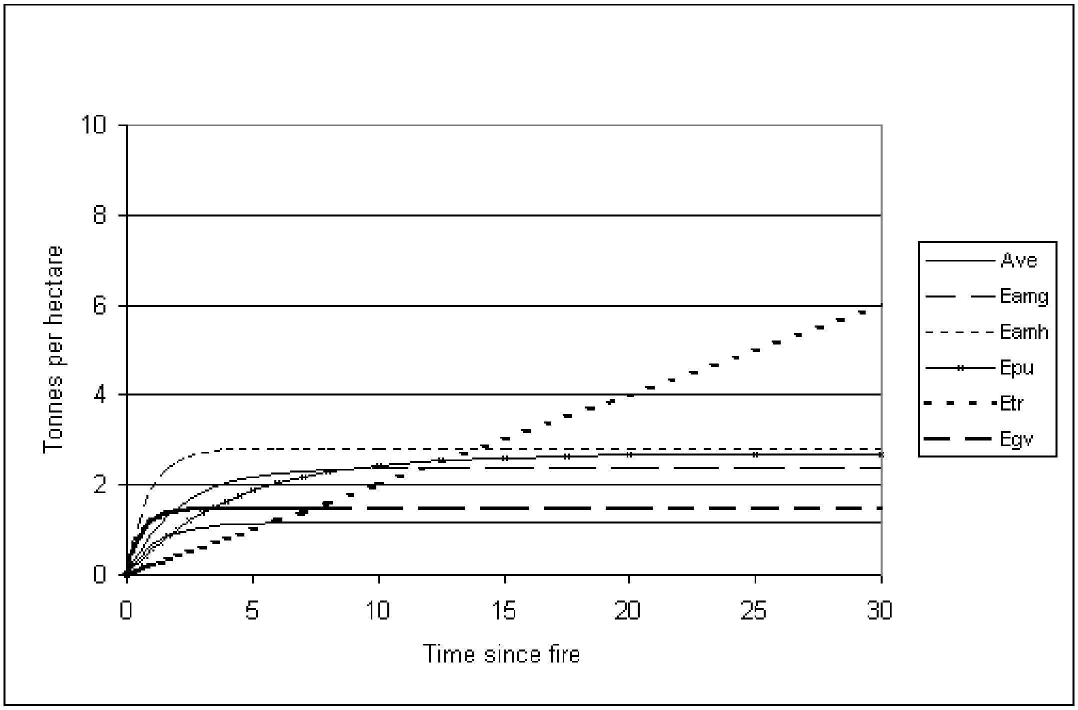


Figure 4: Fuel accumulation- total live fuel

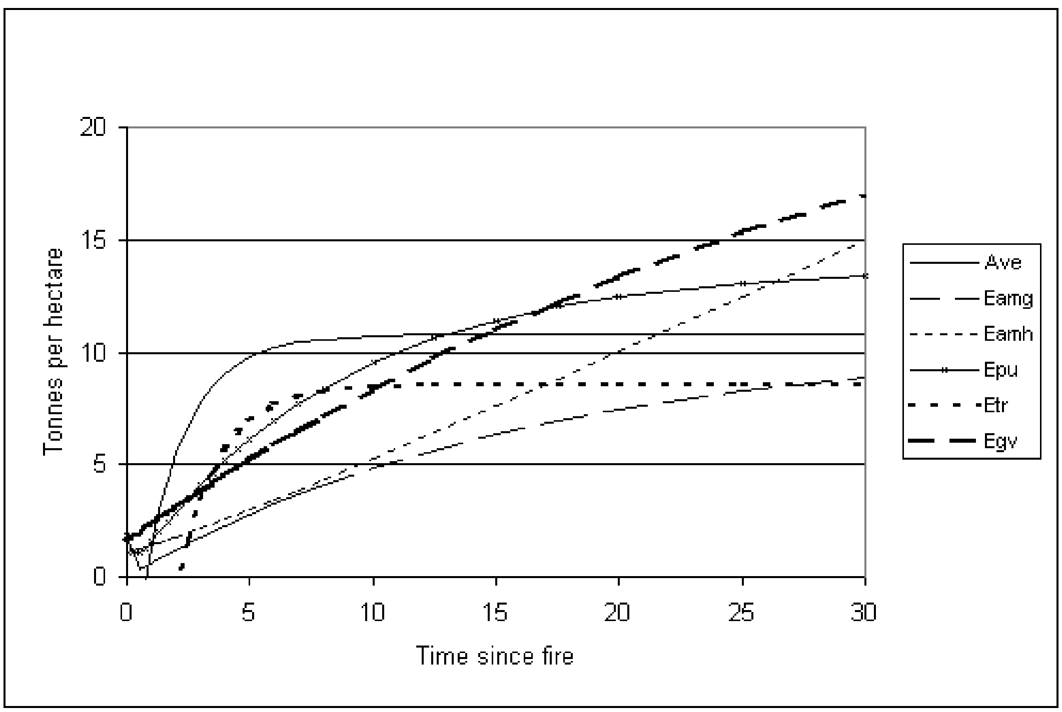


Figure 5: Fuel accumulation- litter fuel

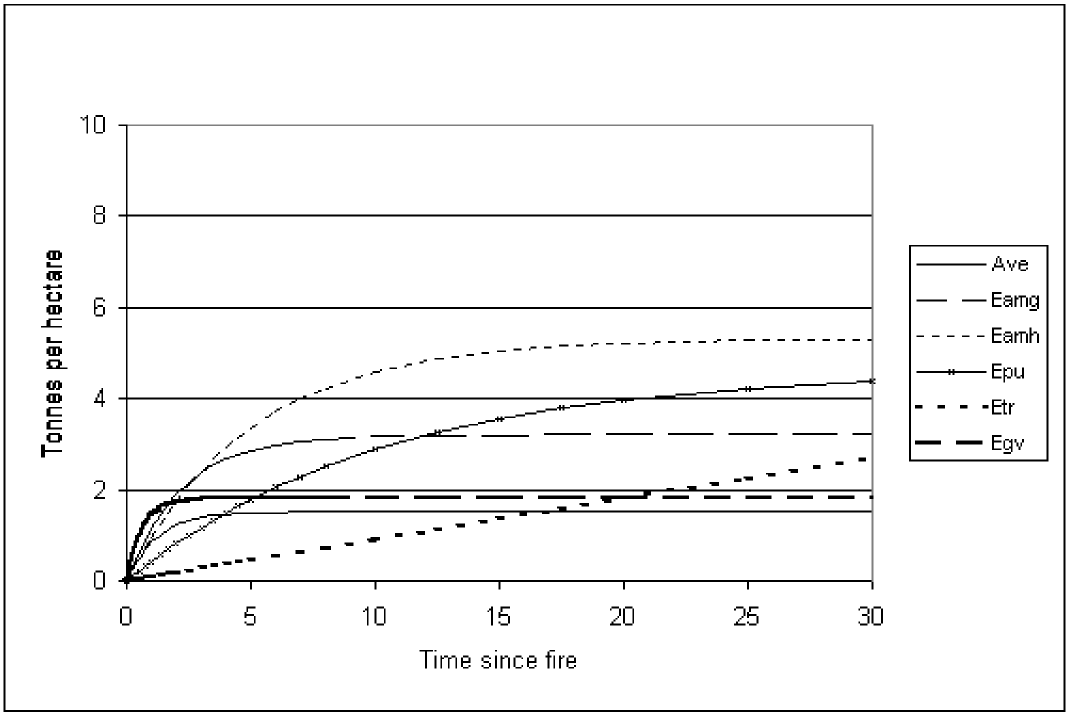


Figure 6: Fuel accumulation- non-litter fuel

The total fuel load of any single classification category (Figure 2) appears to be very strongly related to litter fuel accumulation (Figure 5). Litter makes up as much as 90% by weight of the total fuel weight for any single site and as such the accumulation pattern of all flash fuels is controlled by the behaviour of the litter fuels.

Table 2 to Table 7 (below) shows the equation coefficients for the accumulation curves of all sites sampled, in canopy-dominant ordering. W_{ss} is the Y_{max} component of the model equation- the maximum or steady-state estimate predicted fuel load. The variables k, a and c are, respectively: predicted fuel decay, after-fire fuel residue and immediate post-fire fuel residue decay.

Allocasuarina verticillata

Fuel type	W_{ss}	k	a	c	r^2 value
Total	12.105	0.689	-7.982	0.689	0.78
Live	1.16	0.83			0.37
Dead	10.993	0.647	-7.199	0.647	0.65
Litter	10.788	0.499	-6.339	0.79	0.81
Non-litter	1.515	0.822			0.21

Table 2: Equation coefficients for category *Allocasuarina verticillata*

Eucalyptus pulchella

Fuel type	W_{ss}	k	a	c	r^2 value
Total	18.31	0.114	1.791	3.153	0.93
Live	2.687	0.237			0.72
Dead	15.499	0.105	2.028	3.415	0.87
Litter	13.783	0.117	1.811	3.729	0.83
Non-litter	4.645	0.097			0.73

Table 3: Equation coefficients for category *Eucalyptus pulchella*

Heathy *Eucalyptus amygdalina*

Fuel type	W_{ss}	k	a	c	r^2 value
Total	1199.5	0.0005	2.92	0.0103	0.92
Live	2.813	1.142			0.49

Dead	2799.8	0.0002	1.459	0.153	0.88
Litter	2500	0.0002	1.068	0.149	0.81
Non-litter	5.308	0.199			0.52

Table 4: Equation coefficients for category Heathy *Eucalyptus amygdalina*

Eucalyptus tenuiramis/ E. risdonii

Fuel type	W_{ss}	k	a	c	r^2 value
Total	10.57	0.0001	-19.54	0.734	0.69
Live	1999.4	0.0001			0.64
Dead	8.899	0.564	-19.84	0.564	0.69
Litter	8.52	0.593	-21.69	0.593	0.64
Non-litter	2998.3	0.0003			0.62

Table 5: Equation coefficients for category *Eucalyptus tenuiramis/E. risdonii*

Eucalyptus globulus/E. viminalis

Fuel type	W_{ss}	k	a	c	r^2 value
Total	28.169	0.034	2.959	0.034	0.87
Live	1.471	1.609			0.16
Dead	68.069	0.011	1.976	0.011	0.94
Litter	27.554	0.03	1.557	0.03	0.92
Non-litter	1.821	1.583			0.18

Table 6: Equation coefficients for category *Eucalyptus globulus/E. viminalis*

Grassy *Eucalyptus amygdalina*

Fuel type	W_{ss}	k	a	c	r^2 value
Total	10.51	0.154	2.248	1.665	0.83
Live	2.402	0.482			0.5
Dead	12.988	0.055	4.694	4.139	0.91
Litter	10.542	0.061	58	16.004	0.95
Non-litter	3.206	0.451			0.47

Table 7: Equation coefficients for category Grassy *Eucalyptus amygdalina*

The r^2 value is a measure of the `goodness of fit` of the data to the equation: r^2 values approaching 1 indicate a high level of agreement between the equation and the raw data from which the equation was derived. Table 2 to Table 7 show consistently high r^2 values for total fuel, dead fuel and litter fuel categories, indicating an explanatory power of 70% to over 90% of the pattern shown in the raw data. This is not seen in the live fuel or non-litter fuel categories, where explanatory power varies from 70% in *Eucalyptus pulchella* to less than 20% in *E. globulus/E. viminalis*.

The accumulation of fuels in the live and non-litter classes did not consistently exhibit patterns consistent with the conceptual model (Figure 1). Whether this is an actual inconsistency or an artefact of the site classification scheme is likely to be illustrated in the results from phytosociological or environmental variable based re-classifications of the data set, where classification is based on not solely the canopy dominant species. The assumption can be made that the pattern of litter fuel accumulation is likely to be the underlying factor behind the goodness of fit of the model.

Total fuel

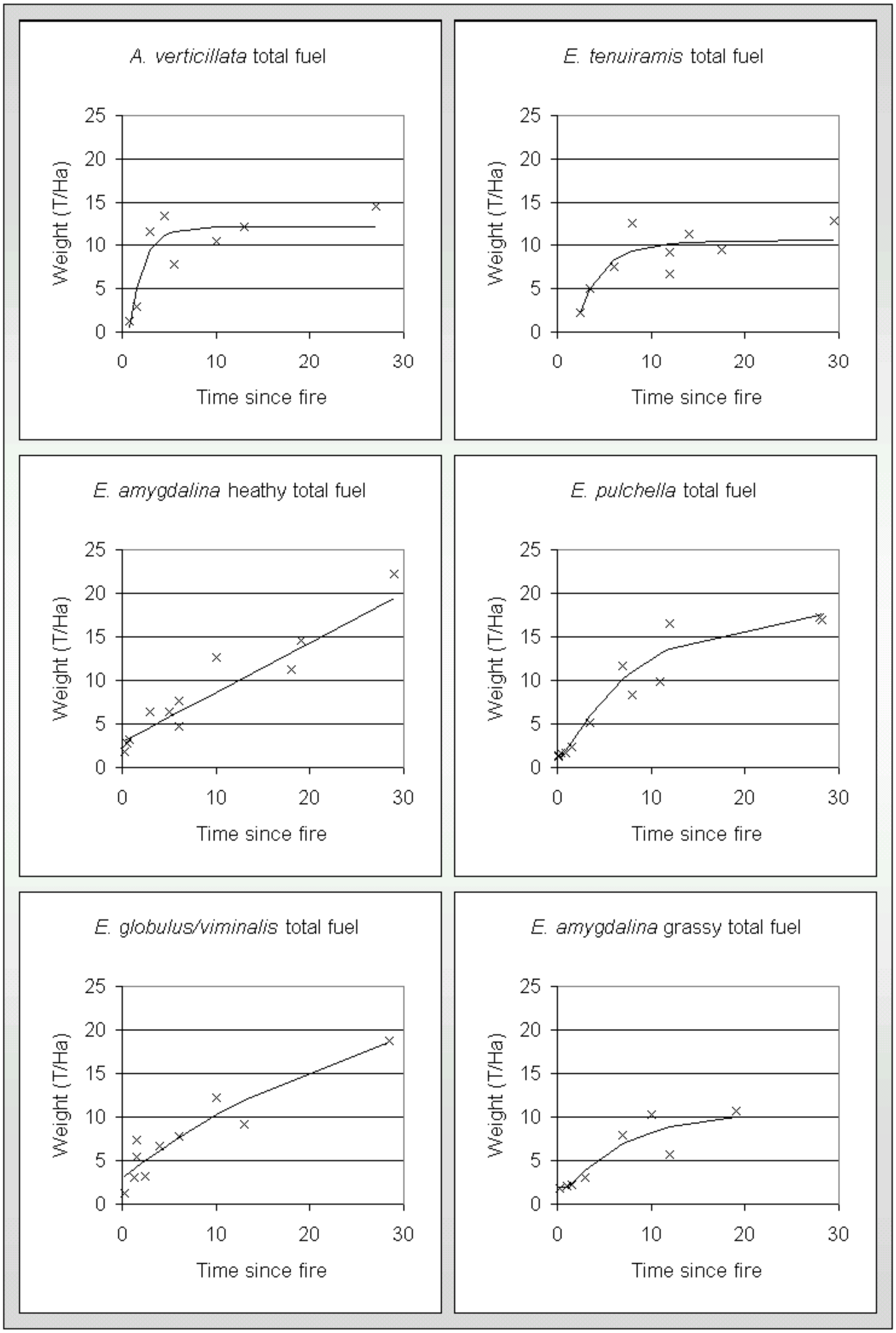


Figure 7: Fuel accumulation- total fuel

Total live fuel

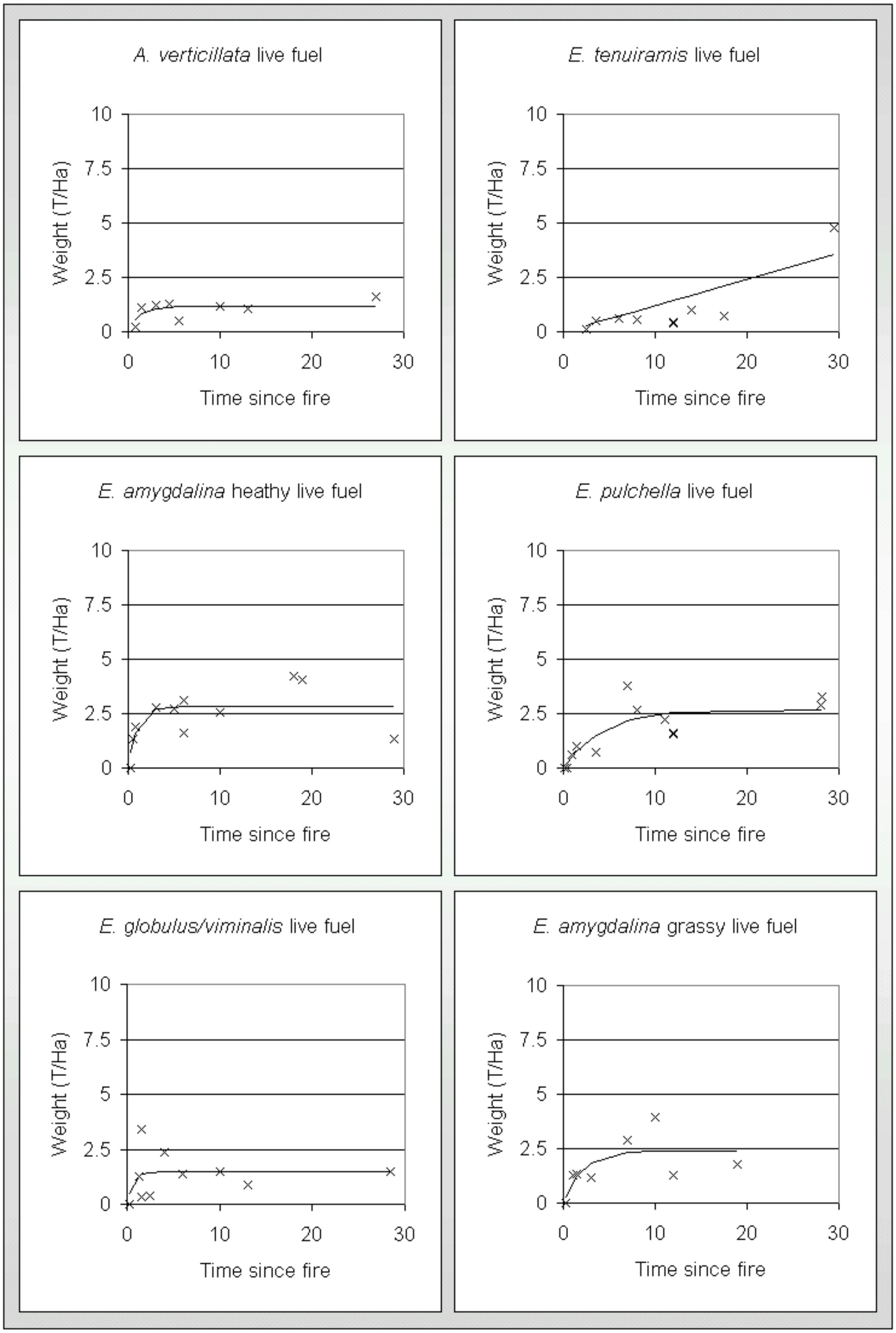


Figure 8: Fuel accumulation- live fuel

Total dead fuel

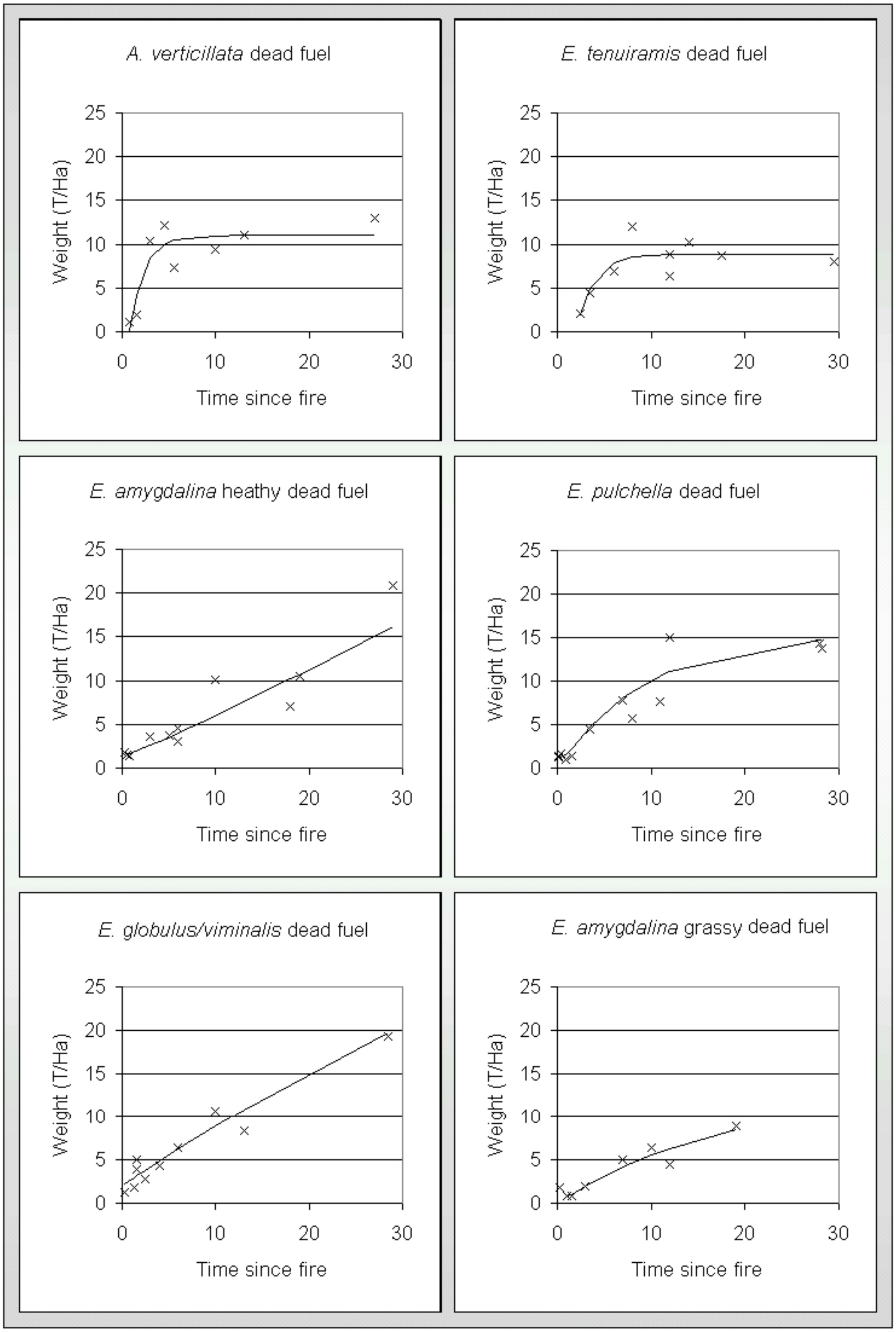


Figure 9: Fuel accumulation- dead fuel

Litter fuel

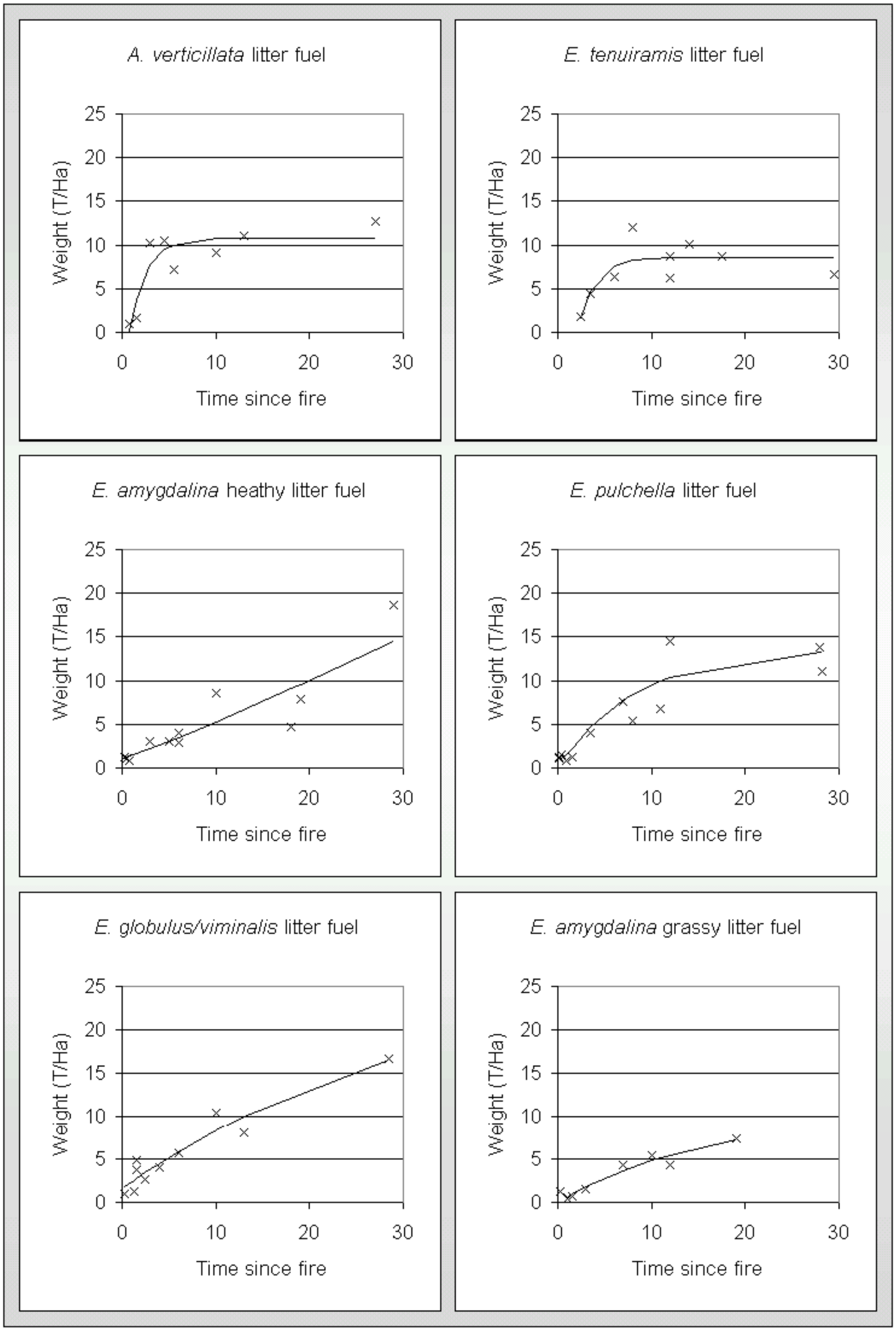


Figure 10: Fuel accumulation- litter fuel

Non-litter fuels

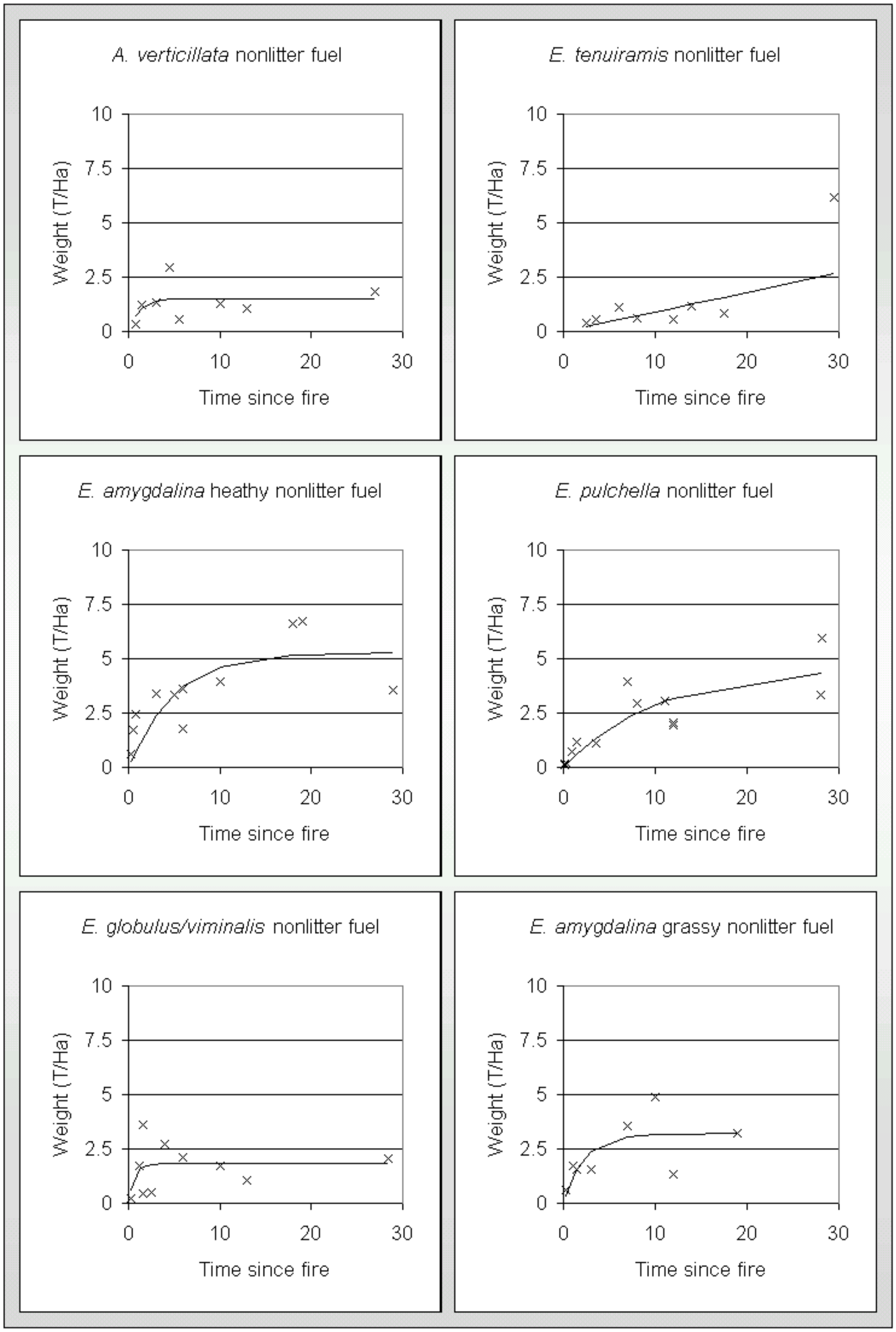


Figure 11: Fuel accumulation- non-litter fuel

The six categories of the canopy ordering appear to fit into two classes. *Eucalyptus tenuiramis*, *Allocasuarina verticillata, E. pulchella* and grassy *E. amygdalina* exhibit a steep initial buildup to around 10-12 t/ha in the first 5-15 years following a fire, with little subsequent fuel accumulation. Heathy *E. amygdalina* and *E. globulus/E. viminalis* have a much slower initial rate of accumulation but appear to continue accumulating well beyond the 25-year mark.

This suggests that *E. tenuiramis*, *A. verticillata* and grassy *E. amygdalina* may not attain fuel loads significantly higher than 10-12 tonnes per hectare (t/ha) regardless of the site's fire age and as such may only require fuel reduction burns on a scale of once per 20 years or more.

Heathy *E. amygdalina, E. globulus/E. viminalis* and *E. pulchella* all appear to be reaching total fuel loads of around 15 t/ha at 15 to 20 years since the previous burn and to be approaching 20 t/ha by 30 years. These are heavy fuel loads; above 10-15 t/ha is considered to be the upper limit of manageable fuel weight (Good, 1981; Raison *et al*. 1986) and as such would require careful monitoring.

Canopy class *E. tenuiramis* exhibits a much slower re-establishment of live fuel and a steady continual increase in fuel weight. This steady increase is driven by a single data point and as such may be an artefact: the apparent build-up for all other *E. tenuiramis* sites reflects a similar pattern to *A. verticillata*.

The fuel curves that have resulted from this section of the study have shown that the modifications to the previously published form of the fuel accumulation model can produce fuel accumulation curves of sufficiently high statistical reliability for use as planning tools. The use of the dominant canopy species as a classification method has produced sensible and useful results, but whether this method is the most appropriate has not thus far been determined.

There is a strong likelihood that a different method of classifying sites may produce more useful results. Given that fuel accession rates are in part controlled by site productivity, and fuel decomposition rates are controlled in part by moisture availability, it is likely that a classification method that takes more of the site productivity and general environmental conditions into account will produce fuel accumulation curves with a greater explanatory power than those produced by the established method of using dominant canopy species.

The entire assemblage of flora species at any one site is more finely attuned to environmental conditions and site productivity than the canopy dominant species (Hogg and Kirkpatrick 1974). A classification scheme based on a system of phytosociological grouping is expected to group sites much more closely along environmental gradients and this has the potential to produce fuel accumulation curves of a greater explanatory power than those presented in this chapter.

5. Fuel Accumulation as predicted by Phytosociological groups

Introduction

The sites sampled and ordered by canopy type often displayed within-category differences in species composition, particularly in the low heath and grass layers. The possibility of using a more complete vegetation community classification as a basis for developing fuel accumulation curves was suggested by the work of Hogg and Kirkpatrick (1974), who investigated the phytosociology of dry forests and woodlands in southeastern Tasmania. The understorey floristics were found by Hogg and Kirkpatrick (1974) to be important factors in community differentiation. Tolhurst (1996b) indicates dry sclerophyll understorey communities were largely the same post-fire as pre-fire, so classification according to species presence data is not likely to have significant artefacts produced by fire age. Bradstock, Bedward, Kenny and Scott (1998) suggest that in fragmented urban fringe bushland, such as is found in some sites within the study area, the risk of fire-driven local extinction is greater than in unfragmented bushlands. The degree of fragmentation in the study area is not likely to be such as to prevent the natural re-introduction of species from nearby areas.

The fifty-nine sites were re-ordered by phytosociological affiliation to determine whether this method provides a stronger explanation of fuel accumulation patterns than the canopy-dominant based classification scheme.

Methods

TWINSPAN (Hill 1979) is a Two-Way Indicator Species Analysis software application developed to produce a hierarchical classification of community data. As described by van Groenwoud (1992), it classifies the communities through determining indicator species that are more common in one group of samples than the other. This is accomplished by a process of dividing an initial Correspondence Analysis (CA) axis into two parts using indicator species. Subsequently, another CA process is performed on each of the groups divided by the previous iteration, with new indicator species being chosen, and on into third and later iterations. It should be noted that the pattern of vegetation communities resulting from the TWINSPAN analysis is essentially descriptive (Minchin 1987b). The technique does not model the processes that produce these patterns.

For this study, the limitations of the TWINSPAN analysis are twofold. Firstly, the technique gives equal weight to all species as it uses presence/absence data only. As fuel loads are largely a product of litter and the litter arises from only a small number of species, TWINSPAN may skew the community classification away from the structurally important or numerically dominant species in favour of other species that do not contribute to litter production. Whether this is an important issue will be seen in comparing the fuel curve results from this classification system to the fuel curves produced from the canopy ordering classification.

Secondly, both Minchin (1987a) and van Groenwoud (1992) indicate caution concerning the use of TWINSPAN, particularly in the second and later iterations of the procedure, as the process of dividing the CA axis can displace sample points. To minimise this and provide suitably large data sets for the curve fitting process, the community groups were drawn from the TWINSPAN output at second and third order iterations (Appendix 4).

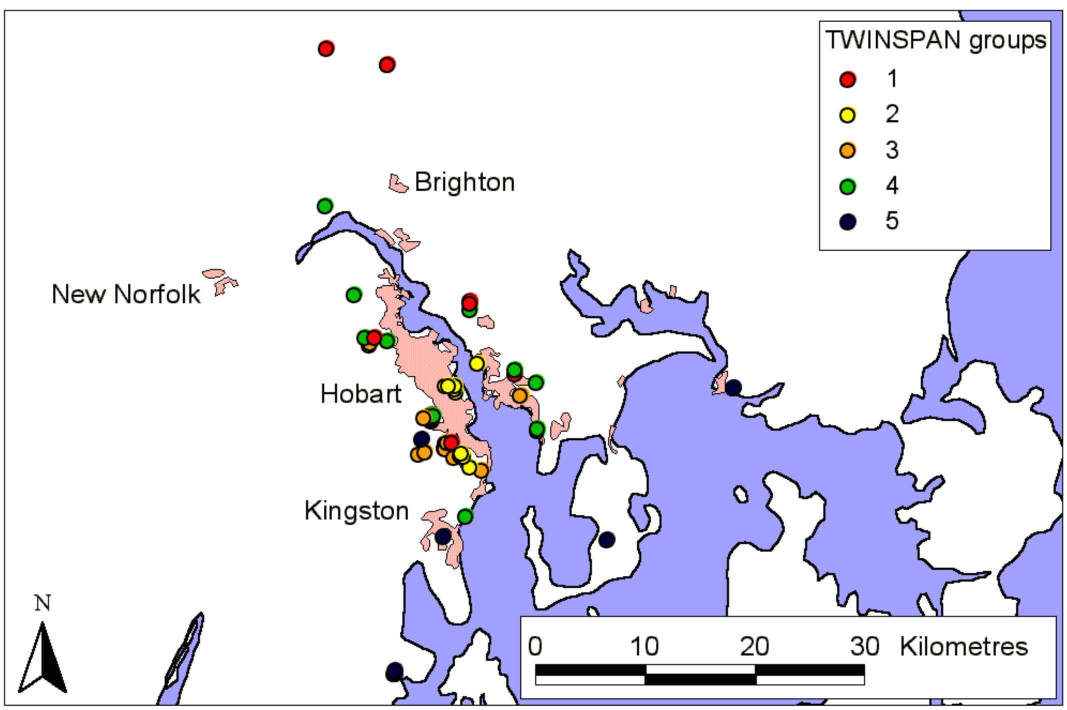
Five classes were selected from the TWINSPAN sorted table and were labelled 1 to 5. The distribution of the five groups across the study area is shown in Map 8. The proportions of species across the TWINSPAN groups are shown in Table 8.

SPECIES	1	2	3	4	5
Acacia dealbata	**90**	84.62	66.67	58.33	75
Acacia genistifolia	**10**	7.69	8.33	8.33	8.33
Acacia mearnsii	-	23.08	8.33	25	**33.33**
Acacia melanoxylon	20	15.38	**25**	**25**	8.33
Acacia myrtifolia	**10**	-	-	-	8.33
Acacia stricta	**20**	7.69	-	-	-
Acacia suaveolens	-	**7.69**	-	-	-
Acacia terminalis	-	7.69	**16.67**	-	8.33
Acacia verticillata	-	-	-	**8.33**	-
Acaena echinata	40	**61.54**	16.67	50	25
Acrotriche serrulata	-	**7.69**	-	-	-
Agrostis spp.	50	30.77	25	50	**58.33**
Allocasuarina littoralis	10	**53.85**	33.33	33.33	8.33
Allocasuarina monilifera	**10**	7.69	8.33	-	8.33
Allocasuarina verticillata	10	15.38	16.67	**66.67**	41.67
Amperea xiphoclada	10	15.38	**25**	-	8.33
Aotus ericoides	**10**	-	8.33	8.33	8.33
Arthropodium milleflorum	10	15.38	**16.67**	**16.67**	**16.67**
Asperula spp.	10	**30.77**	-	16.67	8.33
Astroloma humifusum	60	69.23	58.33	75	**83.33**
Austrodanthonia spp.	**90**	84.62	75	66.67	75
Austrostipa spp.	**100**	92.31	91.67	**100**	75
Banksia marginata	**50**	38.46	41.67	-	16.67
Bedfordia salicina	10	-	-	8.33	**16.67**
Boronia pilosa	-	-	**8.33**	-	-
Bossiaea cinerea	-	15.38	**16.67**	-	-
Bossiaea prostrata	40	53.85	**58.33**	33.33	41.67
Brachyscome spp.	**20**	15.38	-	16.67	-
Bracteantha bicolor	-	-	**8.33**	-	-
Bulbine bulbosa	-	**15.38**	8.33	-	-
Bursaria spinosa	40	53.85	25	50	**75**
Callistemon pallidus	**10**	-	-	-	-
Carex breviculmis	**20**	7.69	8.33	16.67	16.67
Carpobrotus rossii	-	-	**8.33**	-	-
Cassytha glabella	-	7.69	**8.33**	-	**8.33**
Cassytha pubescens	30	38.46	33.33	**41.67**	8.33
Chrysocephalum apiculatum	20	38.46	**41.67**	25	**41.67**
Chrysocephalum semipapposum	-	-	-	-	**8.33**
Clematis gentianoides	-	-	**8.33**	-	**8.33**
Convolvulus erubescens	-	-	-	**8.33**	-
Coprosma hirtella	**10**	-	-	-	-
Crassula sieberiana	**20**	7.69	8.33	-	-
Cyathodes divaricata	-	-	**8.33**	-	**8.33**
Daviesia latifolia	-	-	-	8.33	**16.67**
Daviesia ulicifolia	**30**	23.08	8.33	16.67	16.67
Deyeuxia spp.	**80**	61.54	75	75	41.67
Dianella revoluta	**70**	69.23	41.67	66.67	58.33
Dianella tasmanica	**10**	-	8.33	-	-
Dichelachne spp.	70	53.85	75	**91.67**	**91.67**
Dichondra repens	**30**	-	16.67	-	-
Dillwynia glaberrima	-	**15.38**	-	-	-
Diplarrena latifolia	**60**	46.15	25	33.33	25
Dodonea viscosa	10	30.77	8.33	**50**	**50**
Drosera spp.	-	-	-	**8.33**	**8.33**
Ehrharta distichophylla	10	**38.46**	-	-	-

Ehrharta stipoides	40	15.38	**41.67**	16.67	25
Elymus scaber	**40**	23.08	8.33	25	25
Epacris impressa	**60**	38.46	41.67	8.33	25
Eriostemon verrucosus	**10**	-	-	-	-
Eucalyptus amygdalina	20	**84.62**	75	8.33	16.67
Eucalyptus globulus	**70**	7.69	25	25	16.67
Eucalyptus obliqua	20	23.08	**25**	-	16.67
Eucalyptus pulchella	**50**	23.08	25	41.67	**50**
Eucalyptus risdonii	-	-	8.33	**16.67**	8.33
Eucalyptus tenuiramis	-	-	-	16.67	**33.33**
Eucalyptus viminalis	**70**	61.54	41.67	33.33	58.33
Exocarpos cupressiformis	40	53.85	33.33	**75**	58.33
Exocarpos strictus	**10**	7.69	-	-	8.33
Gahnia radula	**30**	15.38	25	16.67	-
Geranium spp.	**10**	7.69	8.33	8.33	-
Gnaphalium collinum	-	7.69	**16.67**	-	-
Gompholobium huegelii	-	7.69	**8.33**	-	-
Gonocarpus tetragynus	70	84.62	66.67	33.33	**91.67**
Goodenia lanata	**10**	-	-	-	-
Goodenia ovata	10	-	-	8.33	**16.67**
Helichrysum scorpioides	**60**	46.15	58.33	16.67	41.67
Hibbertia hirsuta	-	-	8.33	-	**16.67**
Hibbertia procumbens	-	**7.69**	-	-	-
Hibbertia prostrata	-	**7.69**	-	-	-
Hypericum gramineum	30	**38.46**	25	-	16.67
Hypolaena fastigiata	-	**7.69**	-	-	-
Juncus spp.	10	-	**16.67**	-	-
Lagenifera stipitata	-	7.69	**16.67**	-	-
Lepidosperma concavum	-	**7.69**	-	-	-
Lepidosperma gunnii	-	-	**8.33**	**8.33**	**8.33**
Lepidosperma inops	**10**	7.69	-	-	8.33
Lepidosperma laterale	10	7.69	16.67	**25**	**25**
Leptomeria drupacea	-	-	-	-	**8.33**
Leptorhynchos squamatus	**30**	23.08	16.67	8.33	25
Leptospermum glaucescens	-	**7.69**	-	-	-
Leptospermum scoparium	50	30.77	**58.33**	8.33	8.33
Leucopogon collinus	10	15.38	**16.67**	-	8.33
Leucopogon ericoides	10	**30.77**	8.33	-	-
Leucopogon virgatus	20	15.38	**25**	-	-
Linum marginale	**10**	7.69	-	8.33	-
Lissanthe strigosa	40	53.85	50	25	**58.33**
Lomandra longifolia	90	**100**	91.67	83.33	83.33
Lomatia tinctoria	**30**	-	8.33	-	-
Olearia argophylla	**10**	-	-	-	-
Olearia ericoides	**10**	-	-	-	8.33
Olearia erubescens	**10**	-	-	-	-
Olearia phlogopappa	-	-	-	**8.33**	-
Olearia ramulosa	20	23.08	16.67	**41.67**	33.33
Olearia viscosa	**20**	-	-	-	-
Opercularia varia	-	-	**8.33**	-	-
Oxalis perennans	**60**	23.08	25	41.67	33.33
Ozothamnus ferrugineus	**10**	-	-	-	-
Ozothamnus obcordatus	20	7.69	8.33	**25**	8.33
Ozothamnus purpurescens	-	-	-	**8.33**	-
Ozothamnus scutellifolius	-	-	**8.33**	-	-
Persoonia juniperina	**10**	-	8.33	-	-
Pimelea humilis	**60**	53.85	41.67	41.67	33.33

Pimelea linifolia	**20**	7.69	16.67	-	16.67
Pimelea nivea	-	23.08	**33.33**	-	-
Plantago spp.	**40**	30.77	16.67	16.67	25
Poa spp.	90	76.92	**91.67**	83.33	83.33
Podolepis jaceoides	-	-	-	**8.33**	-
Pomaderris pilifera	-	-	-	**8.33**	-
Pteridium esculentum	**50**	46.15	33.33	8.33	8.33
Pultenaea daphnoides	-	15.38	-	**25**	**25**
Pultenaea gunnii	-	-	-	-	**8.33**
Pultenaea juniperina	**40**	15.38	8.33	-	25
Pultenaea pedunculata	-	-	-	**33.33**	8.33
Pultenaea stricta	**10**	-	-	-	-
Ranunculus lappaceus	10	7.69	8.33	**16.67**	-
Rhytidosperma procumbens	**20**	7.69	-	8.33	8.33
Schoenus apogon	30	23.08	**33.33**	-	**33.33**
Scleranthus biflorus	-	-	**8.33**	-	-
Senecio spp.	40	38.46	33.33	25	**66.67**
Stylidium graminifolium	**40**	7.69	25	-	-
Stypandra caespitosa	**10**	-	-	-	-
Tetratheca labillardierei	30	23.08	33.33	25	**41.67**
Tetratheca pilosa	**20**	15.38	-	-	-
Themeda triandra	20	30.77	8.33	**58.33**	33.33
Ulex europaeus	-	-	**8.33**	**8.33**	-
Viola hederacea	**10**	-	-	-	-
Wahlenbergia spp.	**50**	30.77	16.67	25	25

Table 8: Species percentage frequencies across the five TWINSPAN groups



Map 8: Sites coded according to TWINSPAN classification.

Category	Site numbers
TWINSPAN group 1	9, 42, 43, 32, 35, 37, 38, 20, 29, 30
TWINSPAN group 2	23, 24, 12, 13, 21, 22, 26, 27,28, 14, 33, 44, 45
TWINSPAN group 3	18, 19, 34, 11, 17, 25, 39, 40, 10, 15, 16, 36
TWINSPAN group 4	1, 2, 3, 8, 4, 5, 7, 31, 53, 52, 54, 55
TWINSPAN group 5	41, 50, 51, 46, 47, 48, 57, 58, 59, 6, 49, 56

Table 9: Sites grouped in each TWINSPAN category

Figure 12 shows the degree of similarity between the canopy-dominant and TWINSPAN classifications. The two classifications have a pattern of broad similarity, with some canopy classifications, such as heathy *E. amygdalina* and *E. tenuiramis/risdonii,* being found in only two or three TWINSPAN groups.

	Ave	Epu	Eamh	Eamg	Egv	Etr	
1	2	1	0	2	4	1	10
2	5	5	0	2	1	0	13
3	1	7	0	0	4	0	12
4	0	0	4	0	1	7	12
5	0	0	7	4	0	1	12
	8	13	11	8	10	9	

Figure 12: Comparing canopy and TWINSPAN classifications

Fuel Accumulation Curves

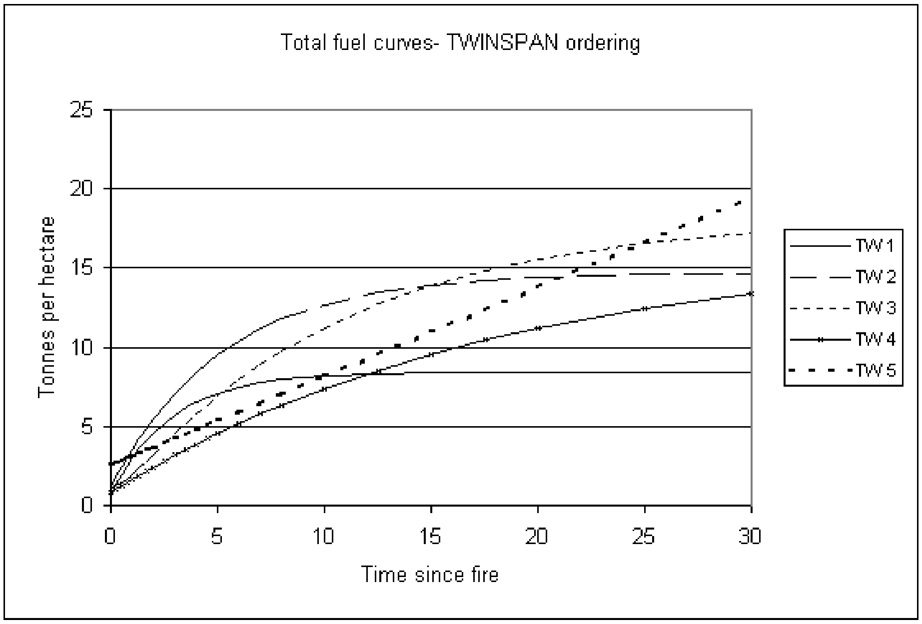


Figure 13: Fuel accumulation- total fuel

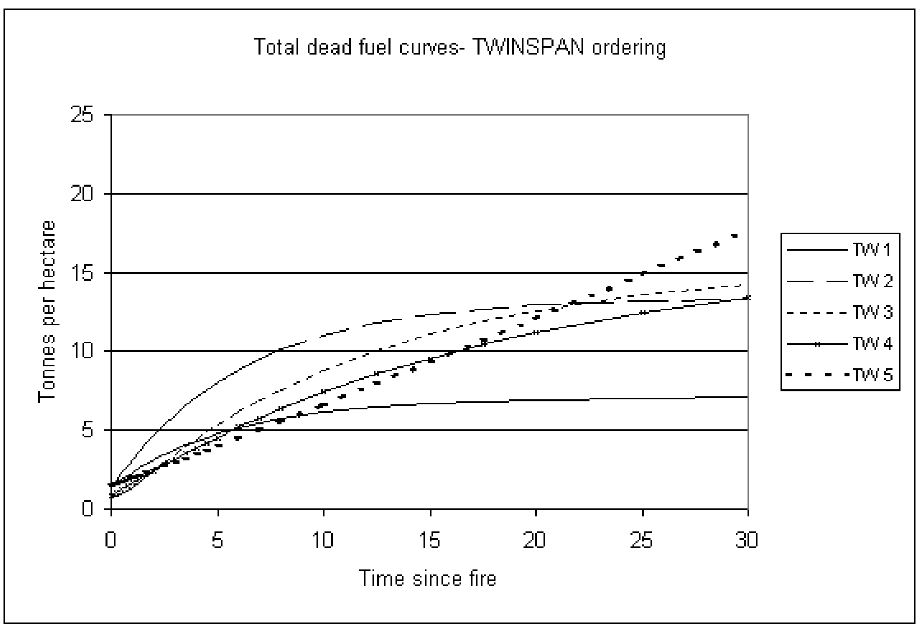


Figure 14: Fuel accumulation- total dead fuel

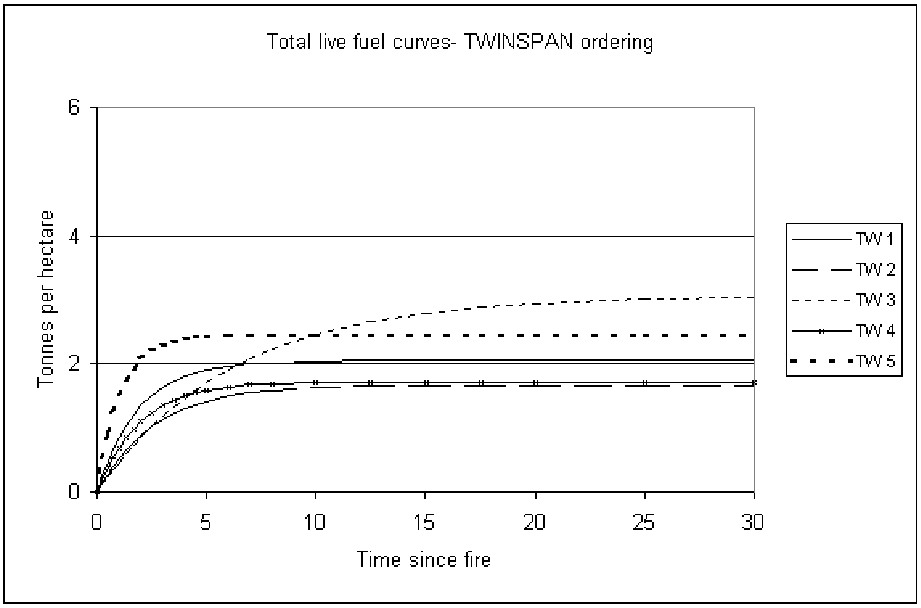


Figure 15: Fuel accumulation- total live fuel

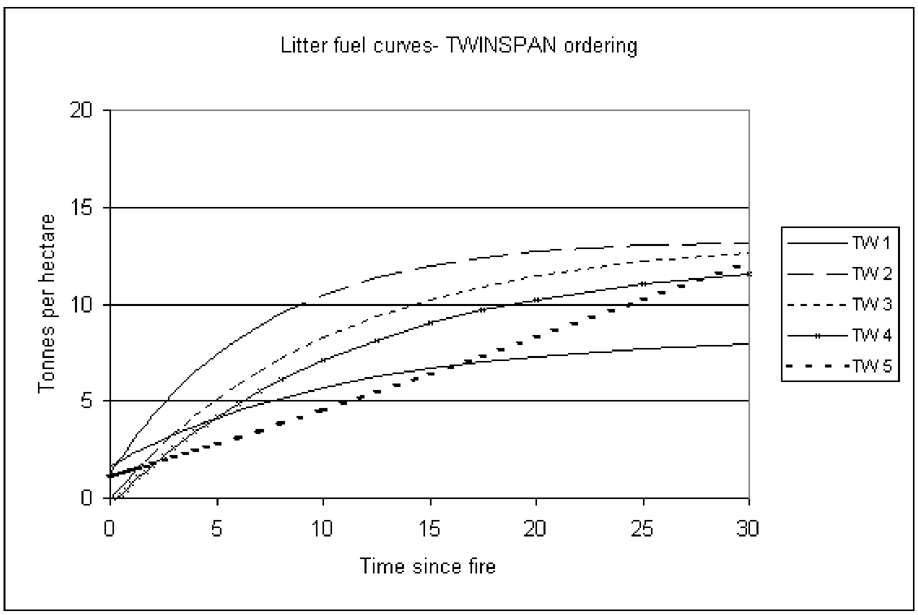


Figure 16: Fuel accumulation- litter fuel

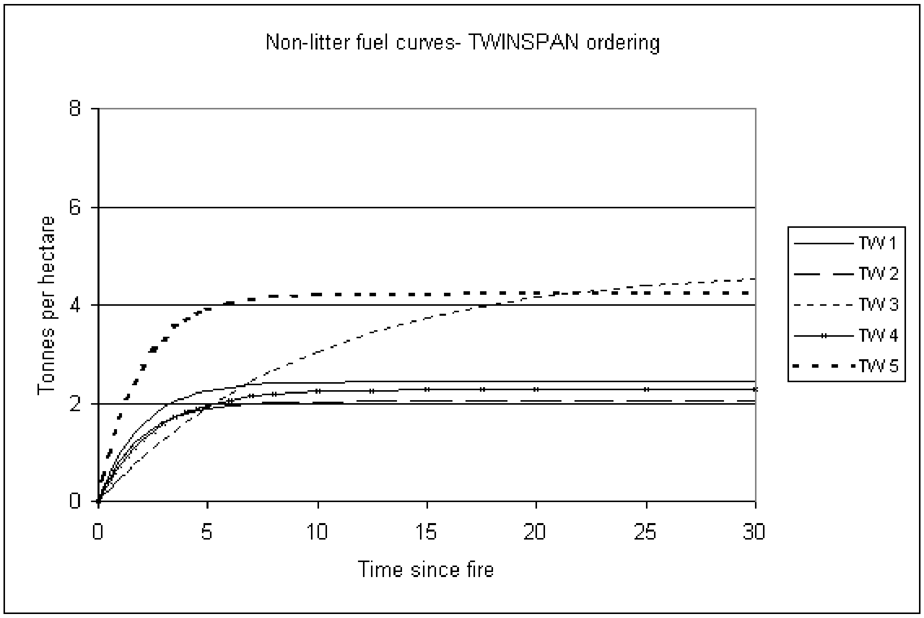


Figure 17: Fuel accumulation- non-litter fuel

Table 10 to Table 14 (below) show the equation coefficients for the accumulation curves for all sites as classified in TWINSPAN ordering.

TWINSPAN group 1

Fuel type	W_{ss}	k	a	c	r^2 value
Total	8.417	0.354	0.723	0.374	0.6
Live	2.049	0.533			0.23
Dead	7.092	0.18	1.37	0.18	0.64
Litter	8.44	0.09	1.641	0.09	0.62
Non-litter	2.444	0.51			0.24

Table 10: Equation coefficients for category TW1

TWINSPAN group 2

Fuel type	W_{ss}	k	a	c	r^2 value
Total	14.69	0.191	1.225	0.191	0.69
Live	1.66	0.378			0.55
Dead	13.38	0.162	1.343	0.1621	0.61
Litter	12.781	0.136	1.245	0.024	0.61
Non-litter	2.038	0.524			0.44

Table 11: Equation coefficients for category TW2

TWINSPAN group 3

Fuel type	W_{ss}	k	a	c	r^2 value
Total	18.327	0.095	1.175	1.363	0.97
Live	3.053	0.163			0.62
Dead	15.45	0.084	0.797	1.741	0.71
Litter	13.413	0.096	-0.066	0.096	0.95
Non-litter	4.759	0.102			0.64

Table 12: Equation coefficients for category TW3

TWINSPAN group 4

Fuel type	W_{ss}	k	a	c	r^2 value
Total	8.375	0.196	0.758	-0.77	0.7
Live	1.719	0.51			0.01
Dead	16.069	0.054	0.795	0.014	0.57
Litter	12.559	0.086	-0.347	0.086	0.56
Non-litter	2.276	0.394			0.02

Table 13: Equation coefficients for category TW4

TWINSPAN group 5

Fuel type	W_{ss}	k	a	c	r^2 value
Total	1500.014	0.0004	2.547	0.016	0.85
Live	2.432	0.956			0.39
Dead	1950.01	0.0003	1.449	0.07	0.81
Litter	1999.998	0.0002	1.061	0.068	0.71
Non-litter	4.216	0.516			0.43

Table 14: Equation coefficients for category TW5

Total fuel

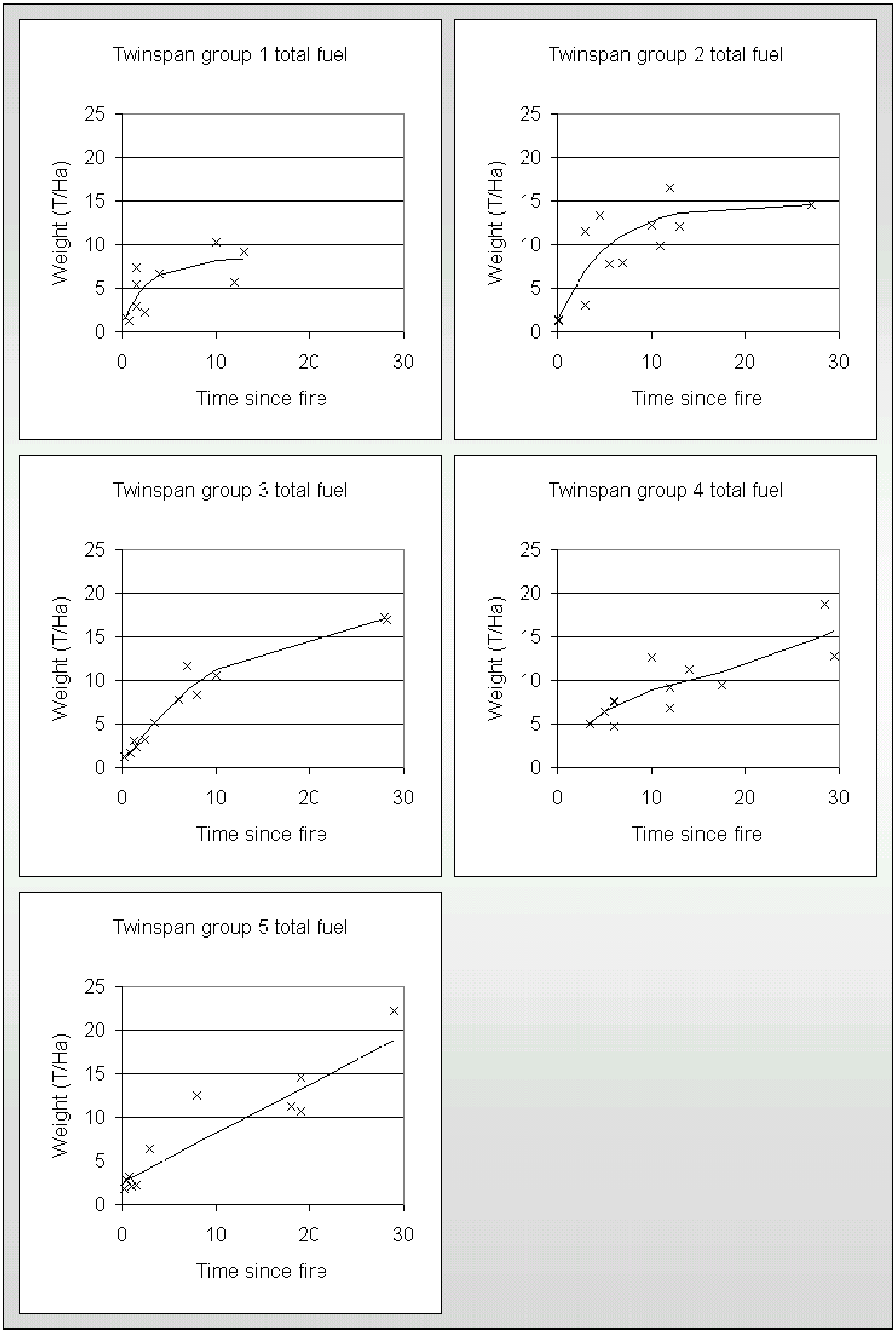


Figure 18: Fuel accumulation- total fuel

Total live fuel

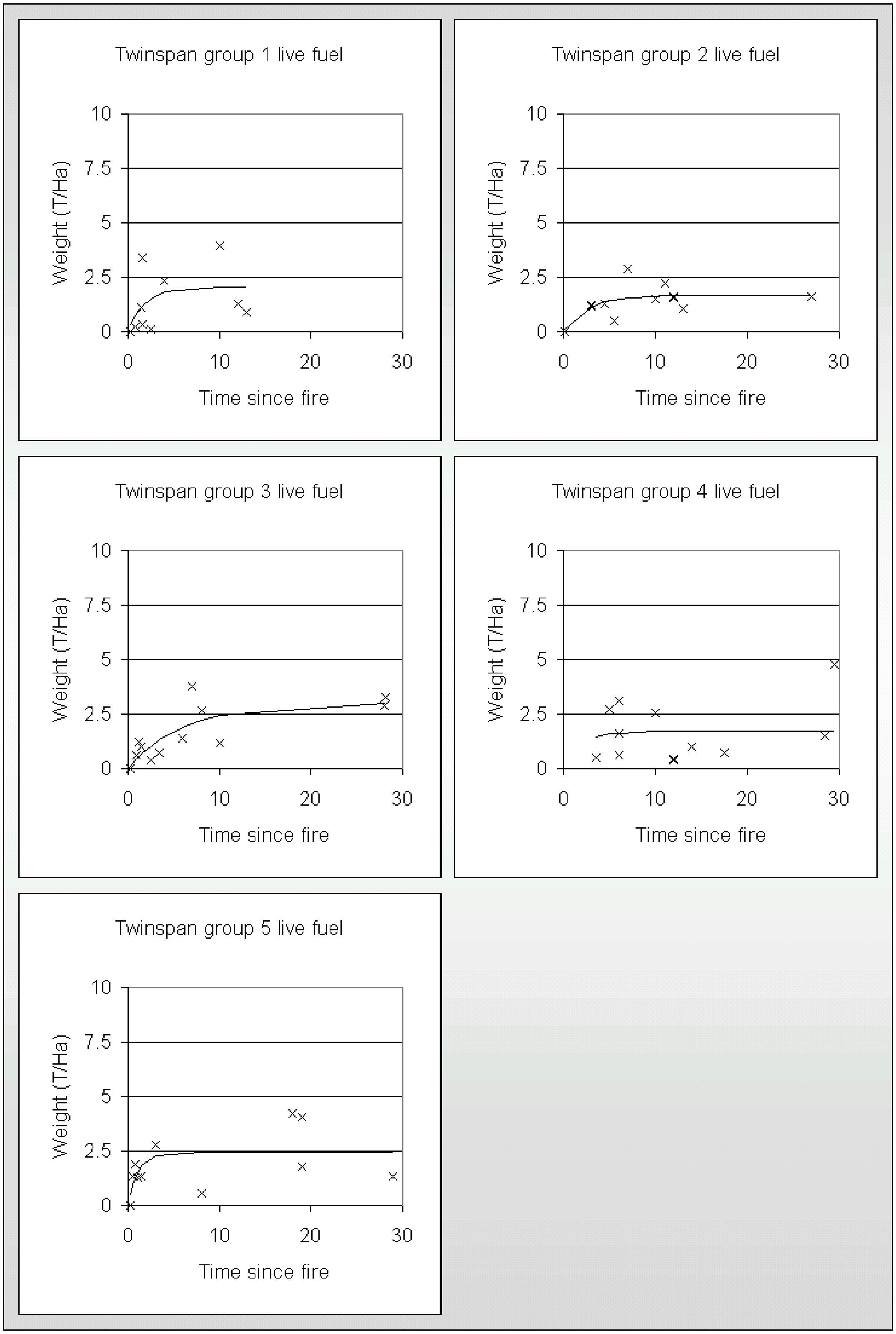


Figure 19: Fuel accumulation- live fuel

Total dead fuel

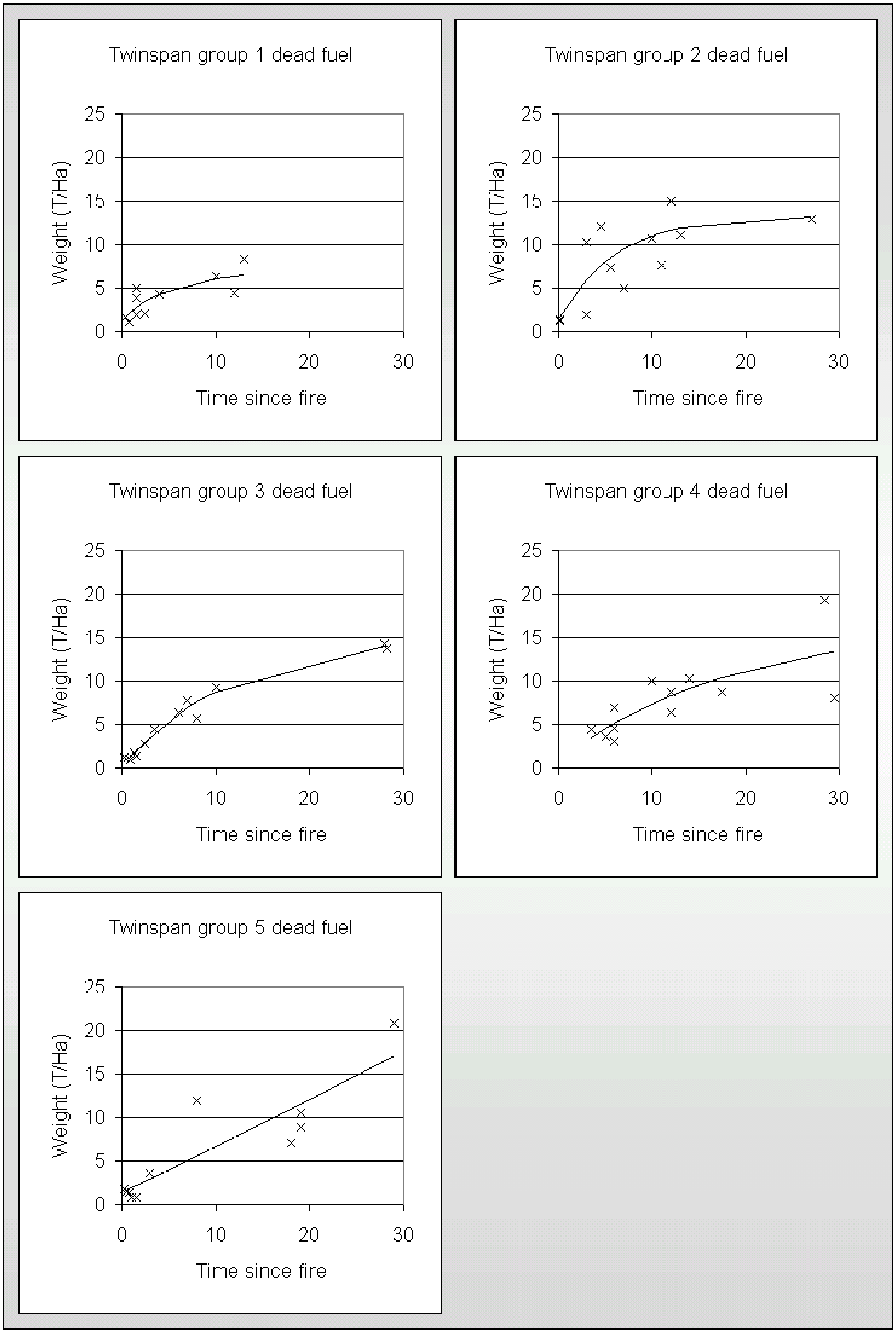


Figure 20: Fuel accumulation- dead fuel

Litter fuel

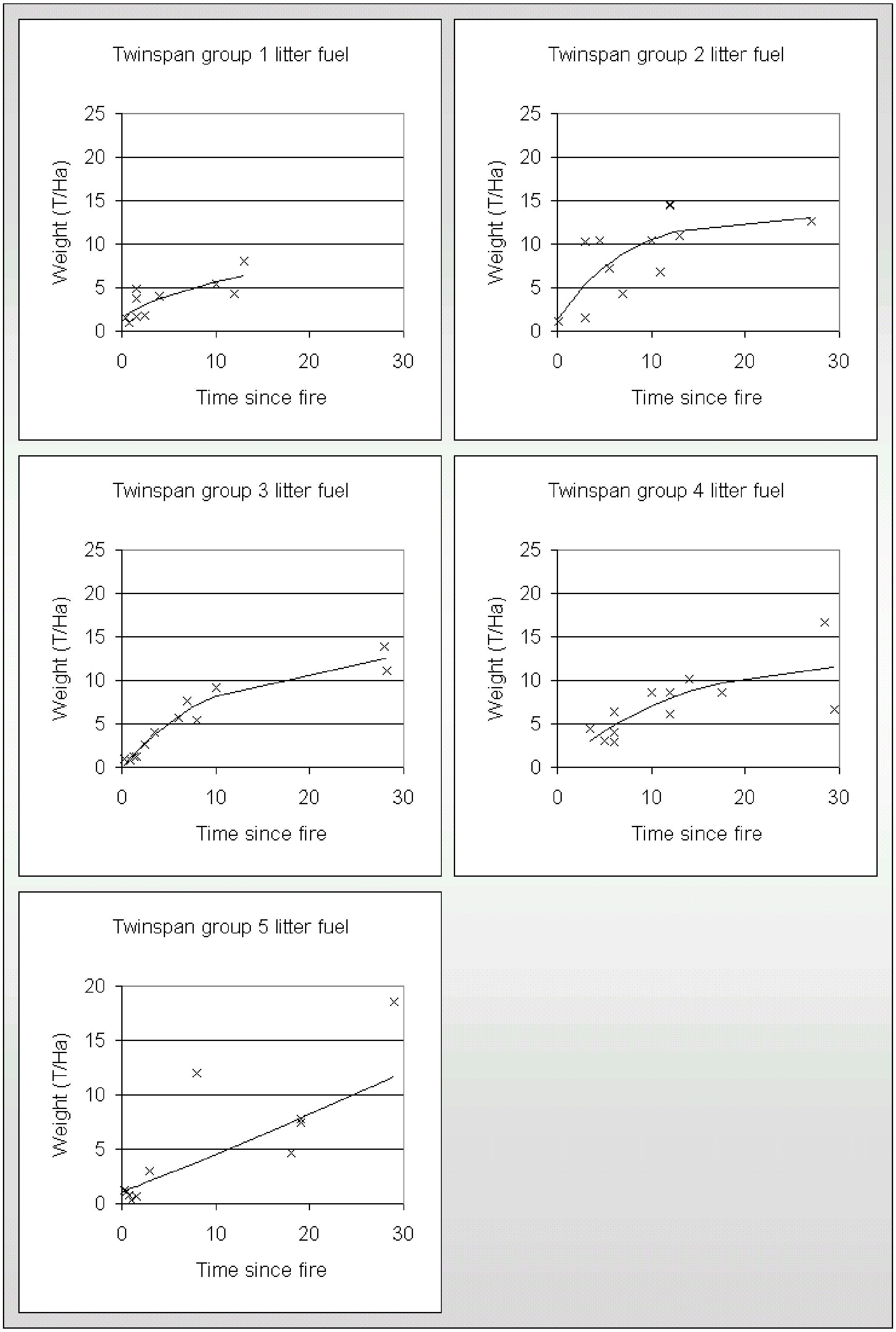


Figure 21: Fuel accumulation- litter fuel

Non-litter fuel

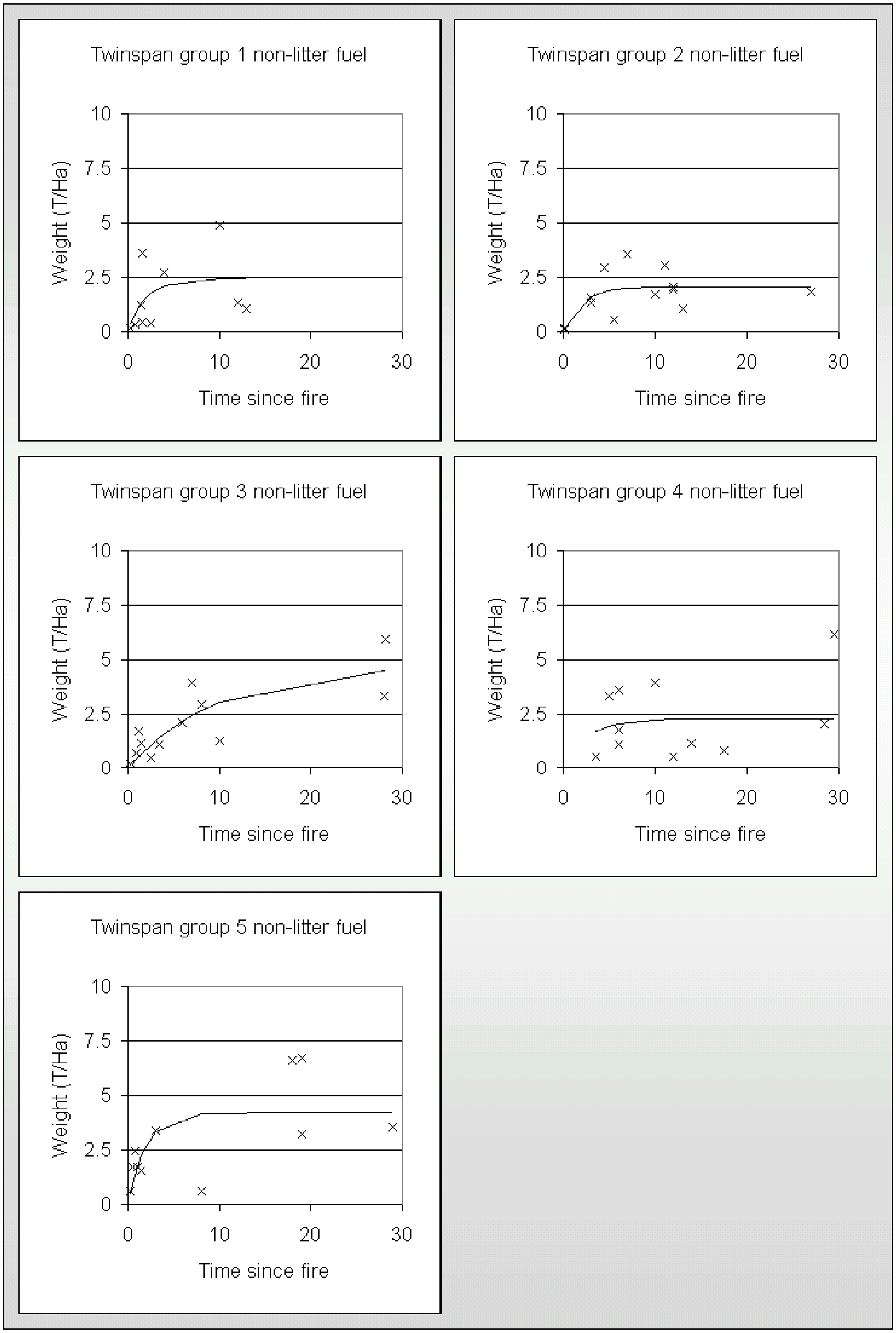


Figure 22: Fuel accumulation- non-litter fuel

The TWINSPAN class based fuel accumulation curves have a general appearance very similar to the canopy dominant species based curves. As for the canopy classes, there are two basic patterns of fuel accumulation. One pattern is of fast recovery and the reaching of a quasi-steady state level within twenty to thirty years, and the other a pattern of slow recovery and steady increase, with a suggested continual increase above the thirty-year mark. TWINSPAN total, total dead and litter fuel groups 3, 4 and 5 match the latter pattern whilst groups 1 and 2 match the former.

The different TWINSPAN fuel accumulation curves have r^2 values with a similar pattern to the equivalent fuel groups in canopy ordering, but with slightly reduced explanatory power. As before, the total fuel, dead fuel and litter fuel categories have the highest r^2 values, ranging from 0.55 to 0.95. Live and non-litter fuels are much more variable, ranging from 0.60+ in TWINSPAN group 3 down to 0.02 or below for group 4.

The ordering of sites according to TWINSPAN has resulted in a set of fuel accumulation curves that are very similar to those produced from the canopy ordering classification, but with statistically slightly less reliability. This lesser reliability is not of practical significance for field fuel load assessments, as it is within acceptable error margins, but it is nevertheless unexpected.

The source of the diminished reliability is most likely a result of the dynamics of the litter sources. The canopy species have been shown to be the major source of surface litter in dry sclerophyll sites (O'Connell 1991, Hart 1995). It is likely that while phytosociological association is more closely linked to site productivity and environmental conditions, it is the canopy dominant species as major litter source that requires more attention in fuel accumulation studies.

A second consideration in the use of phytosociological association as a classification method is that it is not a simple matter to determine this association in the field. The usefulness of site fuel assessments is limited if a site is not easily attributable to an existing fuel accumulation curve or category. Given this, there are a number of easily-recognised environmental indices that are known to have an effect on dry sclerophyll vegetation. The potential for using these formed the next path of investigation.

6. Fuel Accumulation as Predicted by Environmental Variables and Indices

Introduction

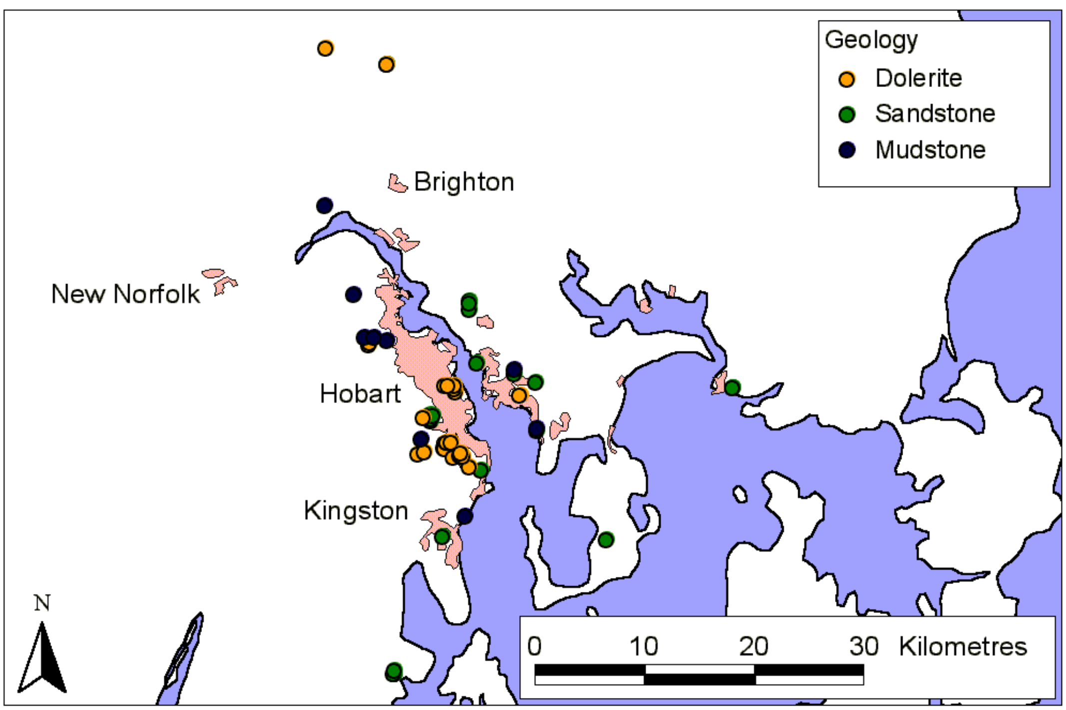
There is a range of environmental factors that are well known to have some controls on the structure or productivity of dry forests. Moisture, temperature and nutrient availability are among the critical factors likely to impact on fuel accumulation, affecting both accession and decomposition rates (Attiwill *et al.* 1978, Birk 1979a, Clarke and Allaway 1996). This indicated that classifying sites for fuel accumulation curves according to controlling environmental factors might be as valid as classifying according to canopy dominant or vegetation community.

Methods

Three classification schemes were chosen, based on geology type, annual average rainfall and tree density. Hogg and Kirkpatrick (1974) indicate geology plays a role in the nutrient levels of the soils and that this has a recognisable impact on vegetation communities in the southeast of Tasmania. Similarly, Duncan and Brown (1985) suggest moisture availability plays a role in the distribution of dry vegetation communities in Tasmania. Laffan (1998) suggests mean annual rainfall is a critical determinant of forest type, but this can be strongly modified by topographical and soil properties. Tree density was chosen as the third scheme based on observations of the proportions of litter and non-litter fuels in the sites sampled. As litter was often over 80% of the total fuel load and virtually all of the litter is derived from the canopy and larger understorey species, the density of small and large trees was considered likely to have an effect on fuel loads.

Geology Ordering

All sites sampled were ordered into geological substrate-based classes. Given that throughout the study area there is a clear link between certain canopy dominant species and geology types, a series of categories were collated to best investigate the phenomenon. These were: *Eucalyptus* on dolerite (EoD), *Eucalyptus* on sand and sandstone (EoS), *Allocasuarina* on dolerite (AoD), *Eucalyptus* on mudstone (EoM) and total vegetation on dolerite (ToD). These new categories were modelled on the same equation form as the canopy and TWINSPAN classification schemes. The categories *Allocasuarina* on dolerite and *Eucalyptus* on mudstone were found to be identical to the *A. verticillata* and *E. tenuiramis* canopy classes respectively.



Map 9: Sites coded according to geology type.

The geology ordering and canopy ordering schemes show a marked degree of similarity. Figure 23 shows that ordering sites by geology types only splits up one of the canopy ordering groups- *Eucalyptus globulus/viminalis*, but other groups either remain intact (*E. tenuiramis/risdonii*) or are grouped into a larger unit. The link between geological substrate and dominant eucalypt species is well understood (Duncan and Brown 1985, Williams 1996), so the correlation shown here between the two schemes was expected.

	Ave	Epu	Eamh	Eamg	Egv	Etr	
Dolerite	8	13	0	0	6	0	27
Mudstone	0	0	0	0	0	9	9
Sandstone	0	0	11	8	4	0	23
	8	13	11	8	10	9	

Figure 23: Comparing sites by canopy and geology ordering schemes

Geology	Site numbers
Dolerite	10, 11, 12, 13, 14, 15, 16, 17, 18, 19, 20, 21, 22, 23, 24, 25, 26, 27, 28, 29, 30, 32, 33, 35, 36, 39, 40
Sandstone	31, 34, 37, 38, 41, 42, 43, 44, 45, 46, 47, 48, 49, 50, 51, 52, 53, 54, 55, 56, 57, 58, 59
Mudstone	1, 2, 3, 4, 5, 6, 7, 8, 9

Table 15: Sites grouped in each geology type category

Fuel Accumulation Curves

Figure 24: Fuel accumulation- Total fuel

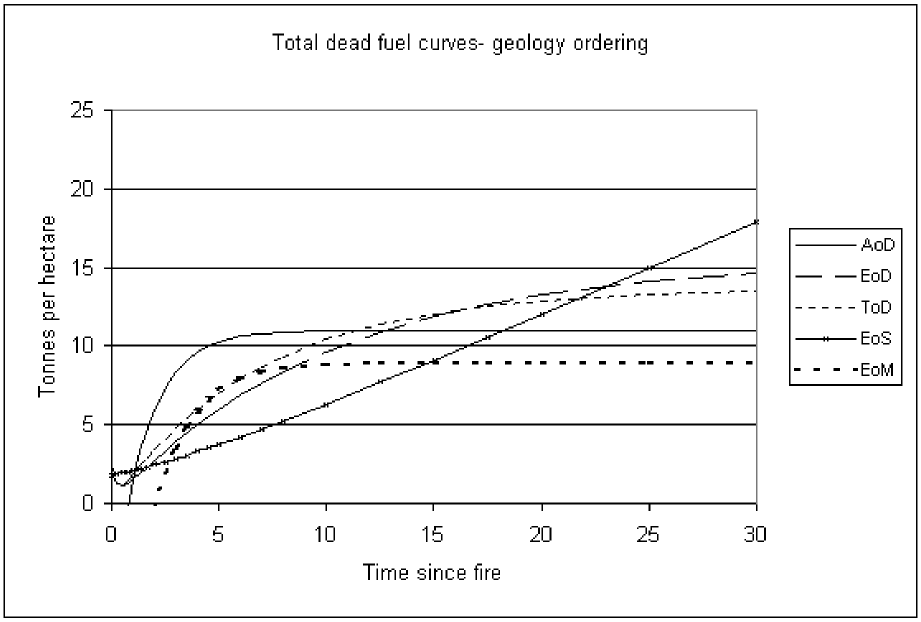


Figure 25: Fuel accumulation- dead fuel

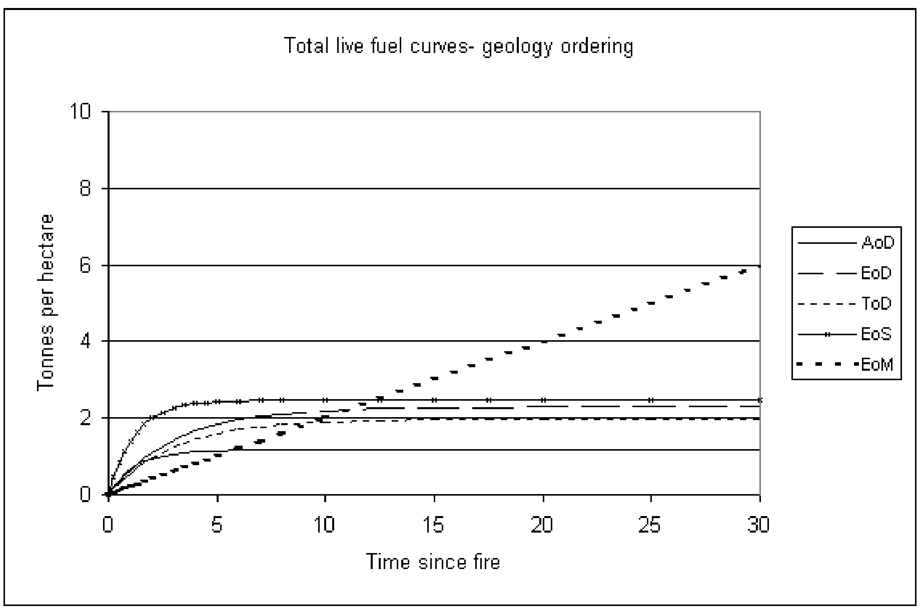


Figure 26: Fuel accumulation- live fuel

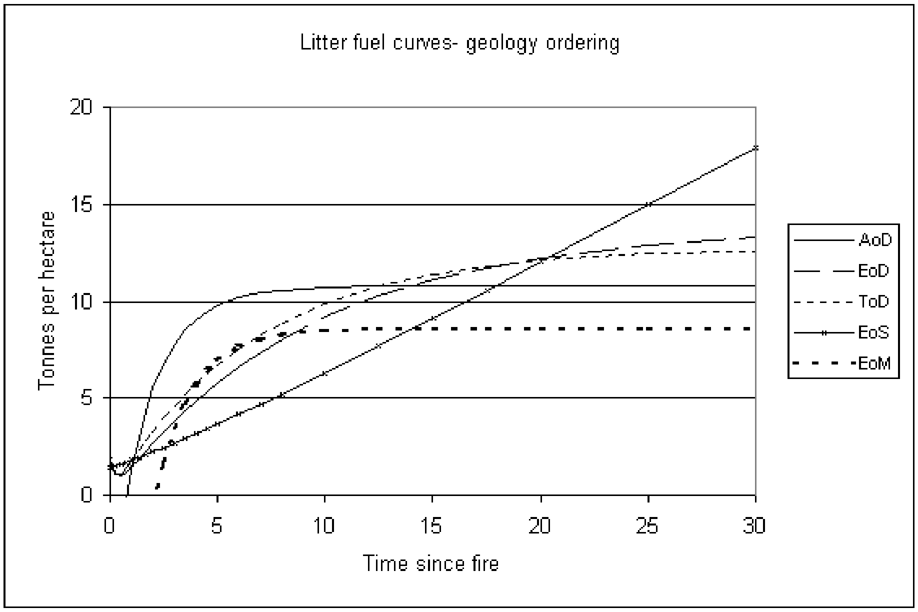


Figure 27: Fuel accumulation- litter fuel

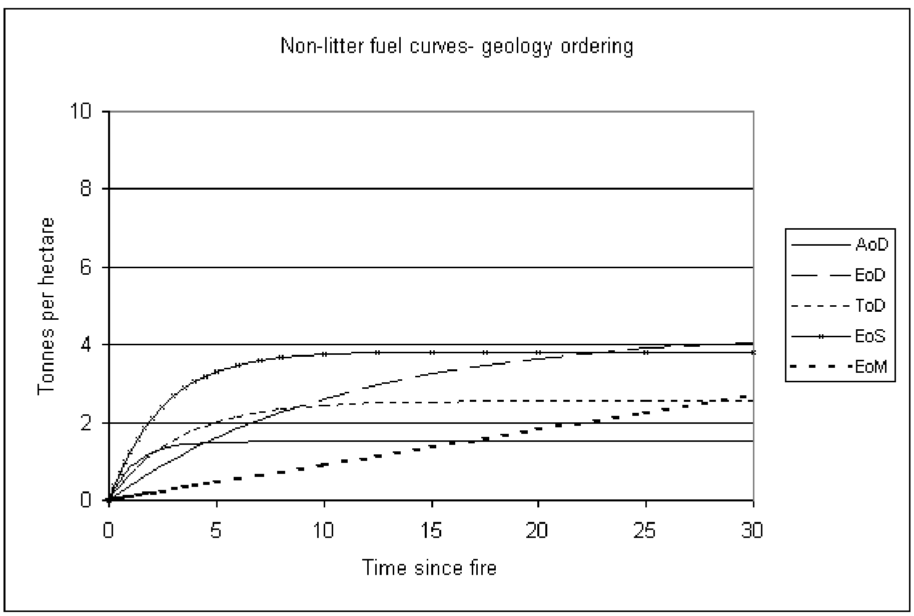


Figure 28: Fuel accumulation- non-litter fuel

Table 16 to Table 18 (below) shows the equation coefficients for the accumulation curves of all sites as classified in geology type ordering.

Eucalypts on dolerite

Fuel type	W_{ss}	k	a	c	r^2 value
Total	17.994	0.1071	1.4817	2.07	0.91
Live	2.286	0.321			0.59
Dead	15.469	0.098	2.011	3.278	0.87
Litter	13.789	0.109	1.866	3.89	0.84
Non-litter	4.334	0.093			0.56

Table 16: Equation coefficients for category EoD

Eucalypts on sandstone

Fuel type	W_{ss}	k	a	c	r^2 value
Total	377.59	0.001	3.251	-0.038	0.86
Live	2.465	0.821			0.33
Dead	1999.9	0.0003	1.802	0.174	0.87
Litter	1.998.9	0.0003	1.421	0.158	0.82
Non-litter	3.814	0.401			0.34

Table 17: Equation coefficients for category EoS

Total vegetation on dolerite

Fuel type	W_{ss}	k	a	c	r^2 value
Total	15.645	0.156	2.192	4.808	0.8
Live	1.972	0.33			0.48
Dead	15.469	0.098	2.011	3.278	0.79
Litter	12.73	0.15	2.136	5.217	0.79
Non-litter	2.563	0.308			0.41

Table 18: Equation coefficients for category ToD

Total fuel

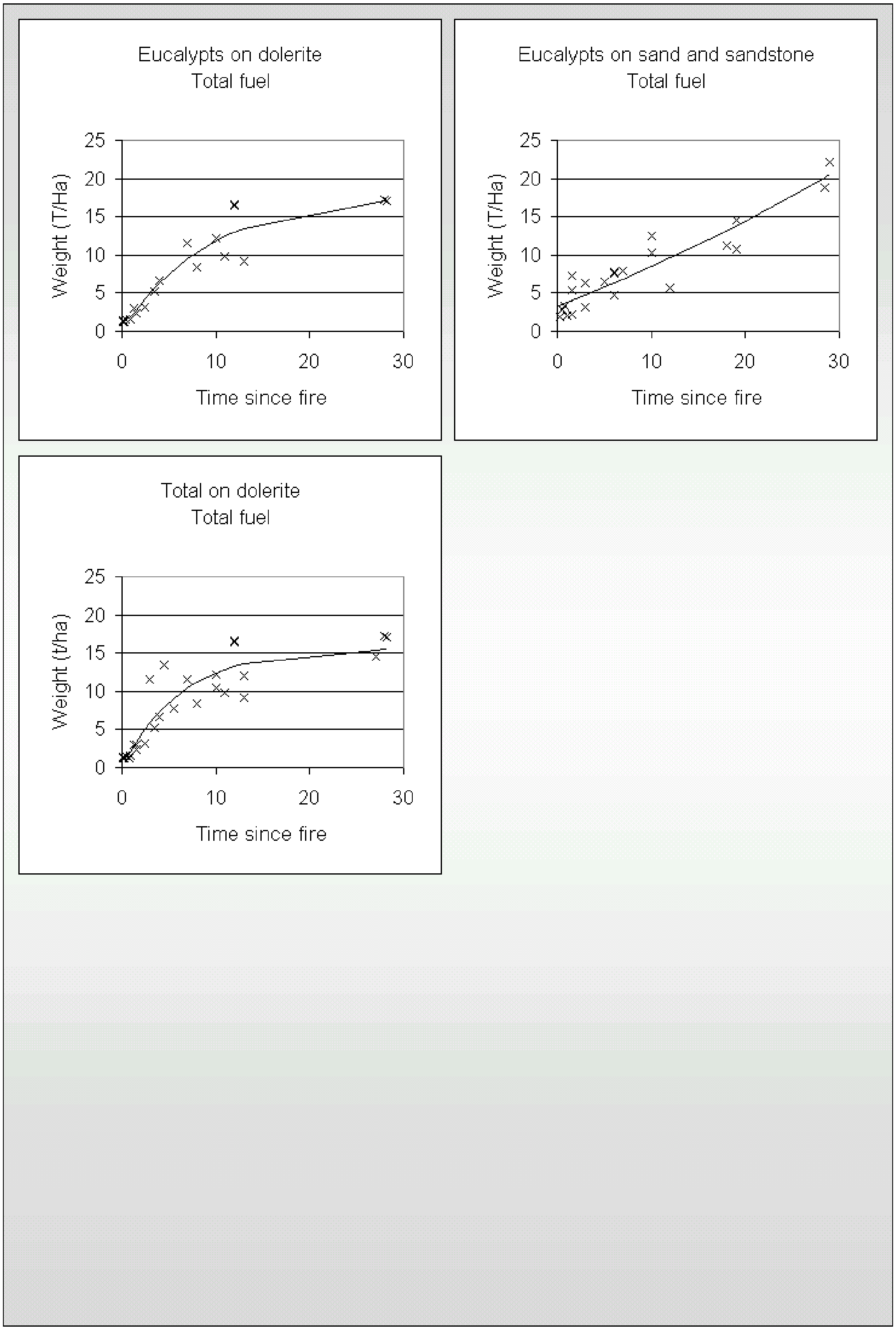


Figure 29: Fuel accumulation- total fuel

Total live fuel

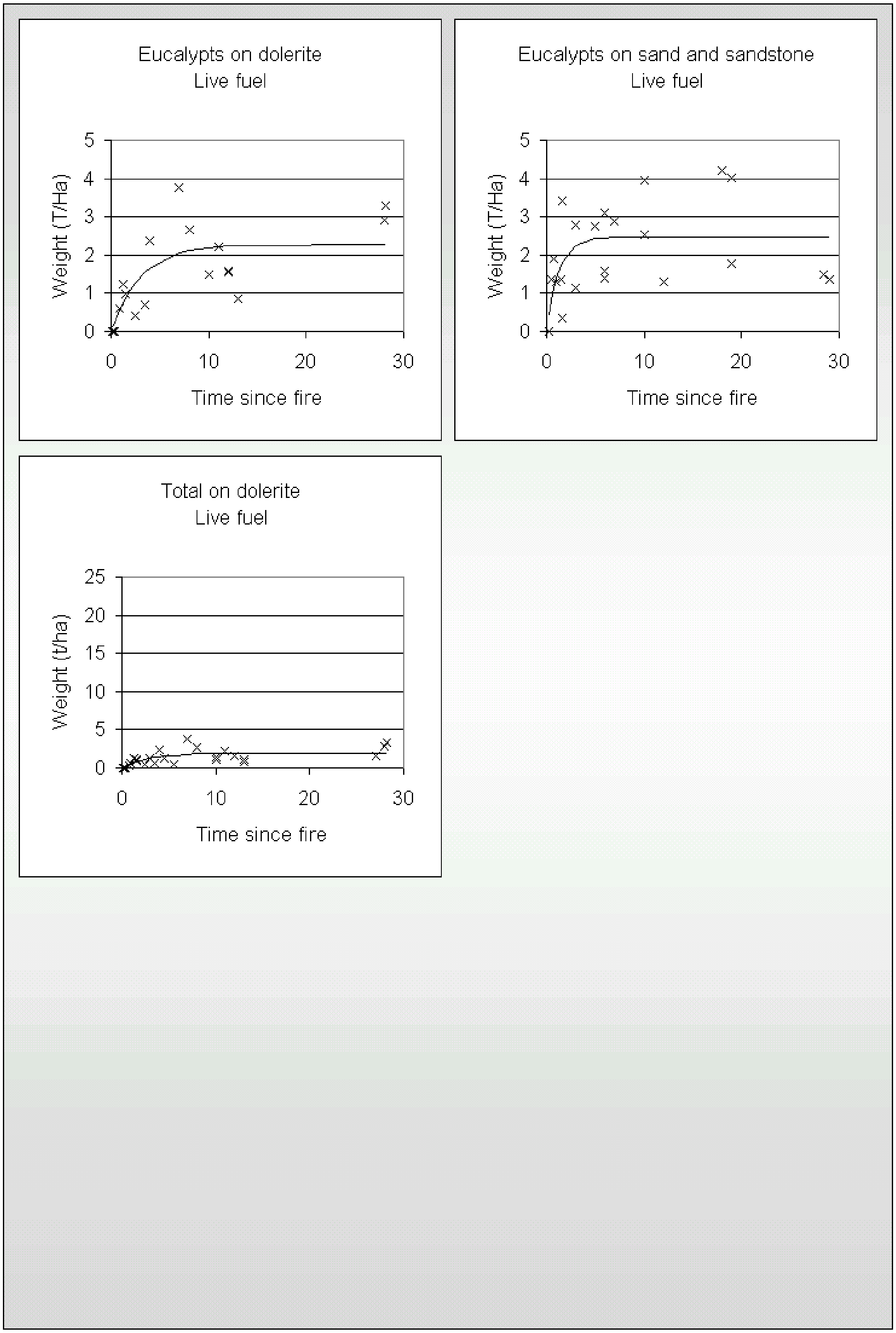


Figure 30: Fuel accumulation- total live fuel

Total dead fuel

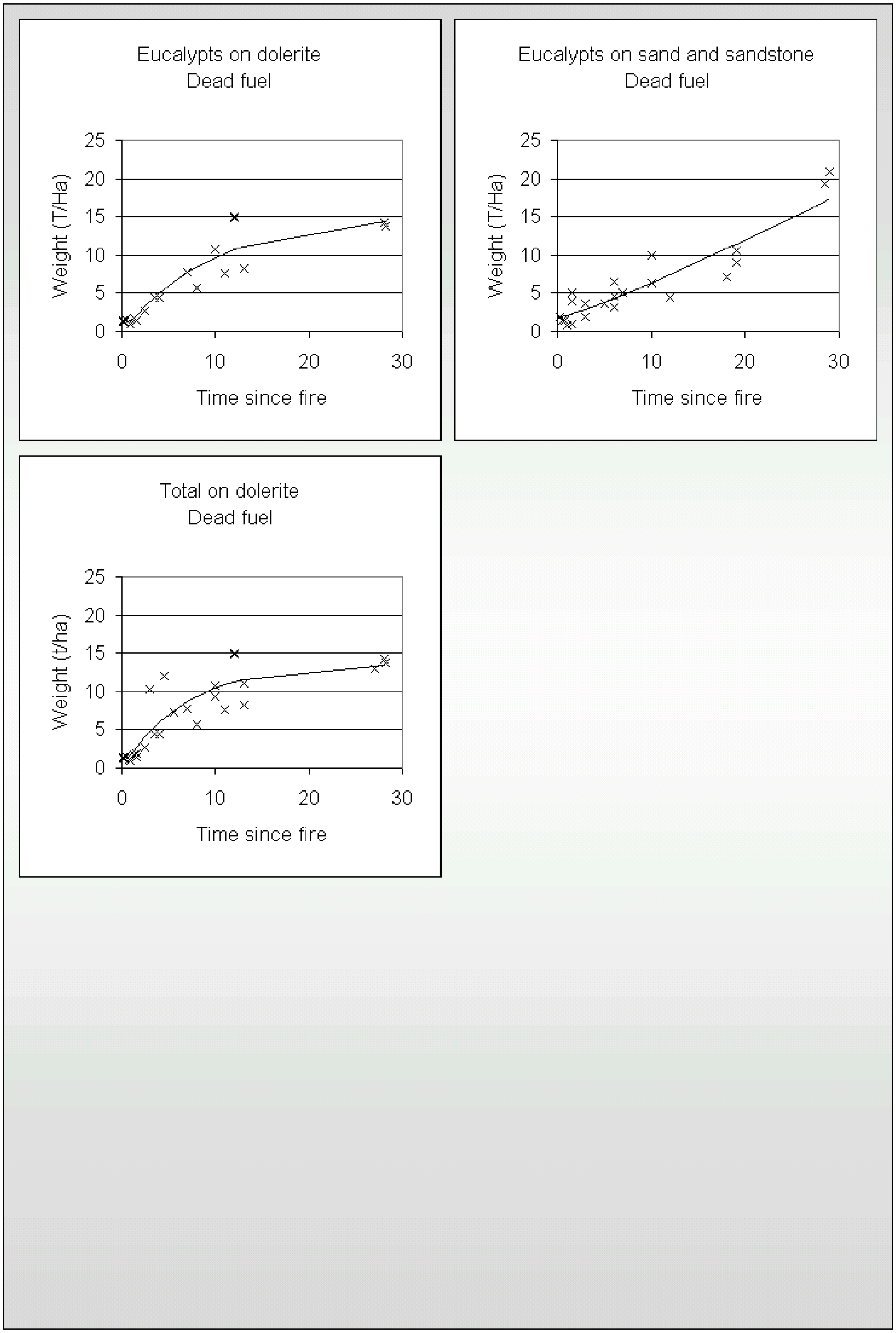


Figure 31: Fuel accumulation- total dead fuel

Litter fuel

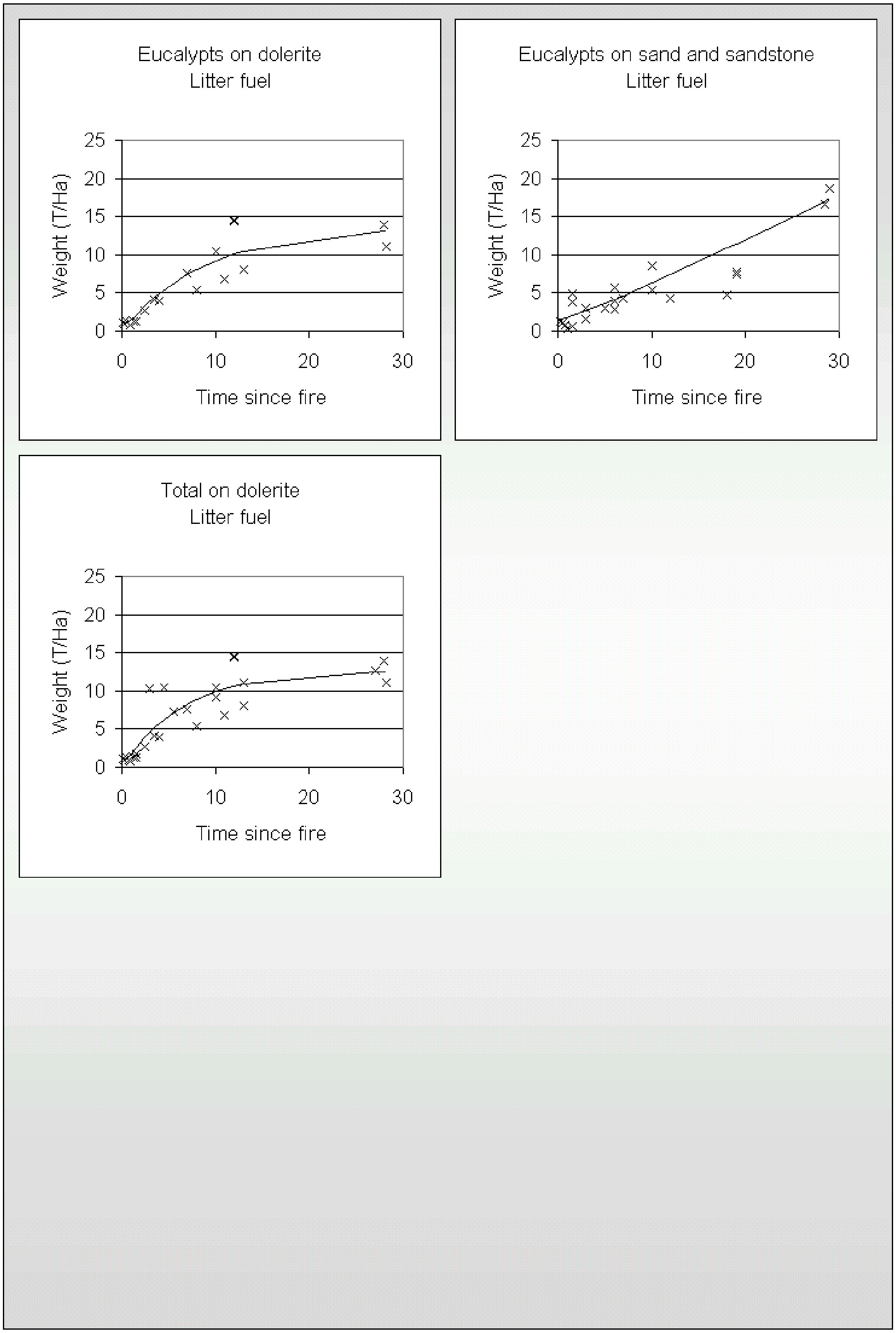


Figure 32: Fuel accumulation- litter fuel

Non-litter fuel

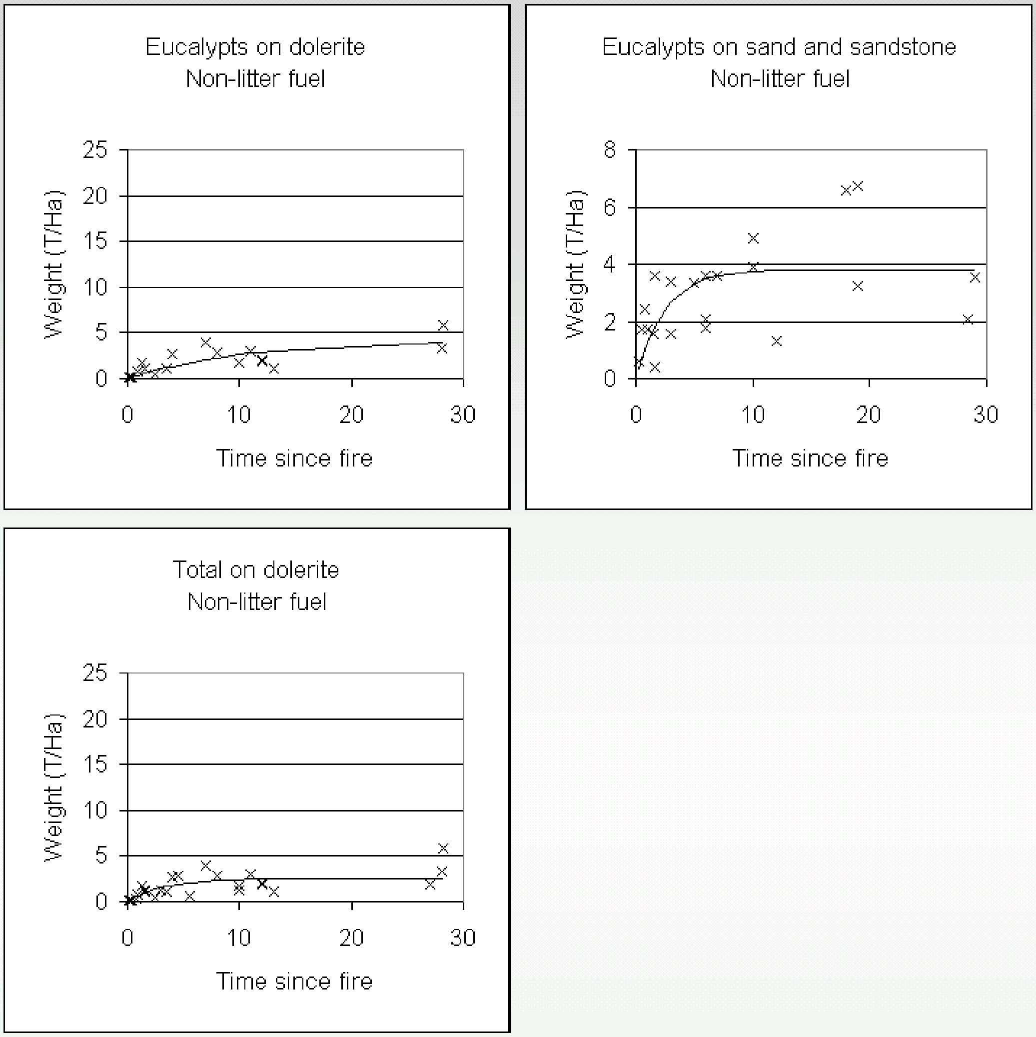


Figure 33: Fuel accumulation- non-litter fuel

Classes EoD and ToD of the geology ordering both reach 10 t/ha in less than 10 years and 15 t/ha in less than 20 years, whereas EoS exhibits a much slower initial buildup. This may be connected with the different nutrient levels in the soils based on the two different substrates. The more nutrient-rich dolerite soils (Laffan 1998) could be permitting a quicker post-fire vegetation recovery and thus a quicker return of the litter layer, trapping moisture and providing a suitable habitat for leaf-litter decomposer organisms.

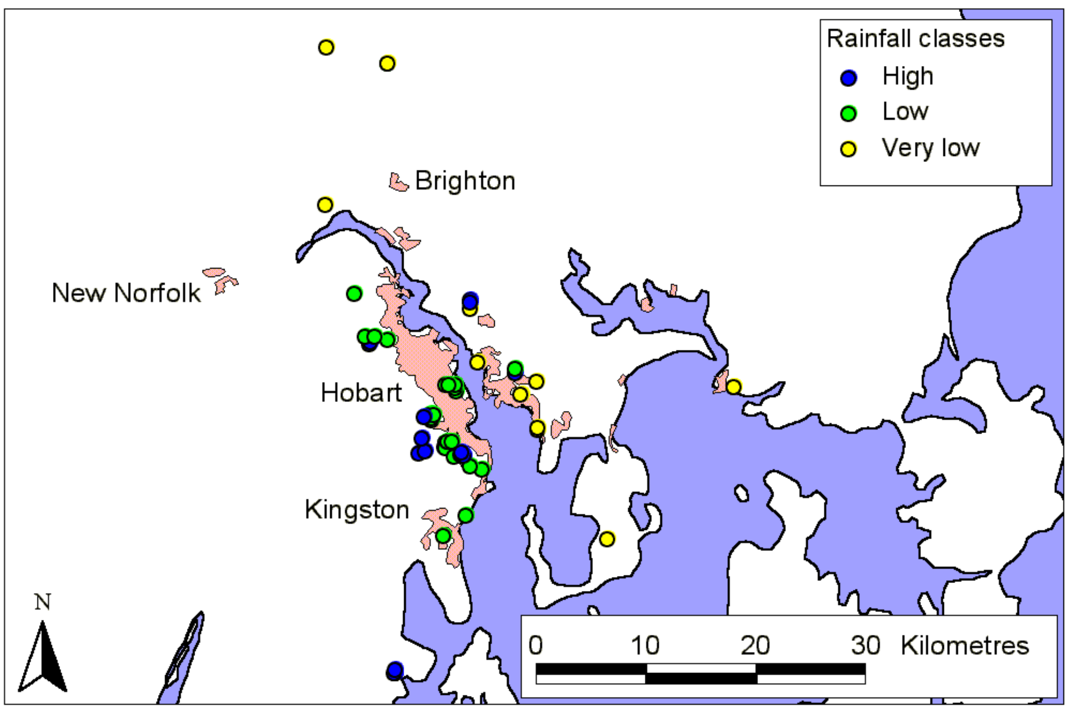
Fuel curves based on geology ordering exhibit r^2 values very similar to those for the corresponding class in the canopy fuel curves. Explanatory power seems to be better than the TWINSPAN fuel curves, particularly in the live and non-litter categories. These categories have r^2 values in the order of 0.35 to 0.59. This increase in explanatory power is likely to be connected to the close relationship between eucalypt species and geological type.

The validity of ordering sites by geology is of a similar reliability to the canopy class ordering, indicating a greater usefulness than the phyto-sociological ordering. Geology type ordering has the advantage of being easily determined in the field or remotely from geology map data. There are detailed geology maps available for the entirety of the study area, making remote fuel weight prediction techniques a simple matter.

Rainfall Class Ordering

All sites sampled were also re-ordered into three rainfall classes based on Davies (1988). Very low rainfall (VLR) included all sites with a mean annual rainfall of 599 mm or less. Low rainfall (LR) is comprised of all sites with an annual rainfall of between 600 and 699 mm. High rainfall (HR) includes the remaining sites, all of which have an annual rainfall of 700 mm or higher. Sites are shown in rainfall classes on Map 10.

Figure 34 shows the relationship between the canopy dominant and rainfall class ordering schemes. There is essentially a random pattern between the two schemes, although all *Allocasuarina verticillata* sites are found in the Low Rainfall category.



Map 10: Sites coded according to rainfall class.

	Ave	Epu	Eamh	Eamg	Egv	Etr	
High	0	7	2	4	4	1	18
Low	8	5	4	2	3	6	28
Very low	0	1	5	2	3	2	13
	8	13	11	8	10	9	

Figure 34: Comparing sites by canopy and rainfall schemes

Rainfall class	Site numbers
High	6, 10, 12, 13, 15, 16, 21, 22, 33, 36, 37, 38, 42, 46, 47, 48, 51, 59
Low	1, 2, 3, 5, 8, 9, 11, 14, 18, 19, 20, 23, 24, 25, 26, 27, 28, 29, 30, 34, 39, 40, 41, 43, 49, 50, 52, 55
Very low	4, 7, 17, 31, 32, 35, 44, 45, 53, 54, 56, 57, 58

Table 19: Sites grouped in each rainfall class category

Fuel Accumulation Curves

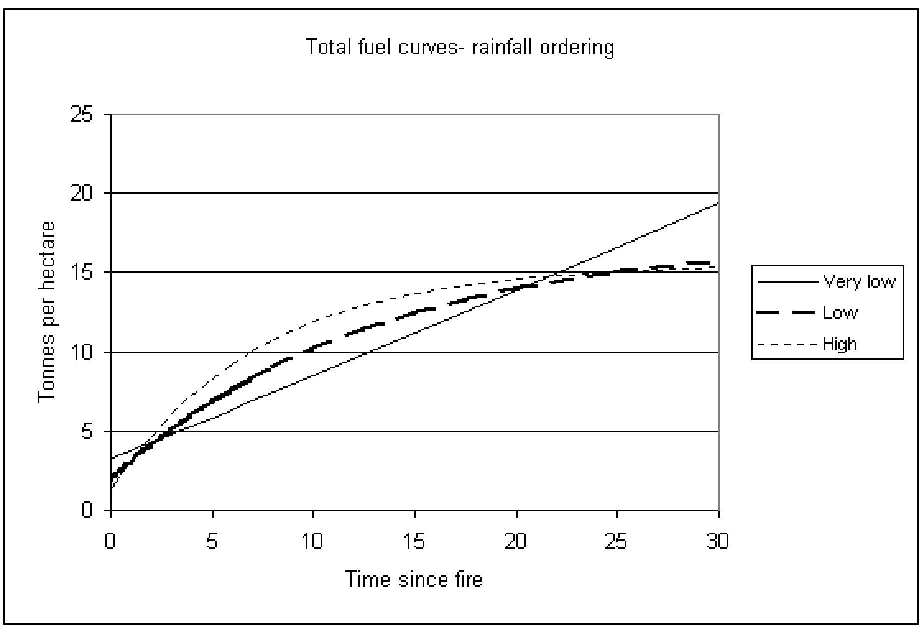


Figure 35: Fuel accumulation- total fuel

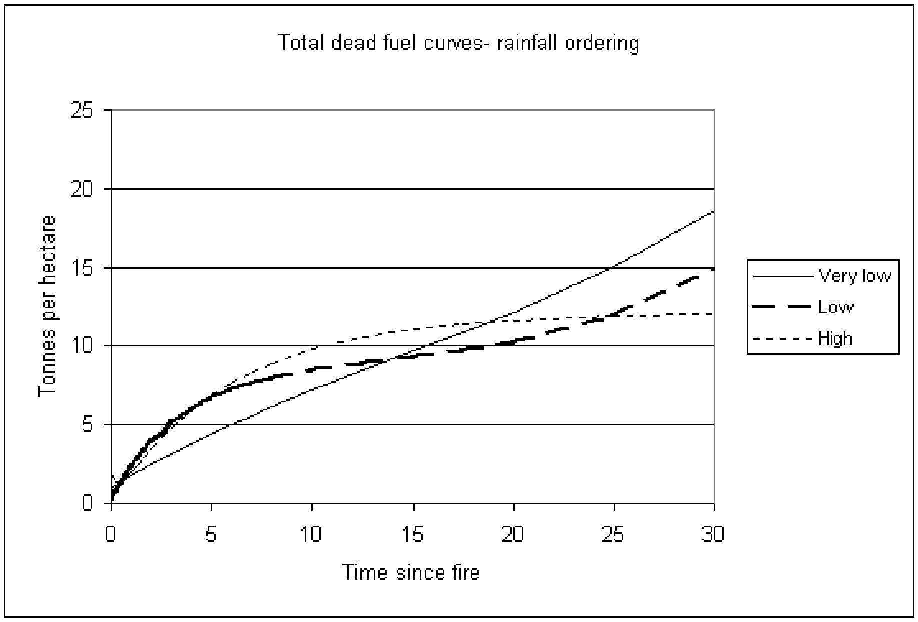


Figure 36: Fuel accumulation- total dead fuel

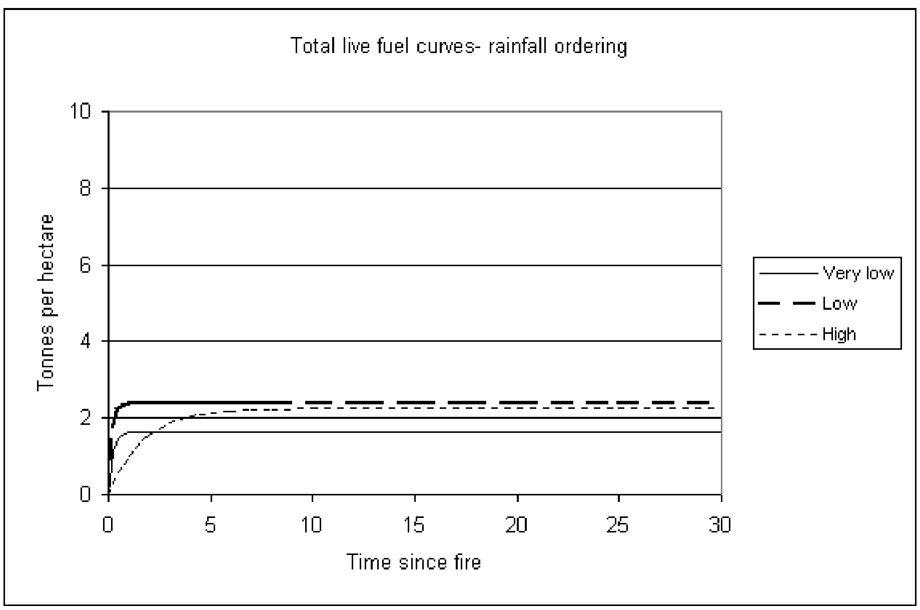


Figure 37: Fuel accumulation- total live fuel

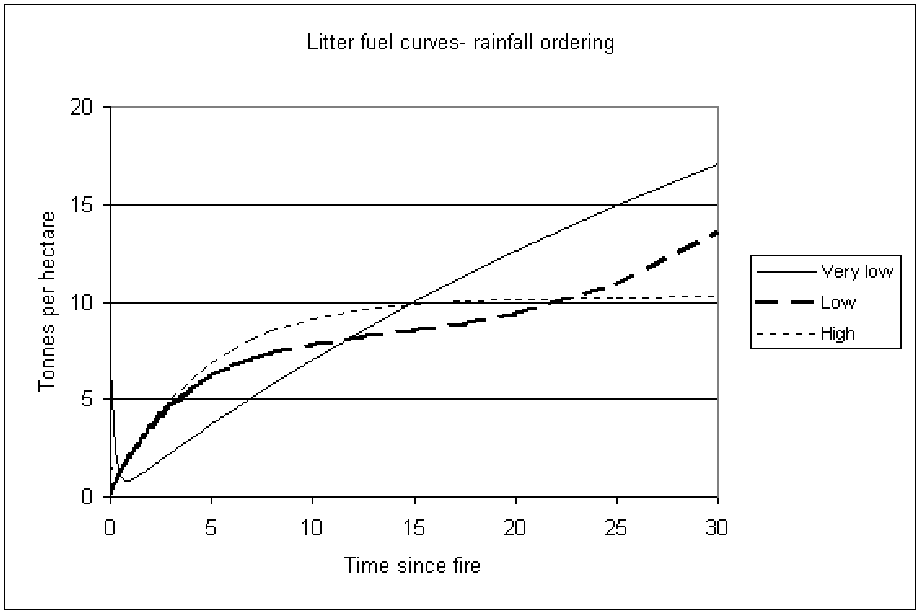


Figure 38: Fuel accumulation- litter fuel

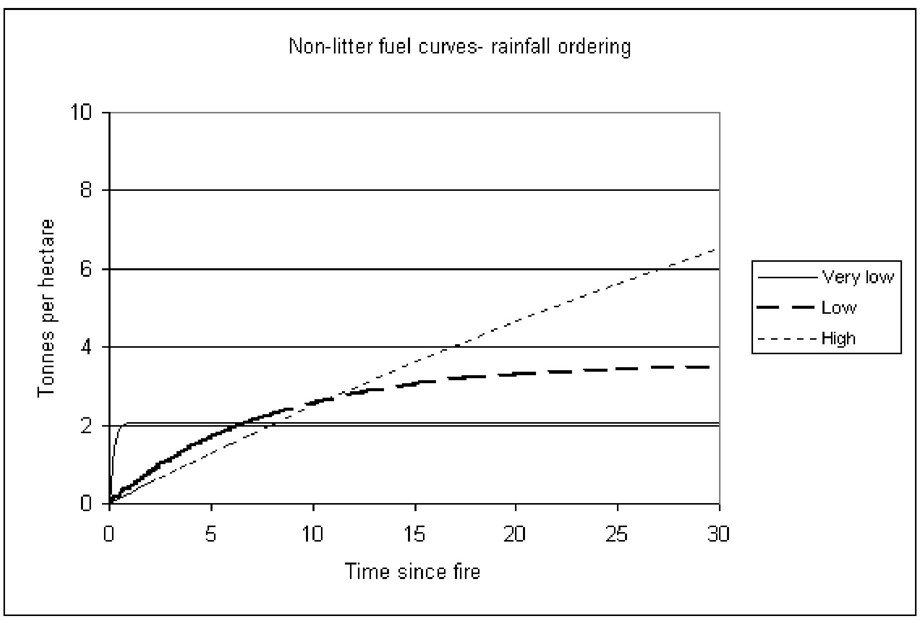


Figure 39: Fuel accumulation- non-litter fuel

Table 20 to Table 22 (below) shows the equation coefficients for the accumulation curves of all sites as ordered in rainfall classes.

Very low rainfall

Fuel type	W_{ss}	k	a	c	r^2 value
Total	1205.47	0.0005	3.243	0.027	0.93
Live	1.645	4.623			0.04
Dead	10.143	0.069	1.003	-0.076	0.95
Litter	34.312	0.023	6.71	4.593	0.95
Non-litter	2.071	4.85			0.04

Table 20: Equation coefficients for category VLR

Low rainfall

Fuel type	W_{ss}	k	a	c	r^2 value
Total	17.298	0.077	1.892	0.77	0.74
Live	2.399	5.35			0.01
Dead	8.393	0.288	0.164	-0.123	0.69
Litter	7.792	0.287	0.123	-0.129	0.67
Non-litter	3.598	0.126			0.33

Table 21: Equation coefficients for category LR

High rainfall

Fuel type	W_{ss}	k	a	c	r^2 value
Total	15.574	0.135	1.339	0.135	0.78
Live	2.246	0.59			0.4
Dead	12.063	0.168	1.872	2.963	0.69
Litter	10.274	0.221	1.676	4.941	0.64
Non-litter	17.987	0.015			0.47

Table 22: Equation coefficients for category HR

Total fuel

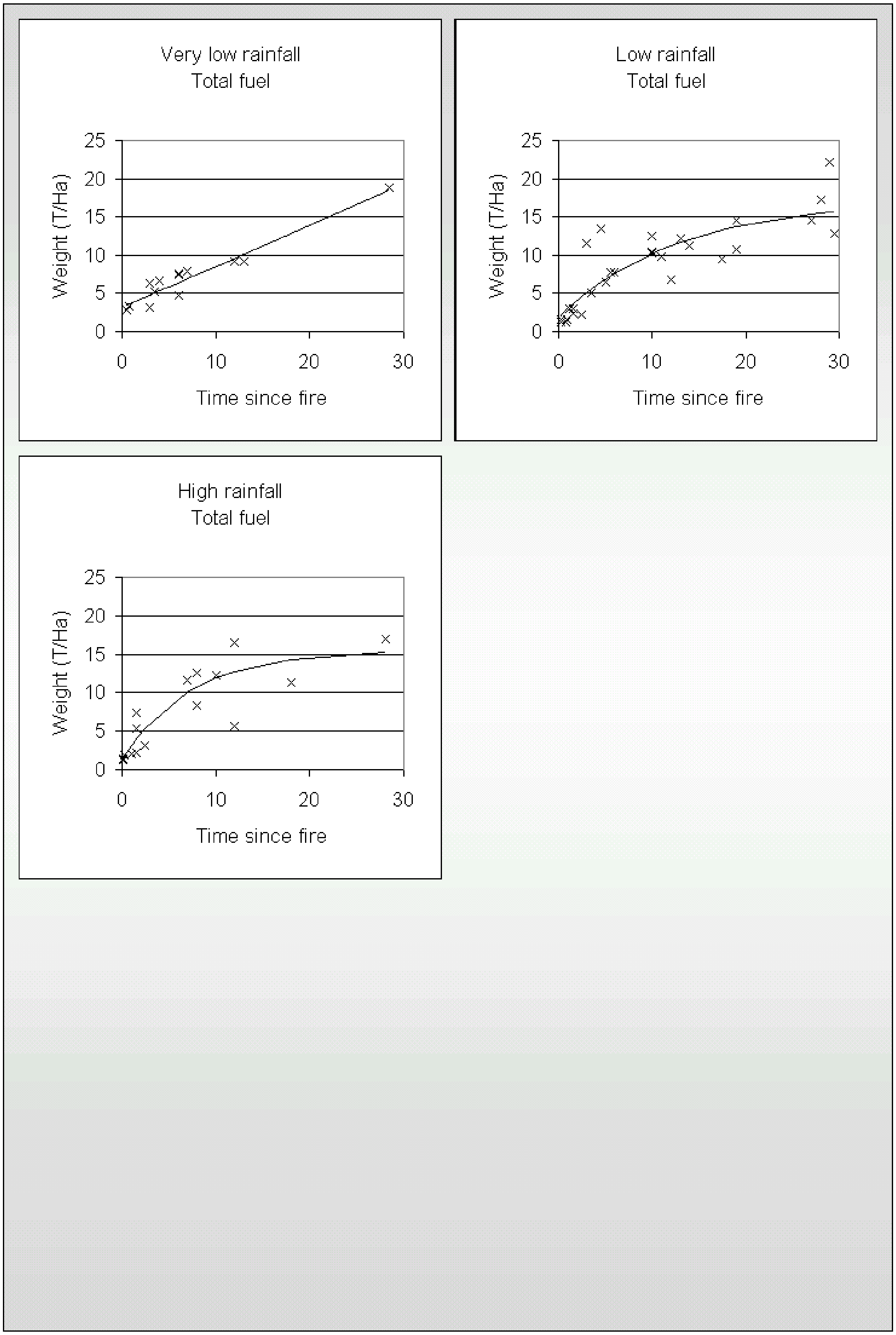


Figure 40: Fuel accumulation- total fuel

Total live fuel

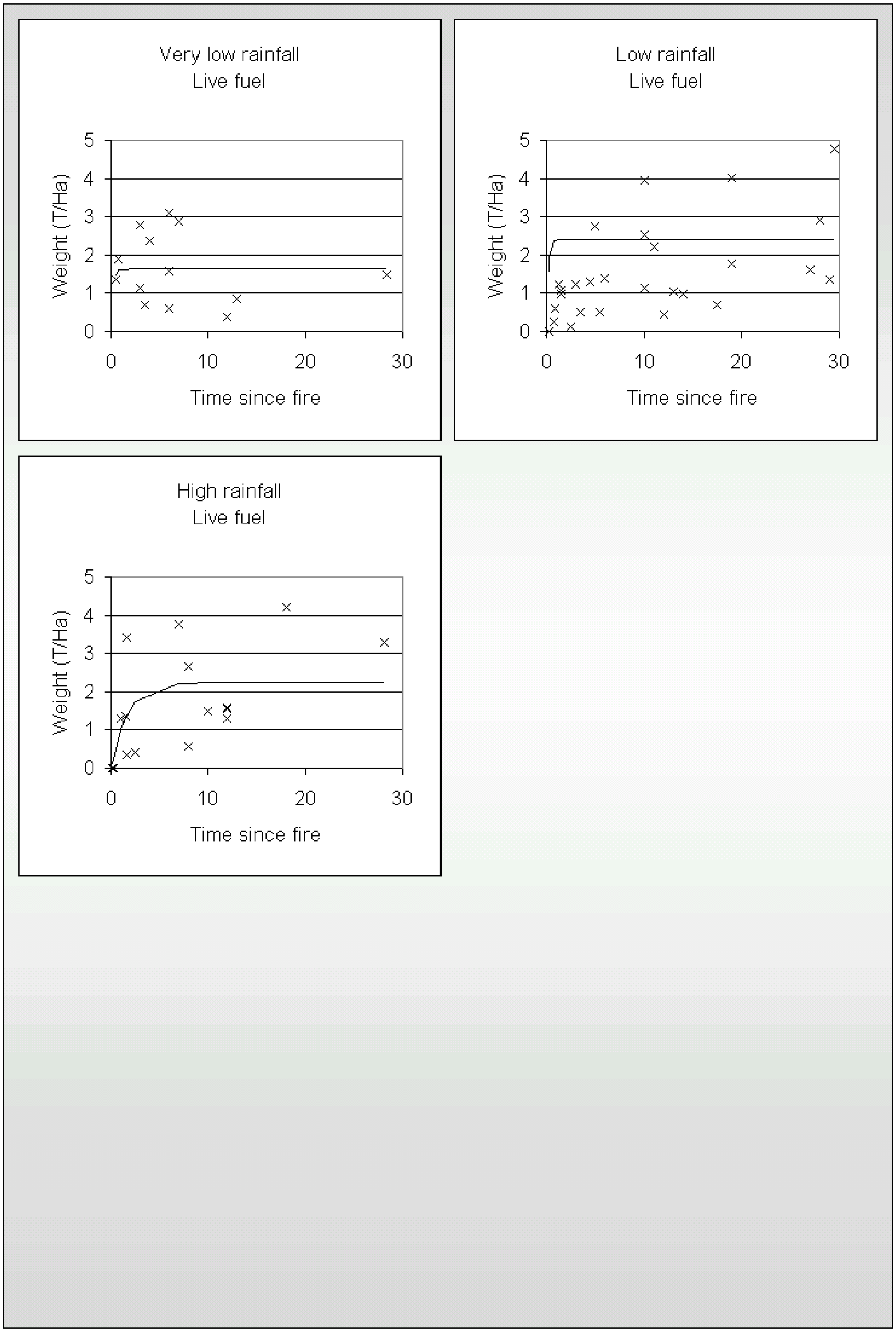


Figure 41: Fuel accumulation- total live fuel

Total dead fuel

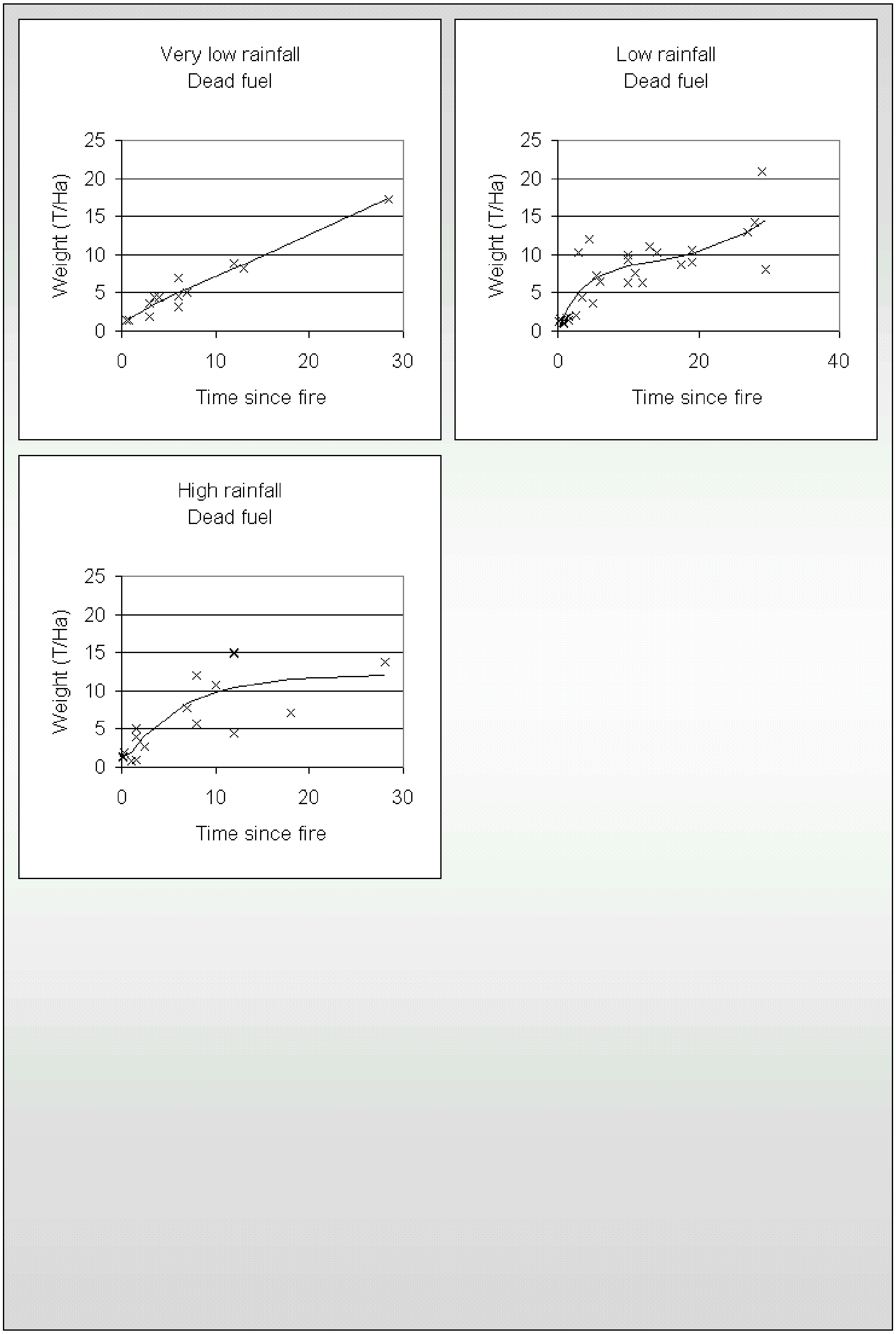


Figure 42: Fuel accumulation- total dead fuel

Litter fuel

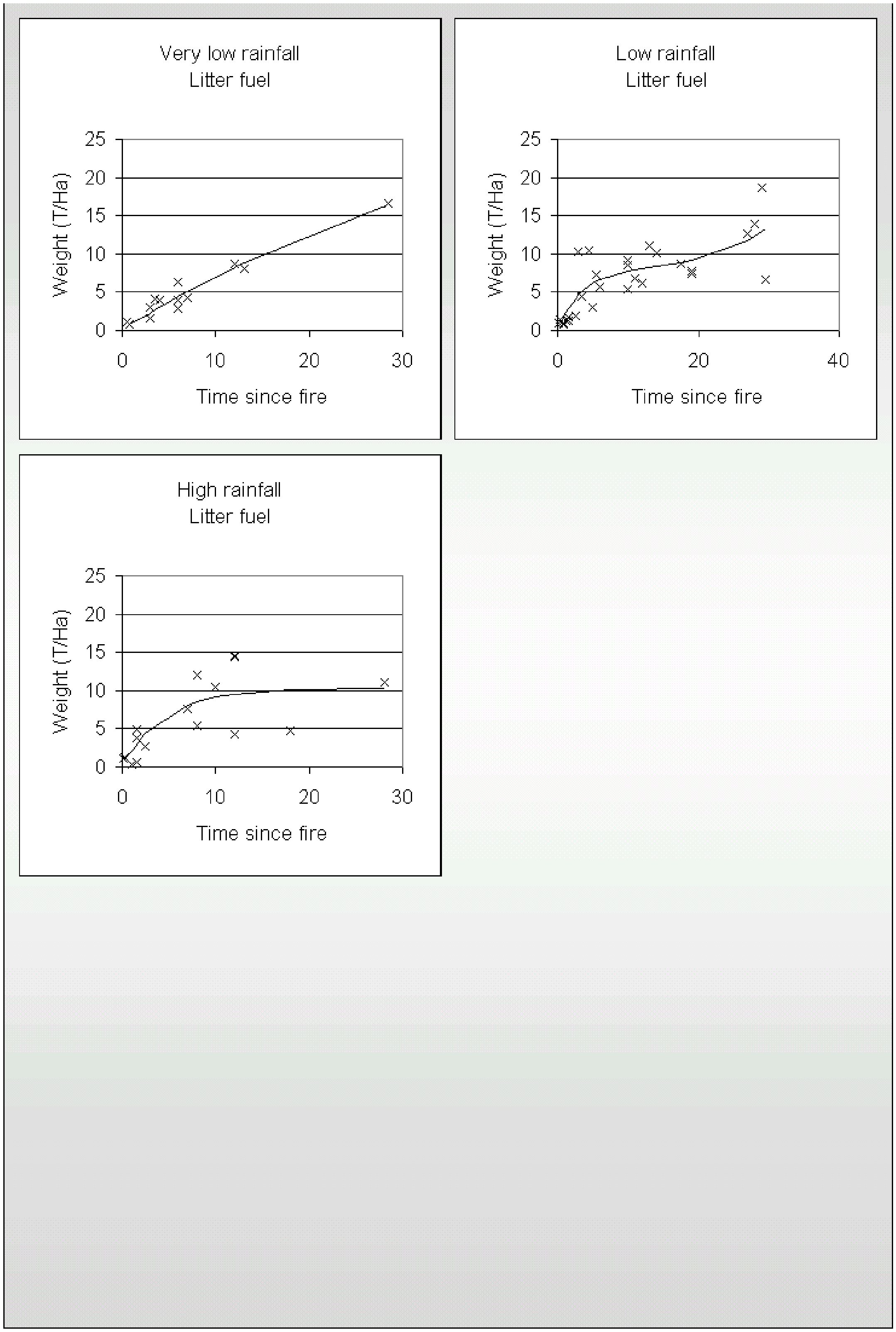


Figure 43: Fuel accumulation- litter fuel

Non-litter fuel

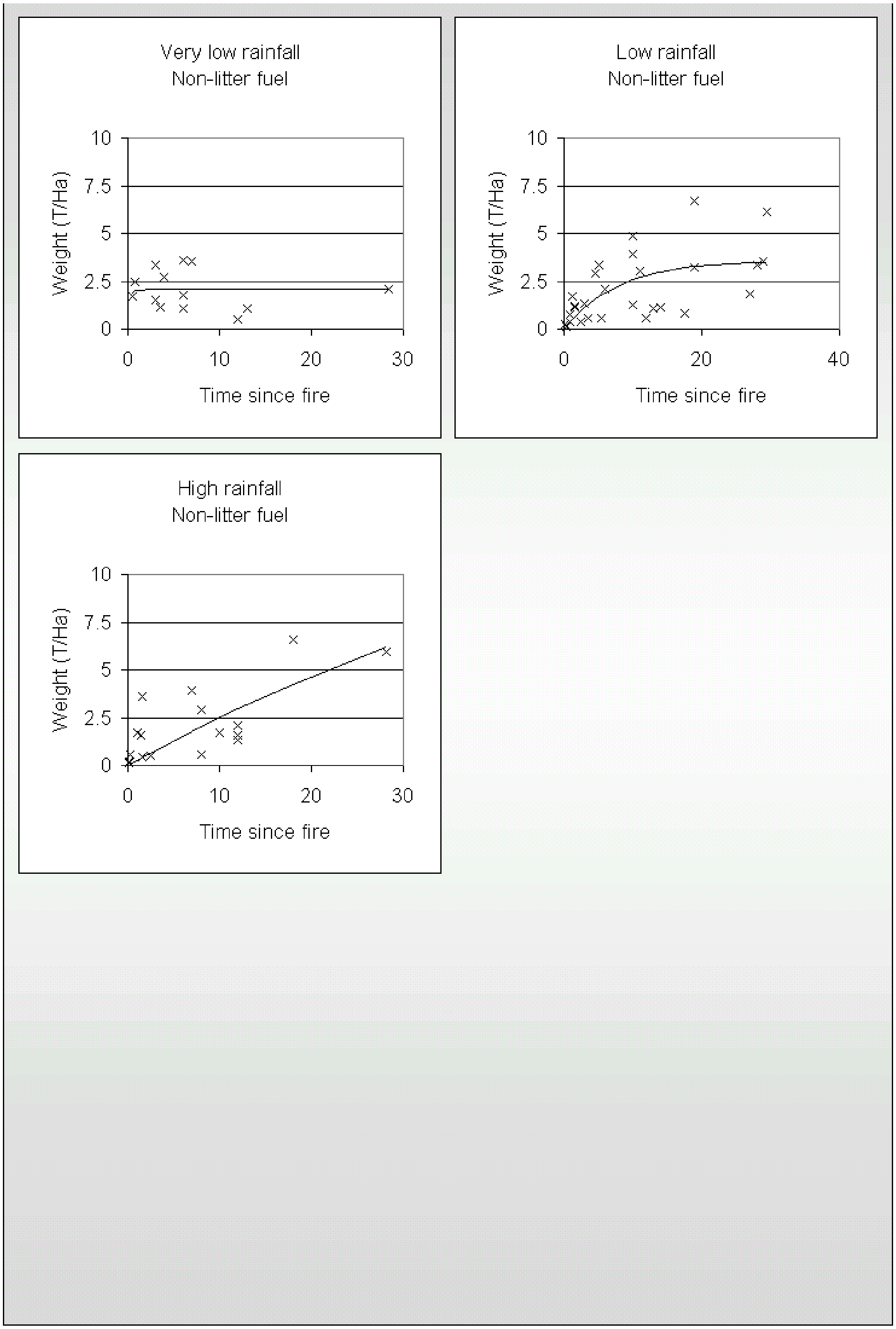


Figure 44: Fuel accumulation- non-litter fuel

Both low and high rainfall classes exhibit a build-up of total fuel loads to approximately 12 t/ha in 15 years and increase by no more than 3 t/ha in the next decade. The very low rainfall class however, builds up far slower, to 12 t/ha in 20 years. This class appears to continue building up fuel, to a projected fuel load approaching 20 t/ha at 30 years whereas the other two classes of this category are projected to be still around 15 t/ha at 30 years. Live fuel accumulation is uniformly low across all classes; with the curve suggesting live fuel weights will not exceed 3 tonnes per hectare.

Non-litter fuels show a marked difference, with Very Low Rainfall sites quickly reaching but not exceeding 2.5 tonnes per hectare, Low rainfall sites accumulate slower and reach a 3.5 tonne per hectare fuel weight in 20 years. High rainfall sites show a steady, almost linear increase in weight, reaching 6 tonnes per hectare in 25 years with no indication of a lessening of the accumulation rate.

Annual rainfall can be seen as being as valid a classification method as geology type or canopy type, with r^2 values very similar in pattern and explanatory power across the categories. As annual rainfall is not the only determinant of site moisture balance, this suggests a model that incorporates more of the environmental variables that impact on moisture balance may provide a better means of predicting fuel accumulation rates. Candy and McQuillan (1998) put forward a growth model for immature red-headed cockchafer beetles that was both time and temperature-linked. There is a possibility model that links time and resource in an accumulative sense may be as valid for fuel accumulation as it is for some soil-dwelling juvenile members of the genus *Coleoptera* (Candy pers. comm.).

Using this concept of resource accumulation over time, two analogues for fire age were developed. Analogue 1 was accumulated rainfall, the product of annual mean rainfall and time since fire. Analogue 2 was accumulated solar energy, based on time since fire and the annual sunlight received at each site calculated using Nunez (1983). This method uses slope angle and aspect to calculate solar energy in megajoules per square metre. Quadratic fitted line plots were used as an initial tool of investigation using MINITAB (1999) and the results are shown in Figure 45 to Figure 53.

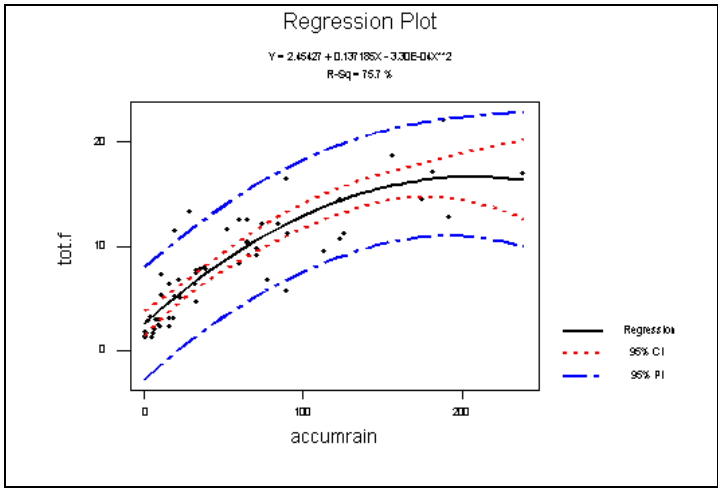


Figure 45: Fitted line plot regression- accumulated rainfall to total fuel

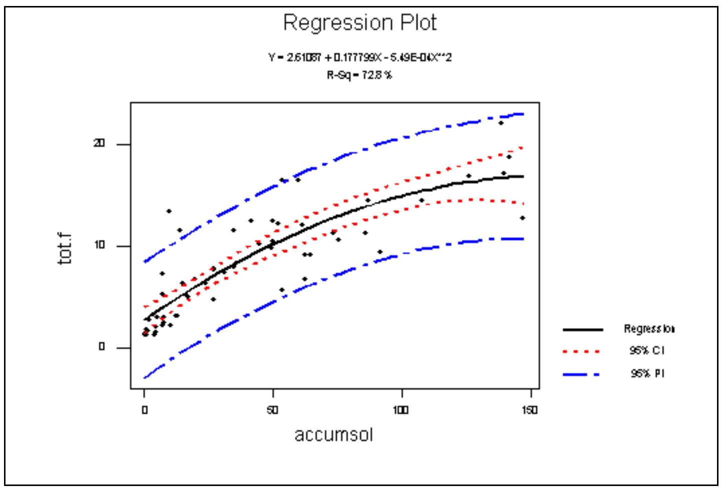


Figure 46: Fitted line plot regression- accumulated solar radiation to total fuel

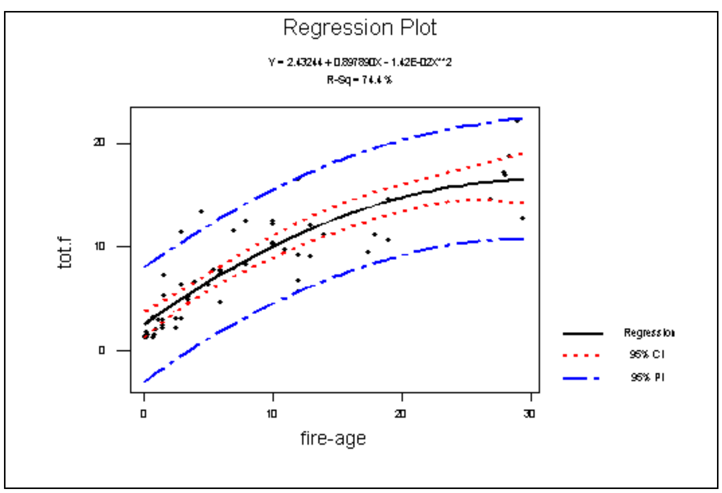


Figure 47: Fitted line plot regression- fire age to total fuel

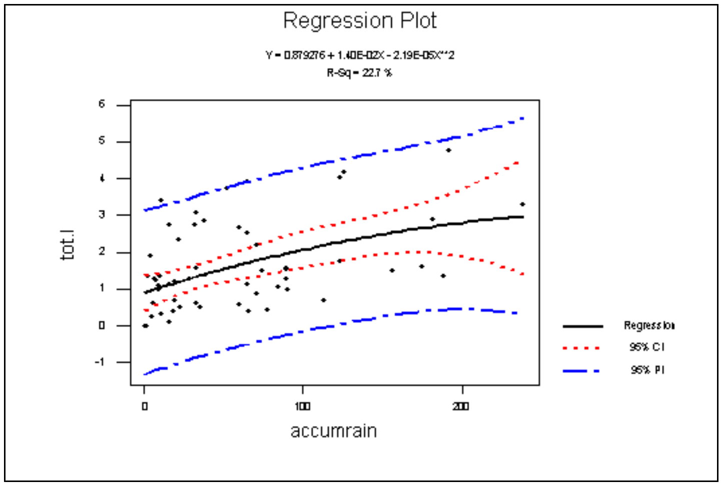


Figure 48: Fitted line plot regression- accumulated rainfall to live fuel

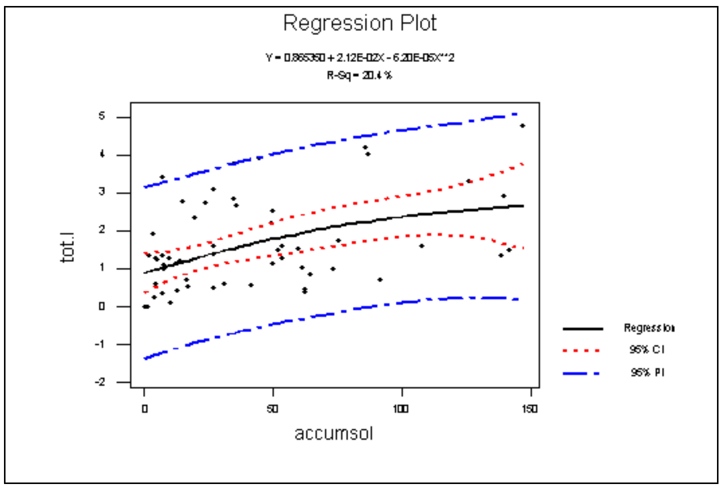


Figure 49: Fitted line plot regression- accumulated solar radiation to live fuel

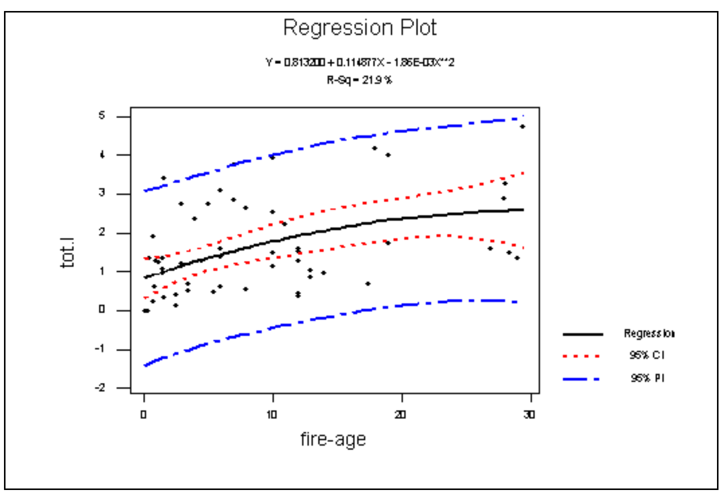


Figure 50: Fitted line plot regression- fire age to live fuel

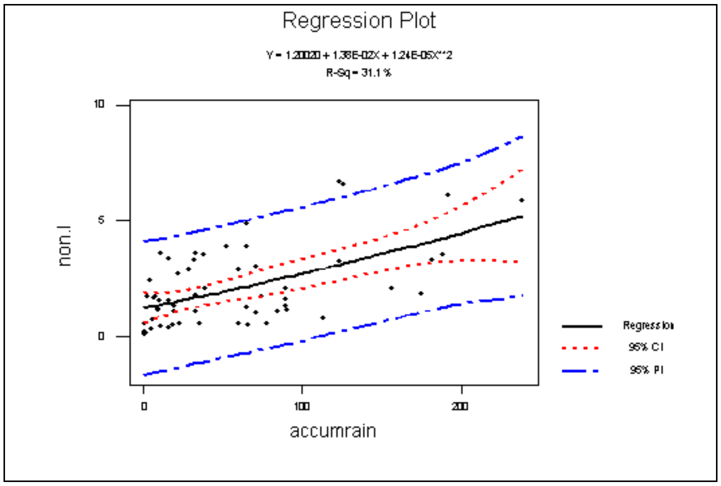


Figure 51: Fitted line plot regression- accumulated rainfall to non-litter fuel

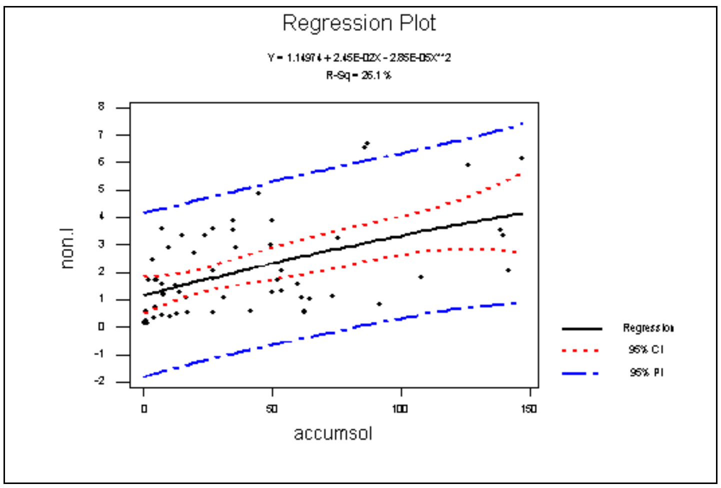


Figure 52: Fitted line plot regression- accumulated solar radiation to non-litter fuel

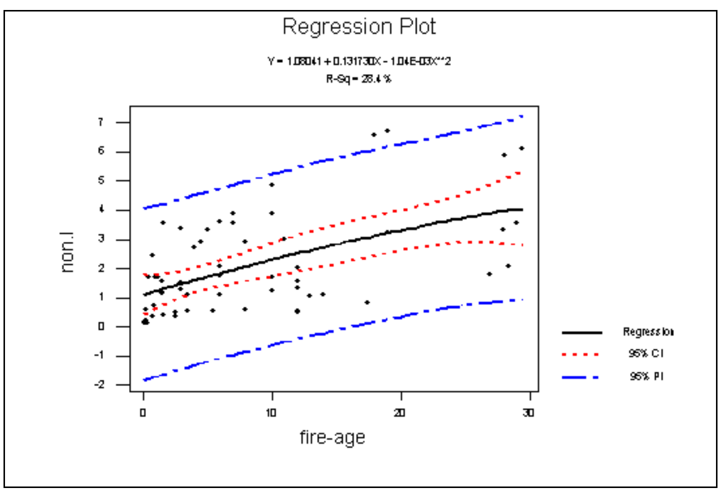


Figure 53: Fitted line plot regression- fire age to non-litter fuel

Figure 45 to Figure 53 (above) show that the two time/resource analogues are very similar to time since fire alone. Explanatory power (r^2 values) are set out in Table 23 below.

Fuel	Fire age	Accumulated Rainfall	Accumulated Solar energy
Total	0.74	0.75	0.72
Live	0.21	0.22	0.2
Nonlitter	0.26	0.31	0.26

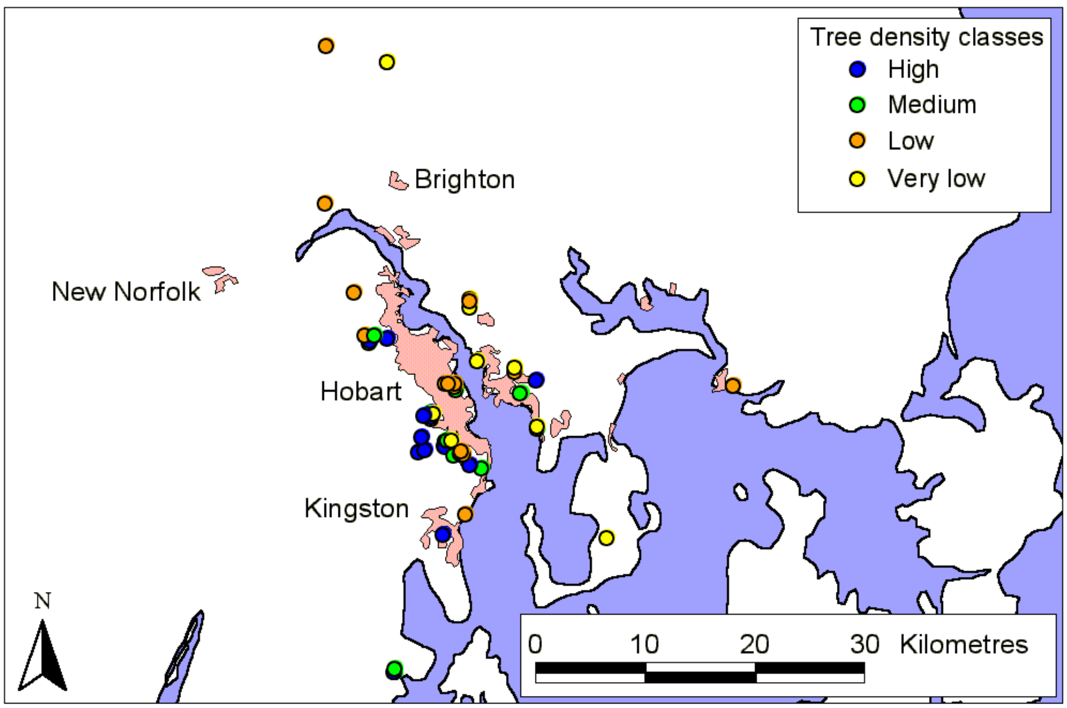
Table 23: r^2 values for time/resource analogue regressions

The levels of explanatory power shown in the time/resource analogues do not show any significant improvement over the time since fire measure alone. Incorporating factors that might have significant impact on site moisture balance makes logical sense and is supported by studies of litter accumulation and decay (Pook 1997). The initial investigations above, however, shows that it adds a layer of complexity to the curve fitting process without necessarily adding to the explanatory power of the result.

Tree Density Ordering

The sites were re-ordered into tree density classes: very low density (vld)- 12.49 m^2/ha or less, low density (ld)- of between 12.5 and 14.49 m^2/ha, medium density (md)- of between 14.5 and 17.49 m^2/ha, and high density (hd)- of above 17.5 m^2/ha (see Map 11).

Figure 54 shows the comparison between tree density ordering and canopy type ordering. The patterns are apparently random between the two schemes, although *Allocasuarina verticillata* does not have any representation in the high tree density class.



Map 11: Sites coded according to tree density class.

	Ave	Epu	Eamh	Eamg	Egv	Etr	
High	0	4	4	1	3	2	14
Medium	3	4	3	3	2	1	16
Low	4	3	2	1	2	4	16
Very low	1	2	2	3	3	2	13
	8	13	11	8	10	9	

Figure 54: Comparing sites by canopy ordering and tree density schemes

Tree density class	Site numbers
High	2, 6, 10, 14, 15, 16, 36, 39, 40, 43, 49, 50, 51, 53
Medium	9, 11, 17, 18, 19, 23, 29, 30, 33, 34, 46, 47, 48, 52, 54, 59
Low	1, 3, 4, 8, 12, 21, 22, 24, 26, 27, 28, 35, 38, 42, 57, 58
Very low	5, 7, 13, 20, 25, 31, 32, 37, 41, 44, 45, 55, 55, 56

Table 24: Sites grouped in each tree density class

Fuel Accumulation Curves

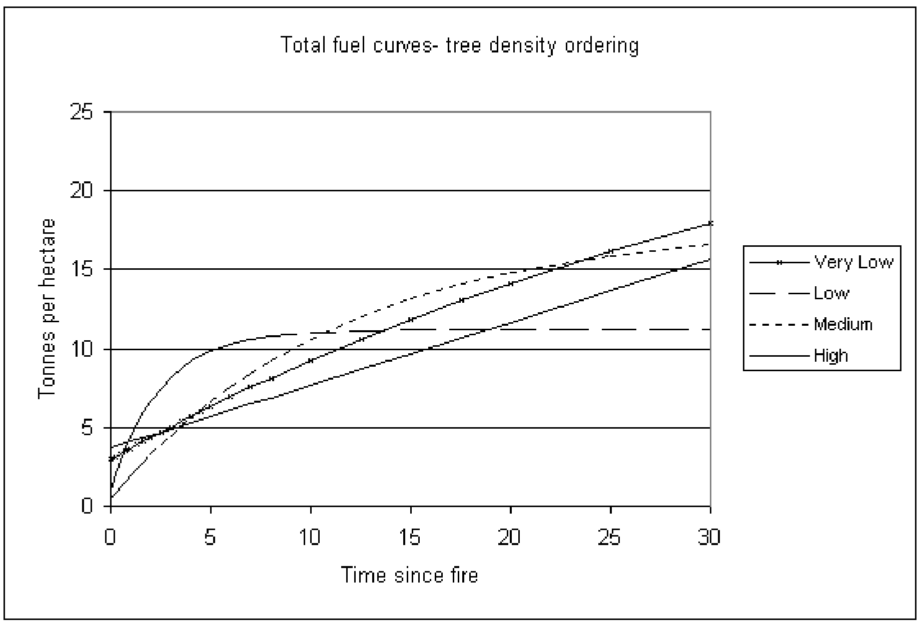


Figure 55: Fuel accumulation- total fuel

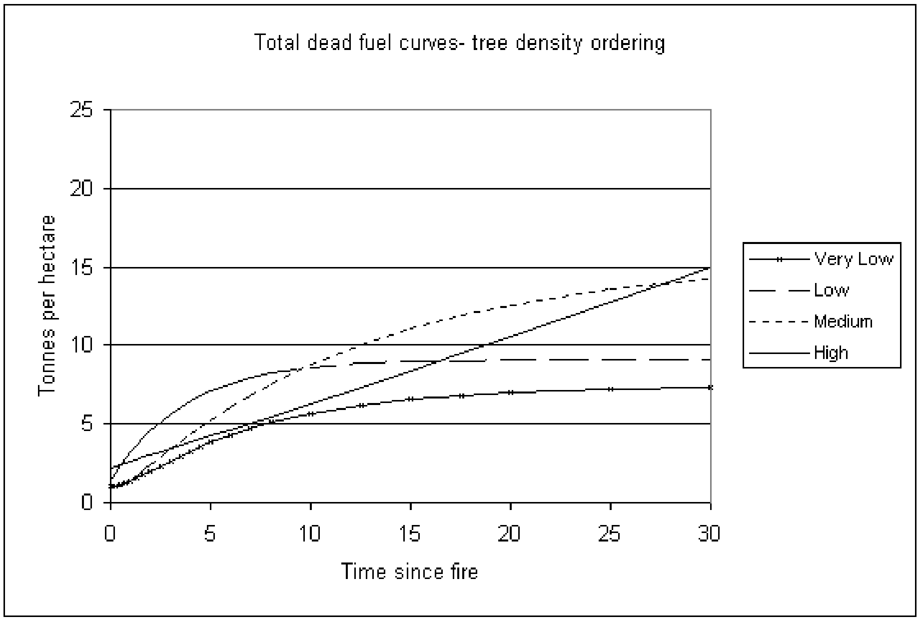


Figure 56: Fuel accumulation- dead fuel

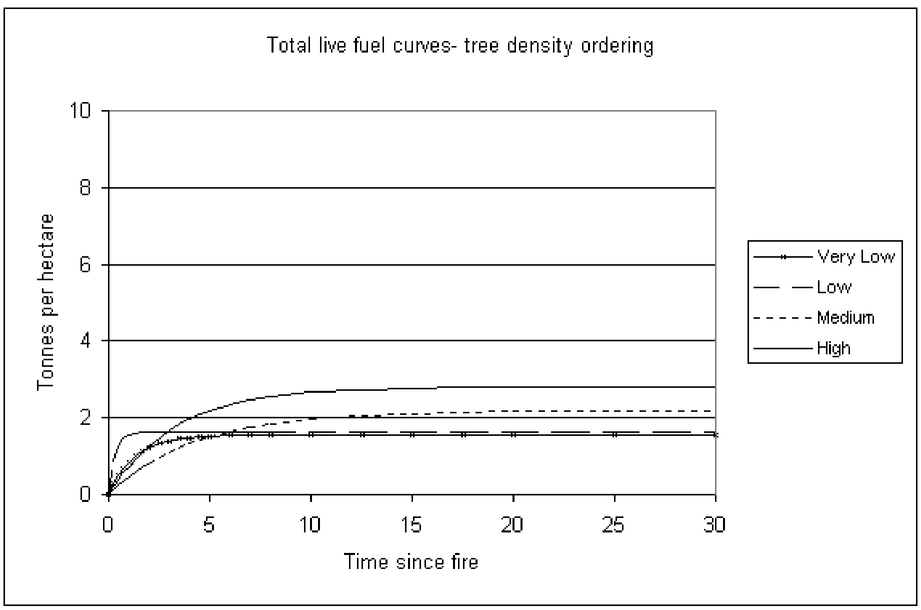


Figure 57: Fuel accumulation- live fuel

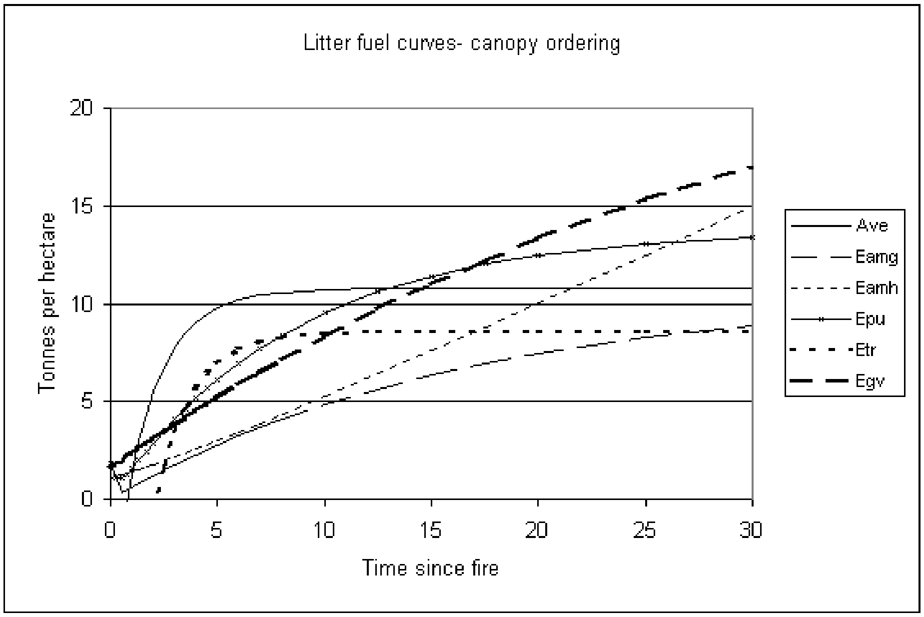


Figure 58: Fuel accumulation- litter fuel

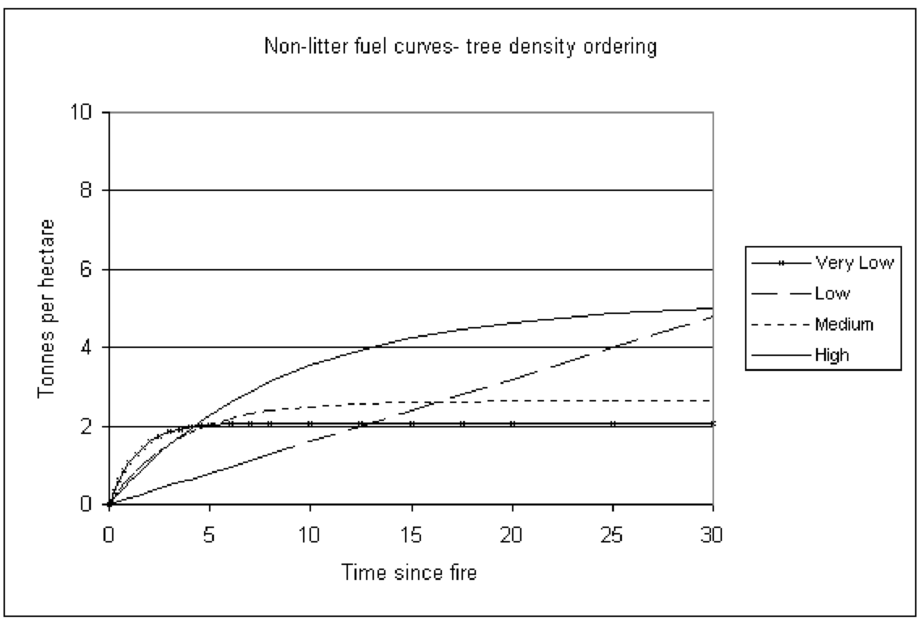


Figure 59: Fuel accumulation- non-litter fuel

Table 25 to Table 28 show the equations for the accumulation curves of all sites as classified into the four tree density classes.

Very low density

Fuel type	W_{ss}	k	a	c	r^2 value
Total	31.32	0.025	2.98	0.025	0.73
Live	1.55	0.782			0.22
Dead	7.431	0.145	1.026	1.078	0.74
Litter	28.749	0.024	1.3	0.0004	0.69
Non-litter	2.082	0.731			0.23

Table 25: Equation coefficients for category VLD

Low density

Fuel type	W_{ss}	k	a	c	r^2 value
Total	11.199	0.405	1.049	0.405	0.63
Live	1.631	3.026			0.18
Dead	9.104	0.283	1.45	0.046	0.59
Litter	8.803	0.288	1.15	0.045	0.6
Non-litter	800.001	0.0002			0.01

Table 26: Equation coefficients for category LD

Medium density

Fuel type	W_{ss}	k	a	c	r^2 value
Total	17.597	0.087	0.505	0.024	0.95
Live	2.18	0.232			0.62
Dead	15.535	0.083	1.22	1.998	0.94
Litter	15.484	0.075	-0.095	0.075	0.94
Non-litter	2.636	0.292			0.51

Table 27: Equation coefficients for category MD

High density

Fuel type	W_{ss}	k	a	c	r^2 value
Total	1999.9	0.0002	3.7	0.0002	0.8
Live	2.805	0.3			0.34
Dead	1198.0	0.0004	2.243	0.039	0.75
Litter	1197.6	0.0002	2.264	0.028	0.62
Non-litter	5.134	0.117			0.42

Table 28: Equation coefficients for category HD

Total fuel

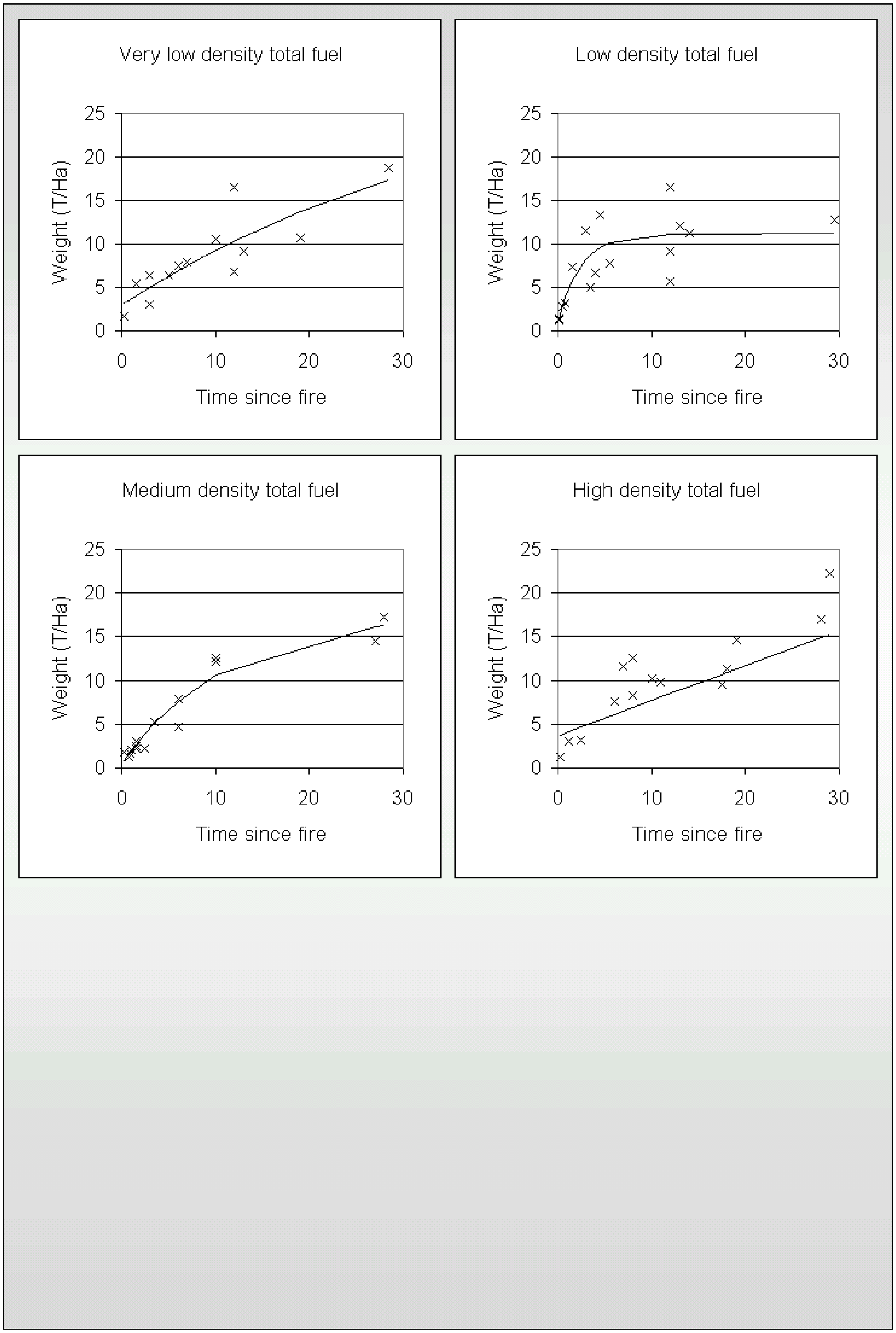


Figure 60: Fuel accumulation- total fuel

Total live fuel

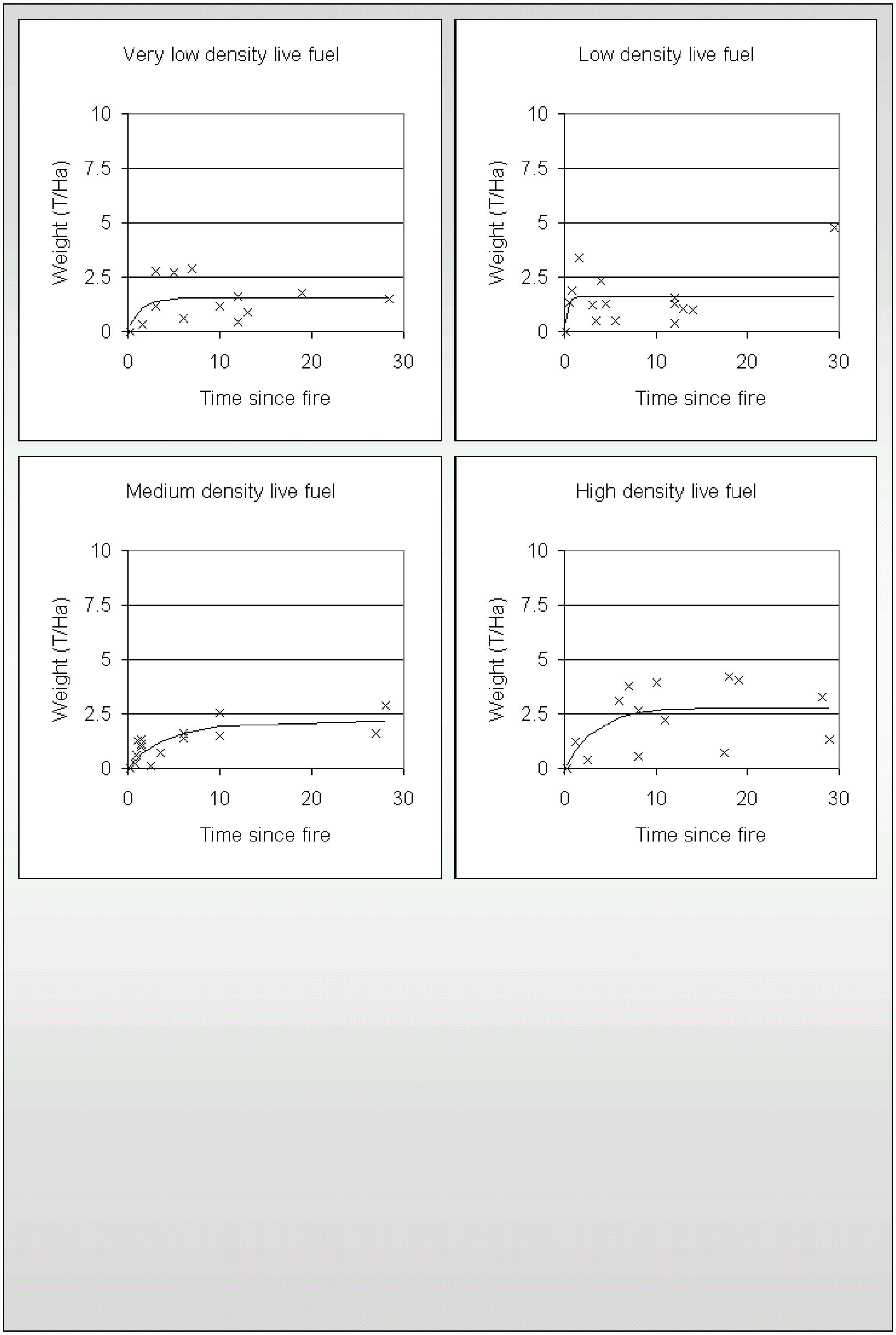


Figure 61: Fuel accumulation- total live fuel

Total dead fuel

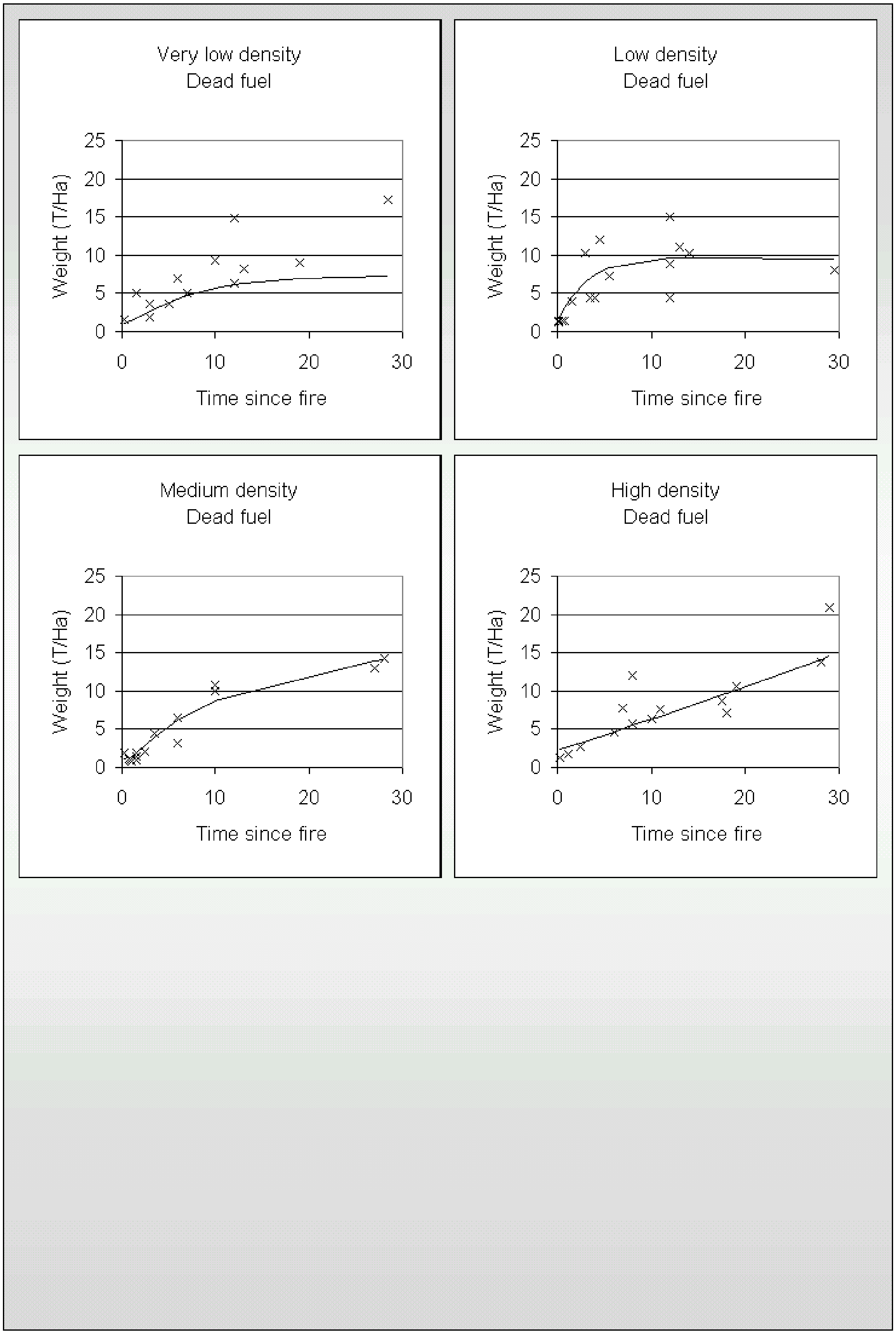


Figure 62: Fuel accumulation- total dead fuel

Litter fuel

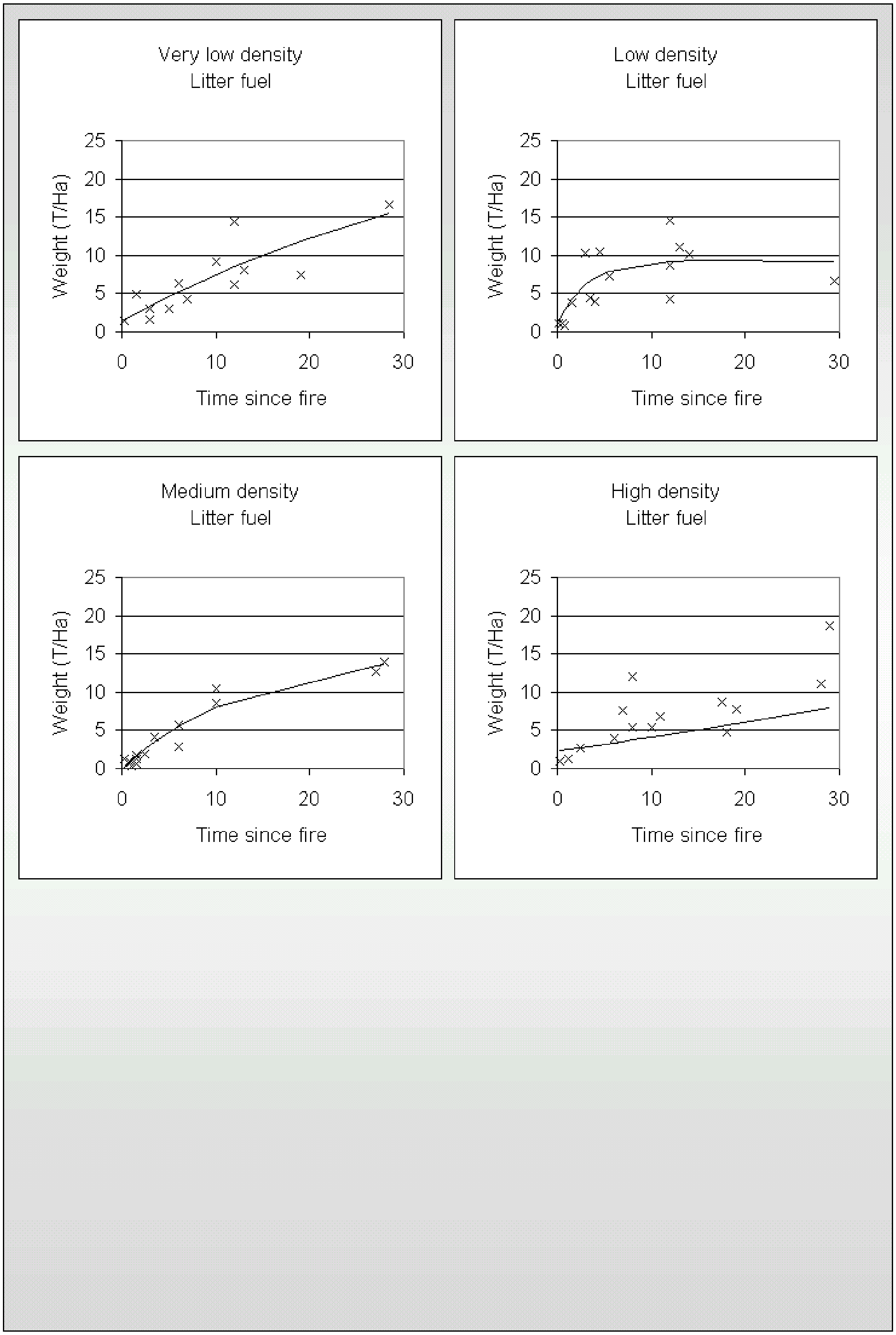


Figure 63: Fuel accumulation- litter fuel

Non-litter fuel

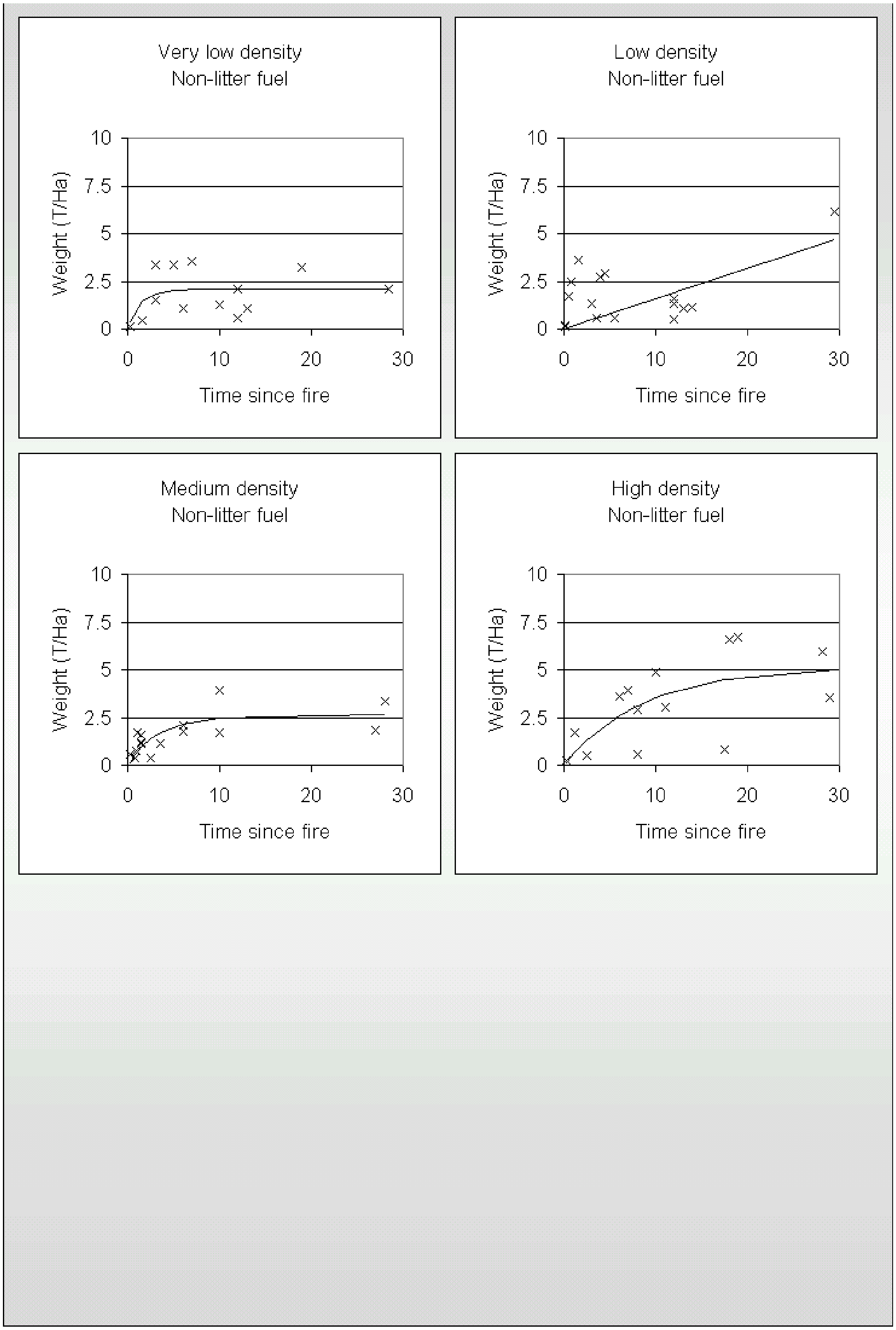


Figure 64: Fuel accumulation- non-litter fuel

Tree density classes VLD, MD and HD each show steady rates of accumulation whereas LD displays a faster initial rate followed by a lower overall fuel load. The mechanism behind this may centre around forest floor moisture levels and tree density- a very low tree density site would logically have a higher proportion of the forest floor exposed to full sunlight and thus the litter would be drier than the higher tree density sites. Moisture levels affect the rates of decomposition and so the dry litter layer would not decompose at a fast rate. The higher tree density categories would have wetter forest floors and faster decomposition rates as a result, but also have higher rates of litter fall. The category of LD, or low density, may be dense enough to maintain sufficient moisture at the forest floor for a high level of decomposition to occur but not as high a rate of litter fall as the more dense sites in this category.

Tree density as a means of site classification displays approximately the same explanatory power as canopy dominant species, rainfall or geology type, with r^2 values virtually identical in magnitude for each of the fuel categories as the aforementioned classifications. Total, total dead and litter fuel categories are all in the order of 0.6 to 0.95, while live fuel and non-litter fuel range from 0.01 to 0.5.

Tree density as defined for this study, using the Bitterlich Wedge method (Mueller-Dombois and Ellenberg 1974), is quickly determined in the field using simple equipment (see appendix 2). This technique cannot be reproduced using remote sensing means. Desktop or GIS studies will require another means of calculating tree density and this measure will need to be tested and new fuel curves developed to permit the use of tree density as a classification means for remote sensing of fuel loads. In its current form, tree density is as valid a classification as canopy dominant species.

The overall usefulness of classifying fuel accumulation study sites by environmental indices appears to be similar for the three indices studied. The results are also of a similar statistical reliability to the canopy dominant species classification and phytosociological classification. The relative worth of using any of these schemes can be assessed, and this formed the next stage of the study.

7. Assessment of Classifications

Introduction

In general terms, predicting the weight of flash fuels in the dry forests of south eastern Tasmania can be accomplished using a wide variety of classification methods with acceptably high levels of confidence in the predictions. These include classifications that can be determined remotely, which is of immense practical benefit for wide-scale fire management planning.

The geological substrate type and rainfall levels are environmental variables that appear to play a major role in vegetation community and therefore fuel accumulation patterns. Similarly, the density of the forest or woodland alone, regardless of substrate or vegetation community, is also a suitable means of classifying study sites for fuel accumulation assessments. The traditional use of canopy dominant species as a tool for site classification is still valid and has explanatory levels as good or better than other classification schemes

Accumulation patterns

As can be seen from the accumulation curves, there exists a wide array of curve forms across the ordering categories. This indicates that some sites will require fuel reduction regimes that differ to those required by other sites. The two main concerns for determining the appropriate regime (without regard to any special site considerations such as nearby land uses or species conservation, which will require individually tailored risk minimisation methods) are the rate of fuel build-up and the maximum projected fuel load.

Live fuel and non-litter fuel accumulation rates in general are initially quite fast and plateau in 5 to 10 years. This may be indicating the re-establishment of the understorey flora to a pre-fire state.

Live fuel weights in general were low- only rarely will the model suggest weights in excess of 3 t/ha. The importance of live fuel from a structural perspective is considerably more than the low weights would suggest- hanging bark, tall shrubs and understorey trees can act as ‘ladders’, allowing a fire access to other fuel layers- most notably the canopy itself.

As the largest component of total fuel weight and dead fuel weight is litter fuel weight, it is not surprising to discover near-identical accumulation patterns in these three categories. Litter is the most significant fuel layer in terms of weight, to the point of masking the accumulation patterns of other fuel strata within total and dead fuel classes.

The litter layer invariably contains 75% or more of the total fuel weight for any site. As such, the litter component is by far the single most important layer of bushfire fuel in terms of total weight. However, the significance of litter weight may be less critical than the structural arrangement of the standing live and dead fuels fuel layers. Litter fuel is very much ground-based- a litter fire without the means of accessing the taller understorey and canopy levels is not as potentially dangerous as a fire in a site where the vegetation will permit the fire to reach the canopy. Ladder fuels are in themselves a very small component of fuel weight but are critical in the fire’s ability to access higher fuel layers.

Site productivity, in the form of geological substrate nutrient status and moisture availability, seems to be the major controller of the rates of litter fall and decomposition. As each site has a microclimate controlled as much by topography as by overall annual rainfall, slope and aspect may have some importance in this regard. It may be the separate cycles of litter accession, understorey development and litter decomposition respond to moisture levels and site productivity in different ways- one cycle masking the effects of the others.

Explanatory Power: r^2 Comparisons

The r^2 values averaged for each classification type are shown in Figure 65 below. It shows that in broad terms, the traditionally used classification of sites by canopy-dominant species is slightly stronger than other classifications in almost all fuel strata. The classification scheme with the least explanatory power is the TWINSPAN based phytosociological groupings, which may be caused through the equal weighting of all plant species in the communities where only a small number of species contribute most of the flash fuels.

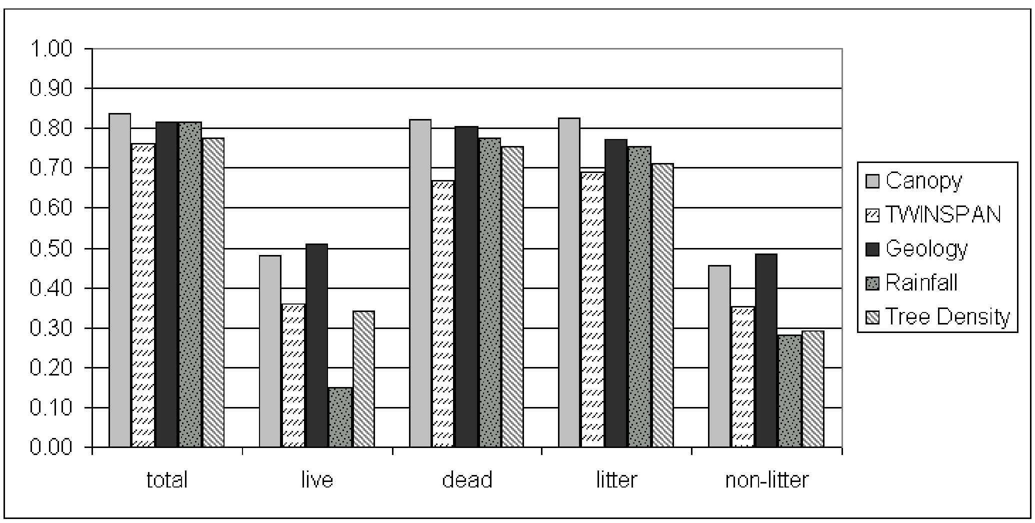


Figure 65: Mean r^2 values across the five fuel types

The accumulation curves for total, dead and litter fuel in most ordering schemes exhibit r^2 values in the order of 0.6 to 0.9, indicating a high to very high agreement between the original data and the modelled curve. The accumulation curves for live and non-litter fuel, however, exhibit r^2 values in the order of 0.1 to 0.5, suggesting these two fuel types are considerably less well explained by the model. It may be these two categories require a different model or a modification of the model presented here, or it may be the live and non-litter fuel categories are simply much more variable than the other three categories.

In terms of the prediction of total, dead or litter fuel weight, the accumulation curves have a high enough level of agreement between original field data and modelled predictions for reliable fuel load estimation. Not only can the accumulation of fuel weight be predicted for any site conforming to the selection method used in this study, but conversely, the estimation of the fire age of any site conforming to the selection method can be made based on measured fuel weight.

Residual Scatter Comparisons

The patterns of residuals indicate both the state of data heteroscedasticity and the goodness-of-fit of the model. Data heteroscedasticity has been discussed in chapter 3.

The residual plots are presented in appendix 3. Very few of these plots show anything other than a random scatter of residuals, indicating there are no variables or processes unaccounted for in the form of the accumulation curve model. The residuals vary in amplitude from one category to another, but no single fuel stratum depicts a pattern suggesting the model requires re-evaluation. This indicates that despite the fact the live and non-litter fuel categories fit the model less well than the total, dead and litter fuel categories, time since fire is likely to be the major determinant of fuel loads in the live and non-litter categories as much as the others.

A best-subsets regression (MINITAB™ 12.23, 1999) was used as an exploratory tool to confirm other environmental factors were not playing a significant role in live and non-litter fuel accumulation (see Figure 66).

Response is non.l

Vars	R-Sq	Adj. R-Sq	C-p	s	fire-age	topo pos	slope	geology	aspect	mean rai	solar	tree den
1	28.2	26.9	19.2	1.4226	X							
1	19.5	18.1	28.2	1.5064		X						
2	36.8	34.6	12.3	1.3462	X			X				
2	36.1	33.8	13.0	1.3541	X	X						
3	43.7	40.7	7.2	1.2822	X	X		X				
3	43.1	40.0	7.8	1.2892	X			X				X
4	47.9	44.0	4.9	1.2454	X	X		X				X
4	47.3	43.4	5.5	1.2525	X			X			X	X
5	51.3	46.7	3.3	1.2150	X	X		X			X	X
5	48.6	43.7	6.1	1.2485	X	X		X	X			X
6	51.5	45.9	5.1	1.2244	X	X	X	X			X	X
6	51.4	45.8	5.2	1.2255	X	X		X	X		X	X
7	51.5	44.9	7.1	1.2356	X	X	X	X	X		X	X
7	51.5	44.9	7.1	1.2356	X	X	X	X		X	X	X
8	51.6	43.9	9.0	1.2469	X	X	X	X	X	X	X	X

Response is tot.l

Vars	R-Sq	Adj. R-Sq	C-p	s	fire-age	topo pos	slope	geology	aspect	mean rai	solar	tree den
1	20.6	19.2	5.6	1.0898	X							
1	12.9	11.4	11.5	1.1415		X						
2	26.9	24.2	2.8	1.0553	X			X				
2	25.5	22.8	3.9	1.0653	X	X						
3	31.1	27.3	1.6	1.0338	X	X		X				
3	30.3	26.5	2.2	1.0396	X			X				X
4	33.3	28.3	1.9	1.0265	X	X		X				X
4	32.2	27.1	2.8	1.0350	X	X		X	X			
5	34.3	28.1	3.1	1.0281	X	X		X			X	X
5	34.1	27.9	3.3	1.0297	X	X		X	X			X
6	34.5	26.9	5.0	1.0367	X	X		X	X		X	X
6	34.3	26.7	5.1	1.0378	X	X	X	X			X	X
7	34.5	25.5	7.0	1.0466	X	X	X	X	X		X	X
7	34.5	25.5	7.0	1.0468	X	X		X	X	X	X	X
8	34.5	24.0	9.0	1.0570	X	X	X	X	X	X	X	X

Figure 66: Best-subset regression output for non-litter fuel (non.l) and live fuel (tot.l)

In both cases, fire age is indicated as the variable with the most explanatory power. Geology and tree density are frequent subordinates, which is in accord with findings earlier in the study. The relatively high importance of topographic position may be a product of site moisture balance, although the low importance of mean rainfall indicates available moisture and fuel responses may be responding to a number of inter-related factors. Of these, mean annual rainfall is not shown as being as significant as aspect, slope and topographic position.

Revision of statistical methodology

Litter is assumed to have a constant within-year rate of accumulation for the purposes of this study. This is rarely the case, however, with dry sclerophyll forest and woodland. Generally, there is a spring to early summer peak in rates of litterfall for eucalypts (Pook *et al*. 1997). In addition to the variations in seasonal litter fall, fuel dynamics also alter with the development of the understorey layers. Investigations into the characteristics of each understorey layer and the common species within these layers would complement the live fuel and non-litter fuel accumulation curves. The use of a smooth exponential accumulation curve masks these variations and as such, models based on different statistical bases and accumulation curve forms may be more appropriate.

In employing a different model structure, it may prove necessary to dispense with parametric statistics. The nature of biological data is typically one of non-normal distributions; the range of the observations usually increases with the magnitude of the observations. The data sets for this study conformed to the requirements of the parametric statistical tests used and as such were appropriate. Parametric models attempting to cater for seasonal litter fall may, however, encounter just such a fatal flaw as data non-normality, leading to the necessity of non-parametric methods, where data normality is not a pre-requisite.

Conclusion

The classification schemes assessed in this part of the study have shown a broadly similar pattern of explanatory power. In fuel strata that include the litter layer, the form of the model is clearly suitable, able to account for 70-80% of the variability regardless of the classification scheme. This is largely a result of the time since last fire being a major determinant of fuel load. Non-litter and live fuel classes are far less well explained by the model form used- in the order of 40% or less- and may require a very different process for accurate fuel accumulation modelling.

The investigations up to this stage of the study have the potential to form the basis of field techniques for assessing fuel loads. For a field technique to be useful, it requires a simple method and an intuitive process that does not rely on a high level of knowledge in the user. The greatest value of a field technique in fire research is repeatability and rapidity, followed by accuracy. As has been shown by the field studies, the fuel load at any one site is variable across short distances, and as such the concept of accuracy in determining fuel loads in the field is more a case of achieving an estimate within the variability found at the site. A technique capable of permitting an estimation of fuel loads to within 3 tonnes per hectare is perfectly acceptable for use in the field.

There are established types of field techniques in fuel load and fire risk studies. These have proven to be useful and well understood by field users. The use of these as a structure to trial methods forms the first step in the development of a field technique.

8. Predicting Fuel Weight from Field-based Measurements

Introduction

One of the limitations of most fuel weight survey methods (including those used for this study) is that they involve a considerable amount of time for the collection of fuel in the field, followed by (typically) 24 hours of oven drying. Should a rapid assessment be required, as is often the case in emergency situations, fuel loads are often simply guessed at from the appearance of the site and the experience of the person making the assessment. This can result in inaccuracies, as estimations of fuel weight vary from one observer to the next.

Land managers and researchers agree that rapid field techniques for assessing fuel loads will not approach the level of accuracy of the oven-drying technique outlined earlier in this study. The value of rapid field-based techniques for predicting fuel weights lies in the speed with which the assessments can be made and in the simplicity of design, so that any field operative may use it effectively. Perhaps more critically, the results of the technique are no longer dependent on the experience and knowledge of the person using it.

Field-based techniques are already in existence for some regions and vegetation communities. These are generally one of two basic types- photographic guides and look-up charts, or are a combination of both, such as McCarthy *et al*. (1999). Broadly speaking, the usefulness of existing field methods reflect the rigorousness of the development of the method. Each method has both advantages and limitations.

Photographic guides depict typical conditions in a predetermined set of vegetation communities or fuel structure classes, such as cured grass, bark or understorey vegetation, and outlining the critical factors used to assess fuel load conditions. The value of photographic guides is in training the users to quantify their observations and to balance the interpretation from one observer to the next. The photographic guide is limited by the site choice and conditions of the original photography and by the print quality of the booklet itself.

Look-up charts rely on a tabular presentation of existing fuel curves. This technique links community type to determinable factors such as time since last fire to indicate the likely fuel loads for the site. The accuracy or usefulness of a look-up table field guide is dependant on the research used to prepare the data upon which the tables are based and the applicability of the community typing. Lookup tables can be further limited if the classification schemes used are poorly explained or difficult to interpret.

Despite the known limitations, a rapid fuel weight assessment guide can still be seen as a useful tool for initial site investigations for the following reasons:

A field-based fuel weight prediction technique would permit a fuel load assessment to be conducted over a wide area with very little time required.

Training, infrastructure and logistical requirements would be small, and

Much of the subjectivity of mere observation would be largely removed.

These factors can be critical in emergency situations where fire-fighting logistics are being determined by fire behaviour tools such as McArthur's Forest Fire Danger Meter Mk. 5 (McArthur 1973) or Rothermel's (1972) mathematical model for predicting fire spread in wildland fuels, which require information concerning fuel loads.

The following sections present the results of investigations into the possibility of developing a rapid fuel weight assessment method for the study area.

Photographic Guide

Introduction

There are a number of photographic guide booklets in current use in fire management planning, including grass curing guides and fuel hazard guides. These guides, while not rigorously accurate, nevertheless form a useful tool for field operatives (McCarthy *et al*. 1999). McCaw (1991) suggested an image-based guidebook to fuels in dry sclerophyll forests would permit rapid assessments but would be of limited accuracy.

The possibility of developing a photographic guide to fuel loads in the study area was investigated using paired photographs taken at each sampling site. The photographic technique employed was similar to that used by Garvey (1992) and is typical of the general technique seen in these publications. One photograph was taken at head-height looking out across the site, the second from head-height looking directly at the litter layer, to mimic the standard observer's perspective. Scale bars in each photograph indicated the size and structural array of the vegetation and the continuity of the litter layer. Photograph 1 to Photograph 12, on the following pages, are a six-site subset of the full array of site photographs used to investigate the possibility of producing this type of field guide.

Fuel estimation photograph subset

Photograph 1: 2.1 t/ha- landscape view, site 47

Photograph 2: 2.1 t/ha- ground surface view, site 47

Photograph 3: 4.7t/ha- landscape view, site 54

Photograph 4: 4.7t/ha- ground surface view, site 54

Photograph 5: 7.6t/ha- landscape view, site 53

Photograph 6: 7.6t/ha- ground surface view, site 53

Photograph 7: 9.2t/ha- landscape view, site 32

Photograph 8: 9.2t/ha- ground surface view, site 32

Photograph 9: 9.2t/ha- landscape view, site 4

Photograph 10: 9.2t/ha- ground surface view, site 4

Photograph 11: 12.5t/ha- landscape view, site 52

Photograph 12: 12.5t/ha- ground surface view, site 52

Assessment of photography-based fuel weight prediction

Photograph 1 to Photograph 12 depict a range of fuel loads typical of urban fringe dry sclerophyll forest. Details of these sites are contained in Table 29.

Site number	Fire age	Fuel weight	Canopy dominant
47	1	2.1 t/ha	*Eucalyptus amygdalina*
54	6	4.7 t/ha	*Eucalyptus amygdalina*
53	6	4.7 t/ha	*Eucalyptus amygdalina*
32	13	9.2 t/ha	*Eucalyptus viminalis*
4	12	9.2 t/ha	*Eucalyptus tenuiramis*
52	10	12.5 t/ha	*Eucalyptus amygdalina*

Table 29: Details of photographs

The full photographic set was tested among a group of fire researchers and students. Initially, the photograph pairs were given to each tester without details of fuel load or community association. Testers were asked to rank the sites from lightest to heaviest and determine the point at which sites were likely to be too heavily loaded with fuel for safe firefighting. Following this, the actual fuel loads measured at each site were attached to the photograph pairs and the discrepancy between estimated and actual fuel loads were discussed.

It became quickly apparent that the use of photographs in a field guide for fuel loads had some limitations. While it was not difficult for the testers to determine sites with a very light fuel load, such as site 47 depicted in Photograph 1 and Photograph 2, assigning an accurate fuel load estimate for the remainder of the test sites was a more difficult matter. Sites 53 and 54 (Photograph 3, Photograph 4, Photograph 5 and Photograph 6) show two sites with identical fuel loads, but most testers thought that site 53 had a heavier fuel load than site 54.

Similarly, sites 32 and 4 (Photograph 7, Photograph 8, Photograph 9 and Photograph 10) also have identical fuel loads but all testers considered site 32 to have a heavier fuel load than site 4. Some testers considered site 53 (Photograph 5 and Photograph 6) to have a heavier fuel load than site 4. Both sites 32 and 52 were often put forward by the testers as being likely to be 'too heavy for firefighting safety', which for these community types is 10-15 tonnes per hectare (Good 1981, Raison *et al*. 1986). Site 52, at 12.5 t/ha, is well inside this criteria. Site 32, at 9.2 t/ha, is still below the level considered dangerous. This alone could have major implications if fuel reduction burns were being planned from these estimates.

The limitations of the photograph based guide to fuel loads were twofold. Firstly, there were no quantifiable visual cues to assist in determining an estimate of fuel loads, and secondly, the estimate was based on the knowledge and experience of the person doing the estimation. A photograph does not convey all information necessary for a field estimate, particularly the depth or density of the litter layer. Inexperienced testers regularly produced results wildly different from more experienced personnel.

In an operational sense, the results of the photographic guide testing showed that the spatial variability of litter and understorey fuels is too high for inexperienced field staff to accurately estimate. Given this fact and the visual similarity of sites with quite different fuel loads, the possibility of creating an effective visual guide for fuel loads in southeastern Tasmanian dry sclerophyll vegetation was considered too small to warrant further examination.

Assessment Based on Field Measurements

Introduction

The fuel curves produced earlier in this study can be readily expressed as a look-up chart to enable sites of known fire age to be assessed. If the details of the site canopy dominant species, geology, rainfall and tree density are known, the site need not be visited at all. GIS systems use this structure as a basis for providing management information, combining vegetation, topography, geology and other data layers with a mosaic of fire ages from previous studies. A look-up chart was developed for field estimation and is presented in Table 31.

Assessment techniques based on field measures, while not necessarily as accurate as time-based charts, confer a greater degree of reliability and repeatability in prediction than photographic guides. This is essentially a product of the fact there are actual measurements involved, which removes a degree of subjectivity (Beck 1994). The key to producing a rapid field technique is in the identification of an environmental condition or variable that permits easy measurement and has a demonstrable and consistent relationship with the variable being estimated. The relationship between the variable being measured and the variable being estimated must be based on solid data and appropriate statistical methods. Baxter and Woodward (1999) used field and satellite data spanning three years in the development of a grass curing guide based on measures of soil dryness and pasture quality.

The information collected during fuel weight sampling appeared to be both sufficiently accurate and compendious as to permit the investigation of a field measure based fuel weight prediction tool. McCaw (1991) and Beck (1994) discussed the potential for simple and rapid flash-fuel weight assessment methods. The methods proposed rely on linking litter weight with litter cover or litter depth, usually in the form of a multiplier model. To illustrate:

for West Australian jarrah forests, litter weight (W_{litt}) can be estimated from litter depth (D_{litt}) and a multiplier constant (Sneeuwjagt and Peet 1985):

$$W_{litt} = D_{litt} * 5.27$$

Equation 5: Predicting litter weight in WA jarrah forests

As the data collected for this study included litter cover and depth measurements as well as litter weight, the potential for developing a rapid fuel weight estimation method could be explored.

Relationship of litter weight to total weight

Estimating the litter fuel weight will only indicate the fuel load within that fuel stratum, not the total flash fuel for the site. As the near-surface and elevated fuel weights are usually much less than the litter fuel weight but contribute to fire behaviour in a much different manner, to be able to assess total fuel weight from litter weight would provide an estimate of the weight within other fuel strata.

Litter fuel weight was compared to total fuel weight, effectively showing the pattern of the relative proportion of litter fuel through time in each fuel ordering category. Throughout the full set of fuel categories, a simple linear relationship was observed to exist between total fuel weight and litter fuel weight.

A process of linear regression was employed to give a series of equations allowing the prediction of total fuel weight from the litter weight, and an r^2 value indicating the reliability of the prediction. The following array of graphs will permit the estimation of total fuel weight from litter fuel weight.

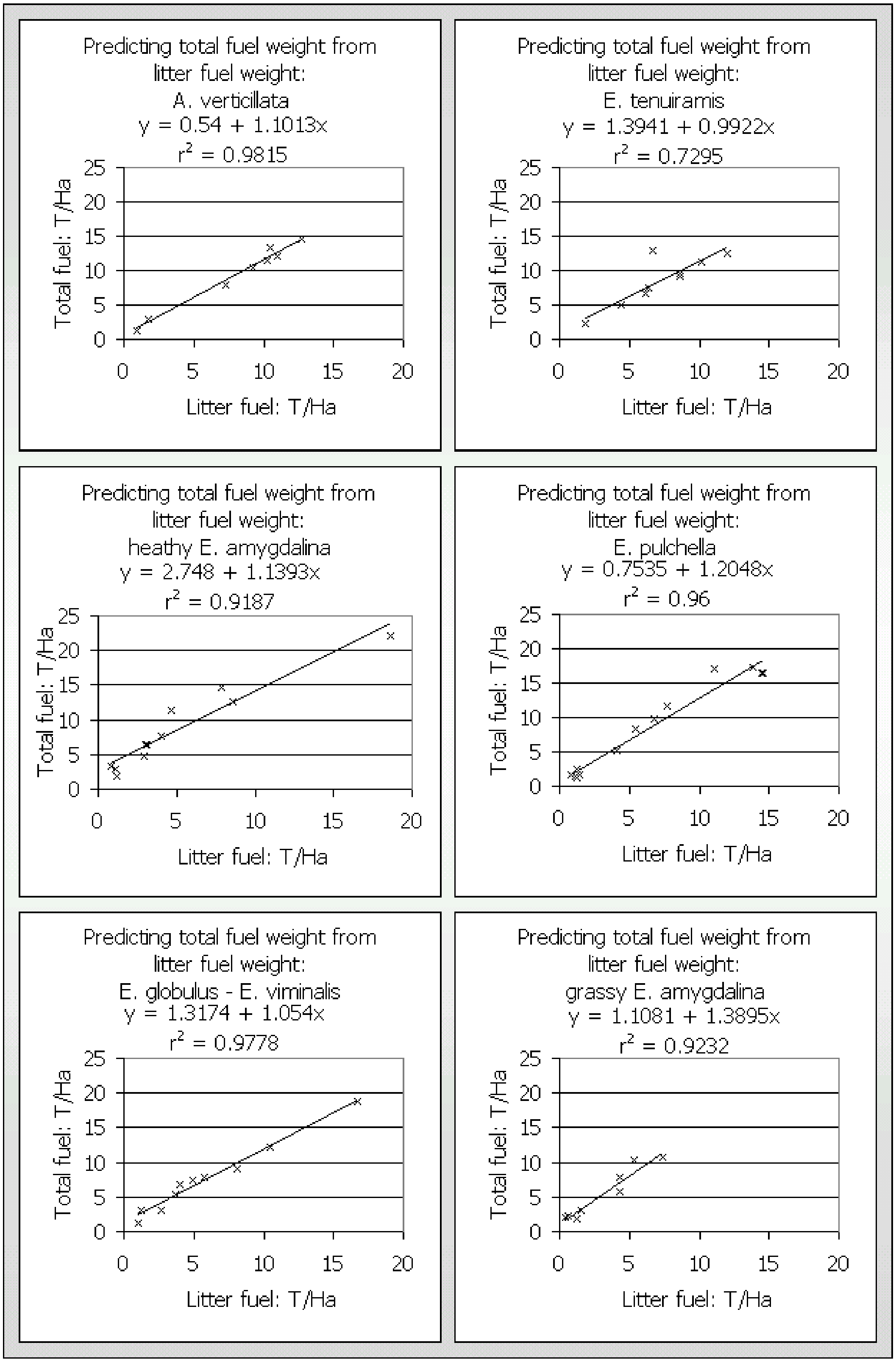


Figure 67: Predicting total fuel from litter fuel: canopy ordering

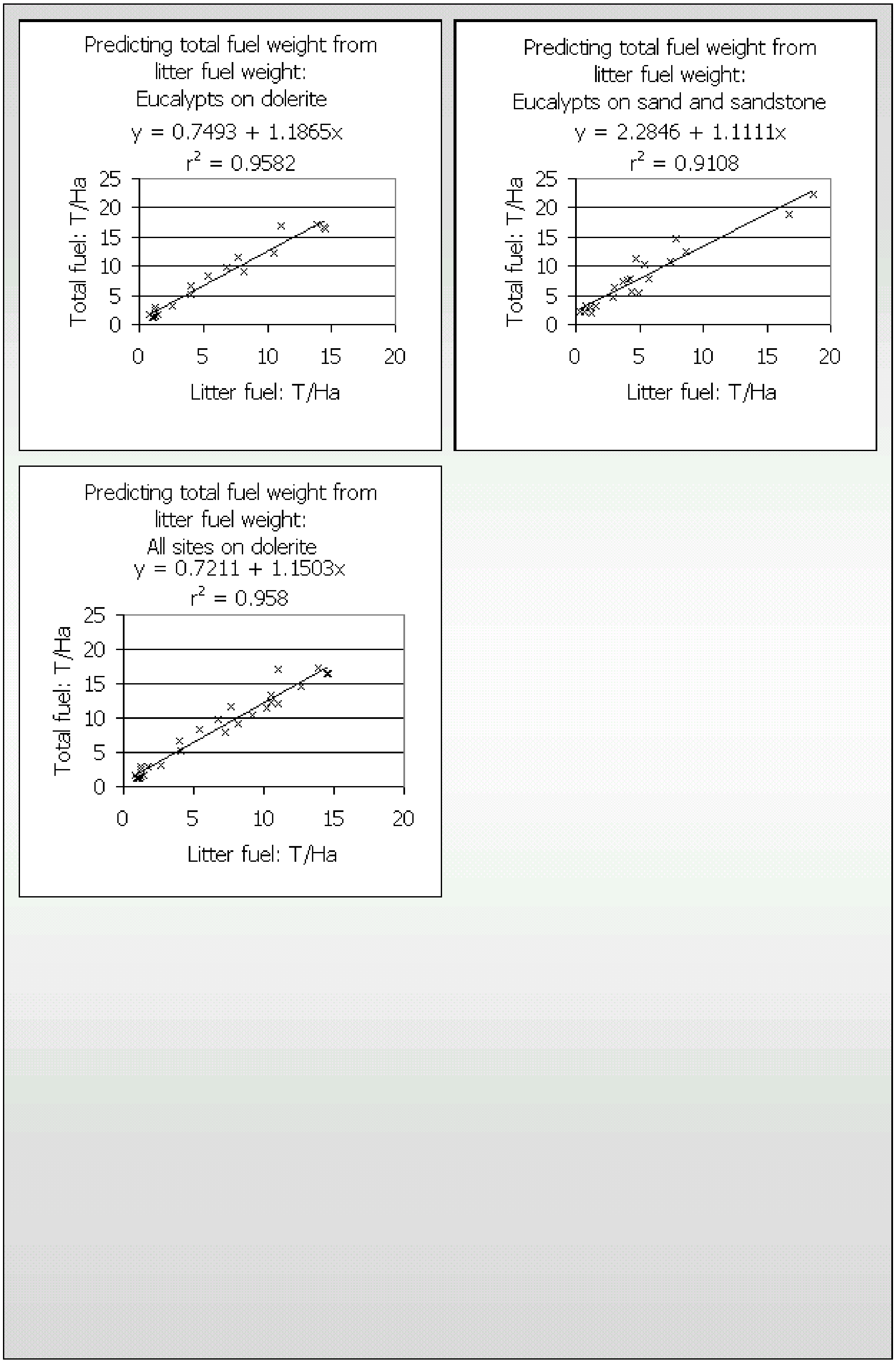


Figure 68: Predicting total fuel from litter fuel: geology ordering

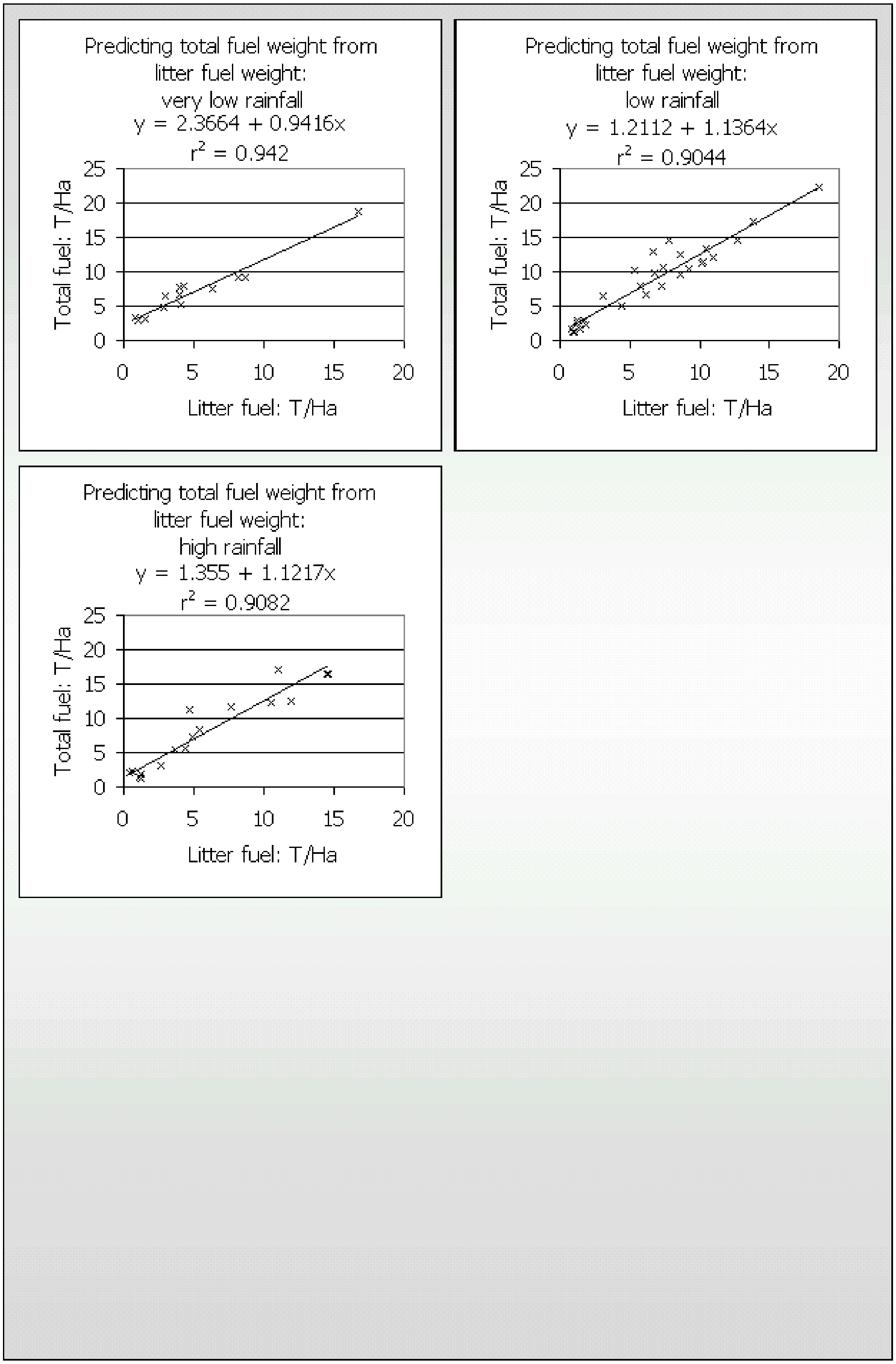


Figure 69: Predicting total fuel from litter fuel: rainfall class ordering

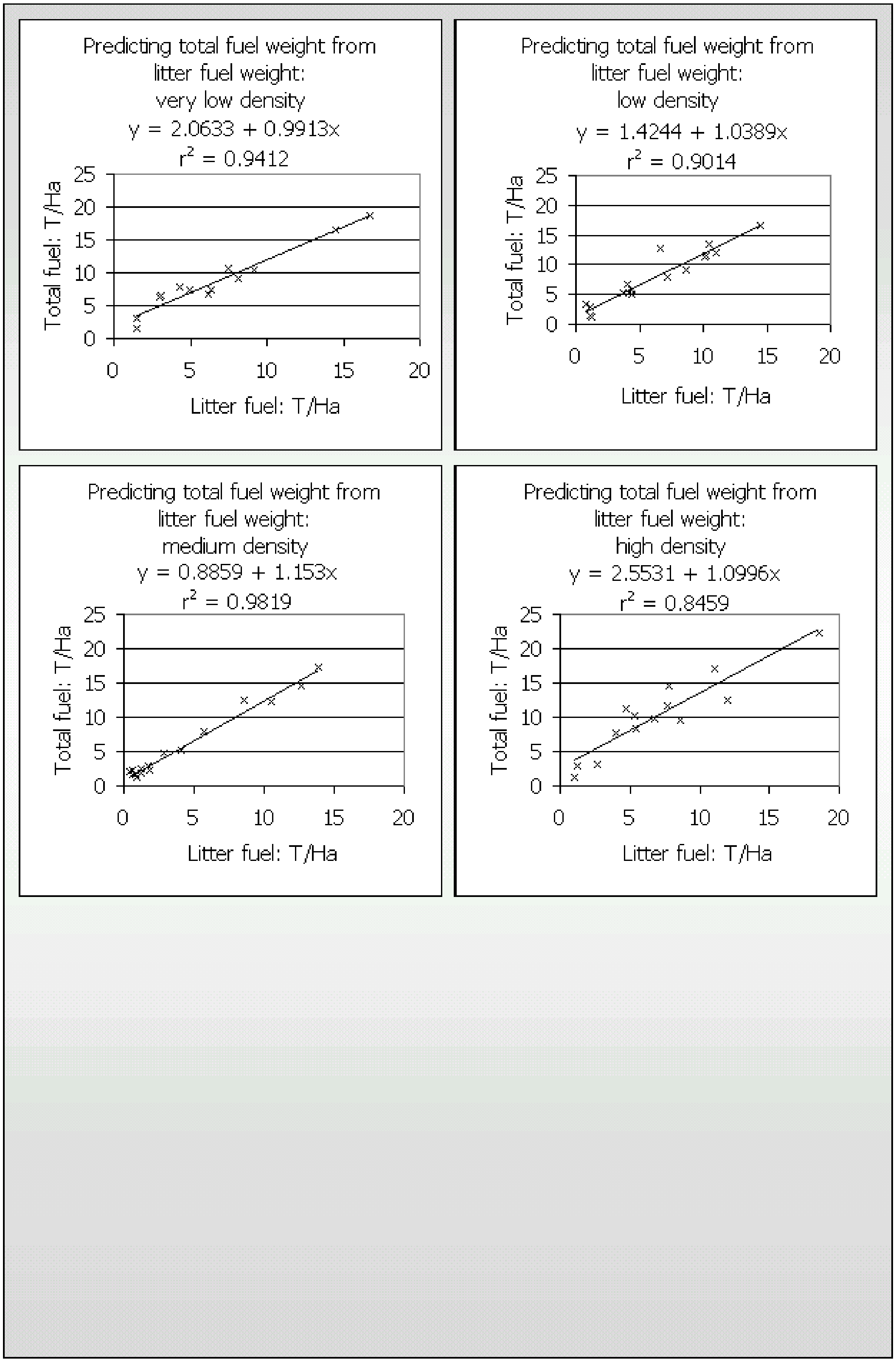


Figure 70: Predicting total fuel from litter fuel: tree density ordering

Relationship of litter weight to litter field characteristics

Litter fuel weight was examined for correlations with all field measures taken during sampling. There were consistent strong positive correlations for litter cover, litter depth and litter volume results across all categories in all site orderings. Beck (1994) discussed predictive modelling using litter depth and cover to determine litter fuel weight. Linear regression modelling showed the potential for determining litter fuel weight from these simple field measures.

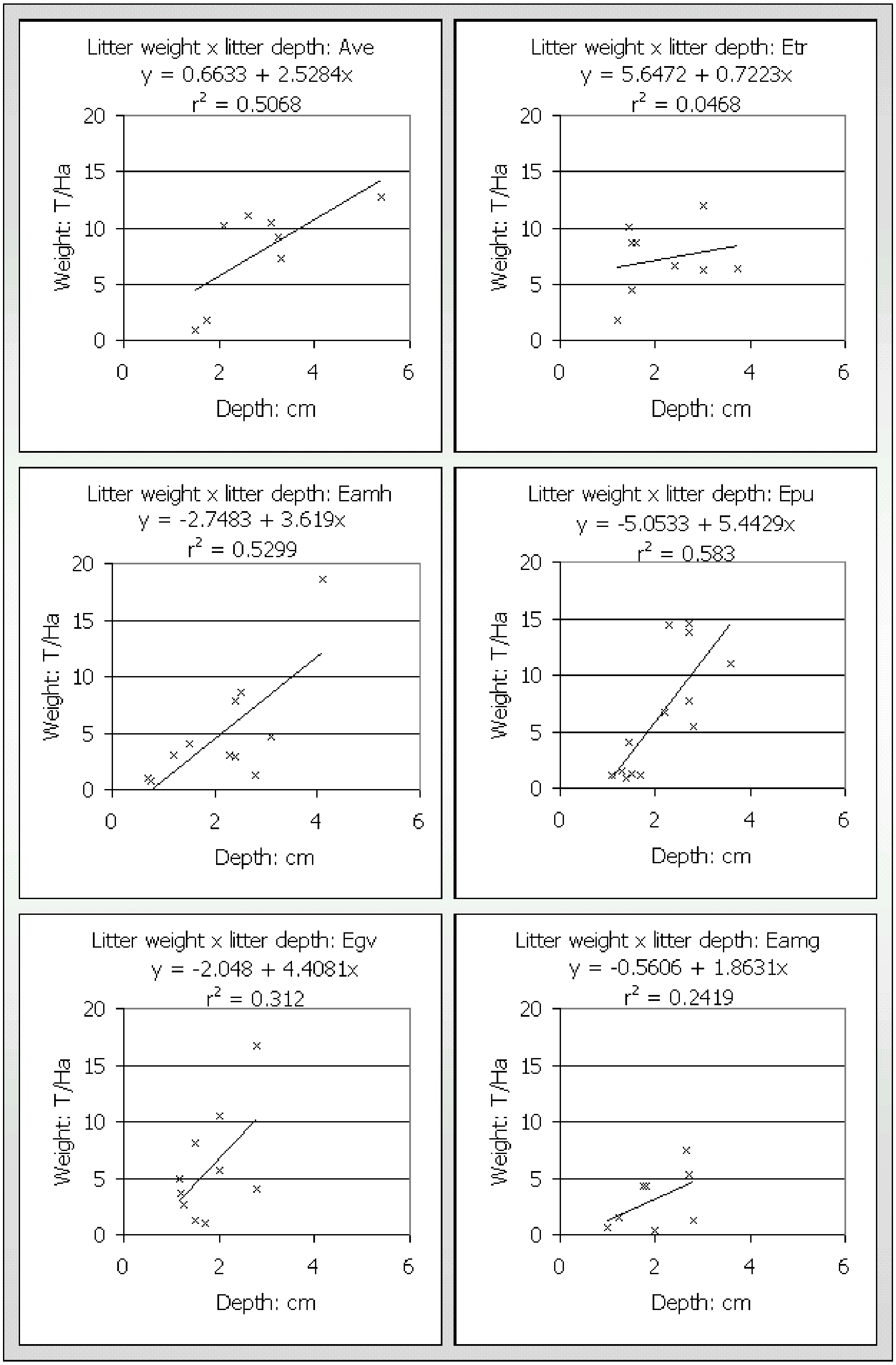


Figure 71: Litter weight relationship to litter depth: canopy ordering

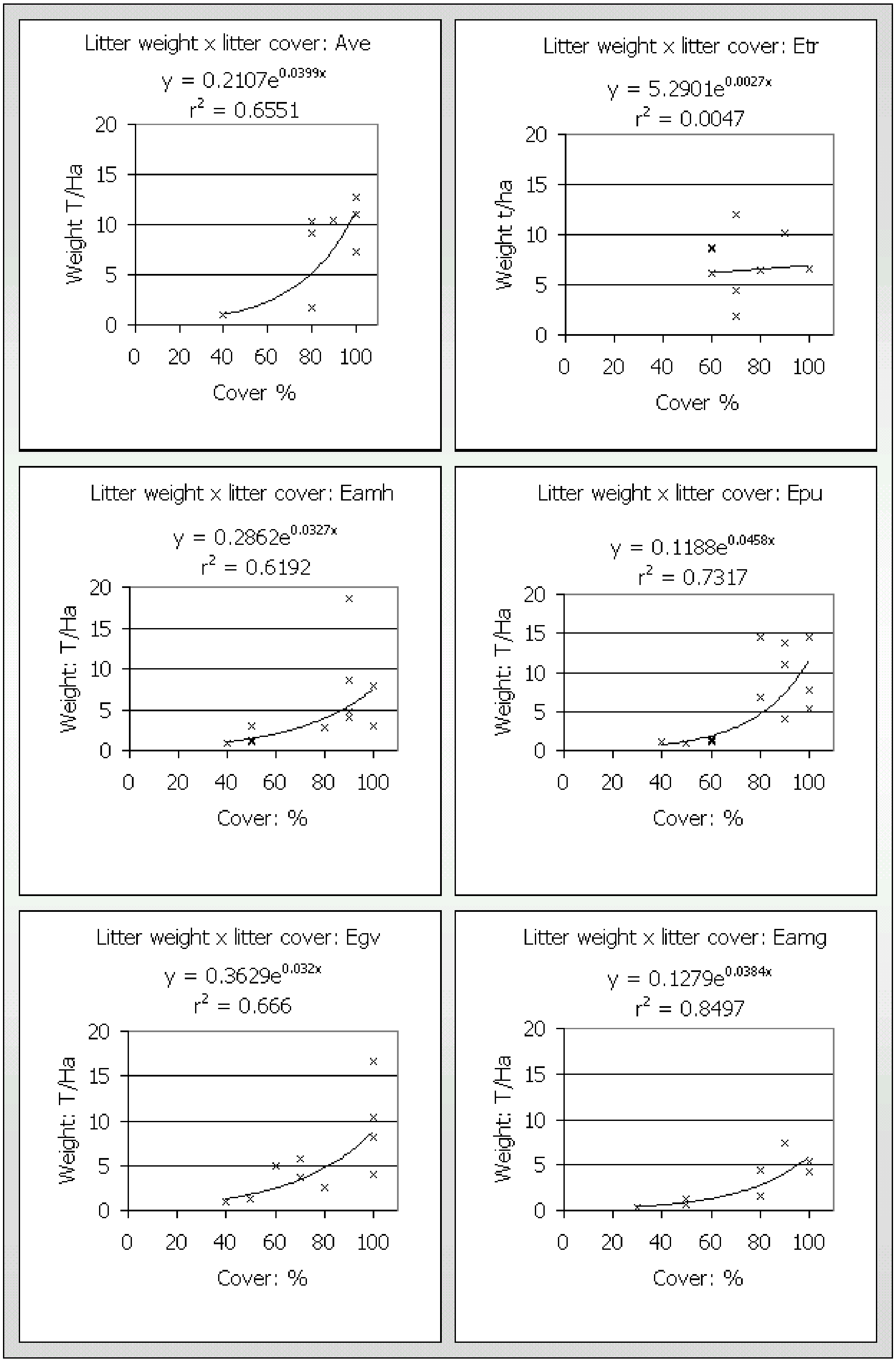


Figure 72: Litter weight relationship to litter cover: canopy ordering

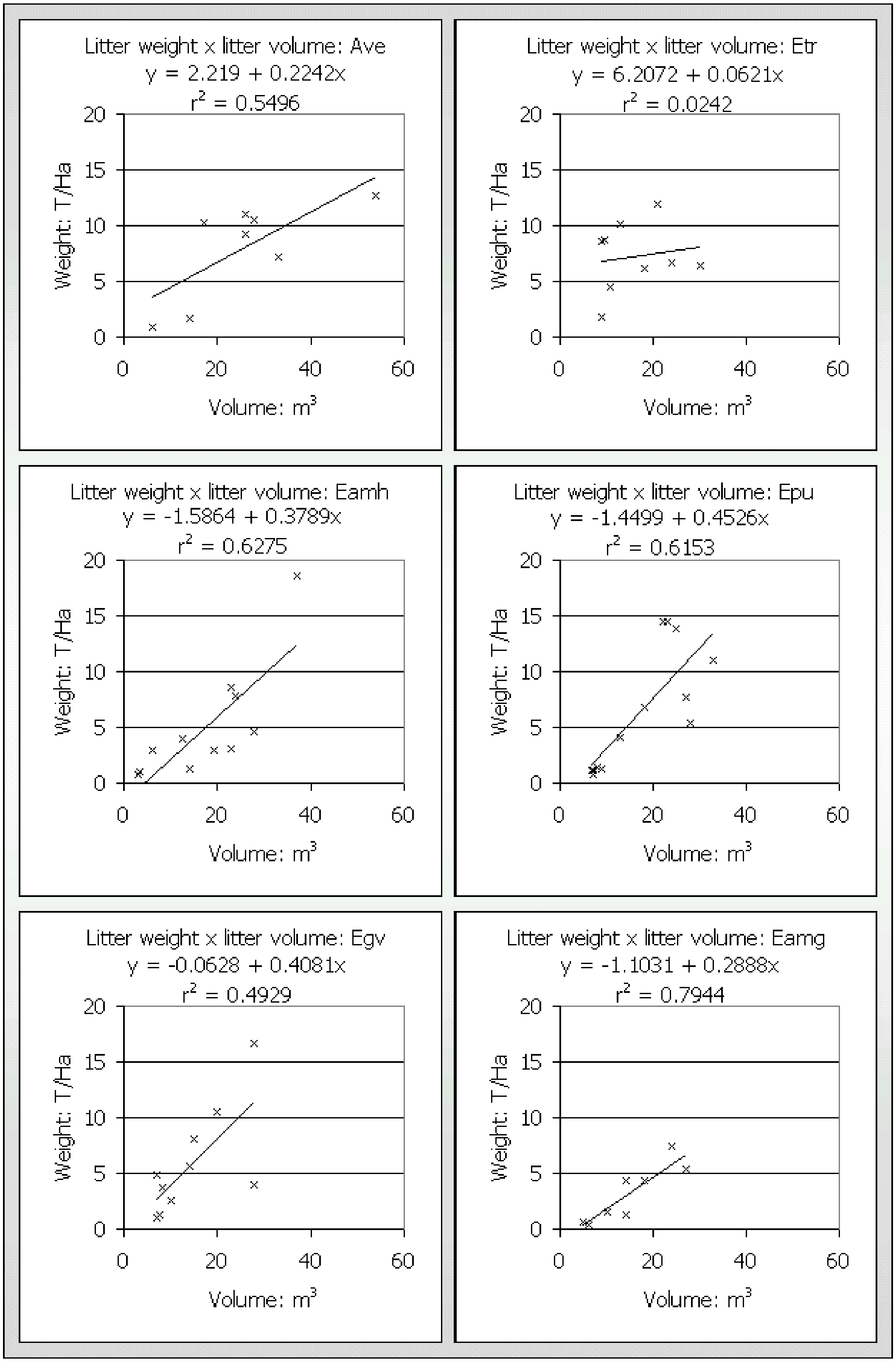


Figure 73: Litter weight relationship to litter volume: canopy ordering

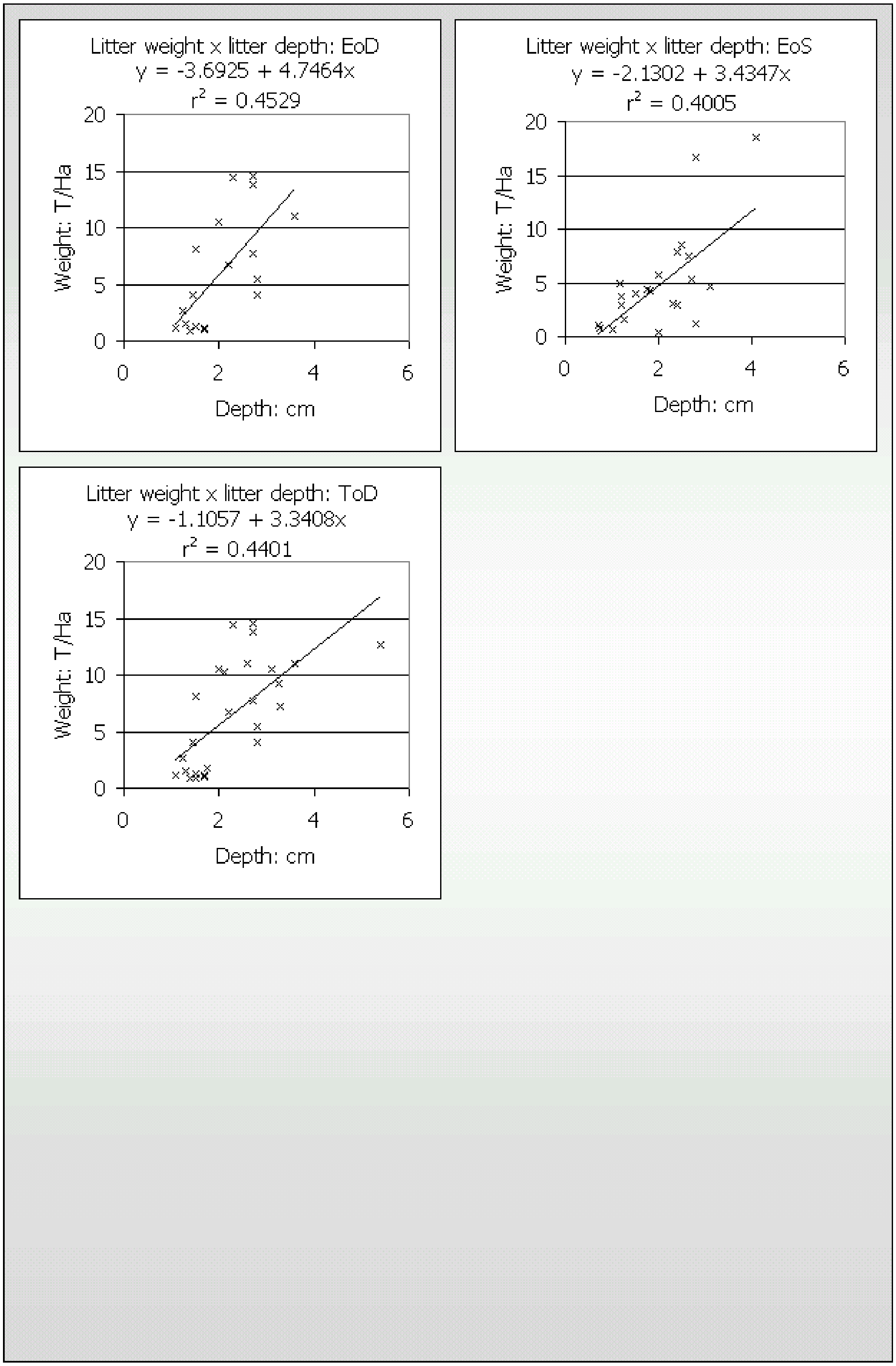


Figure 74: Litter weight relationship to litter depth: geology ordering

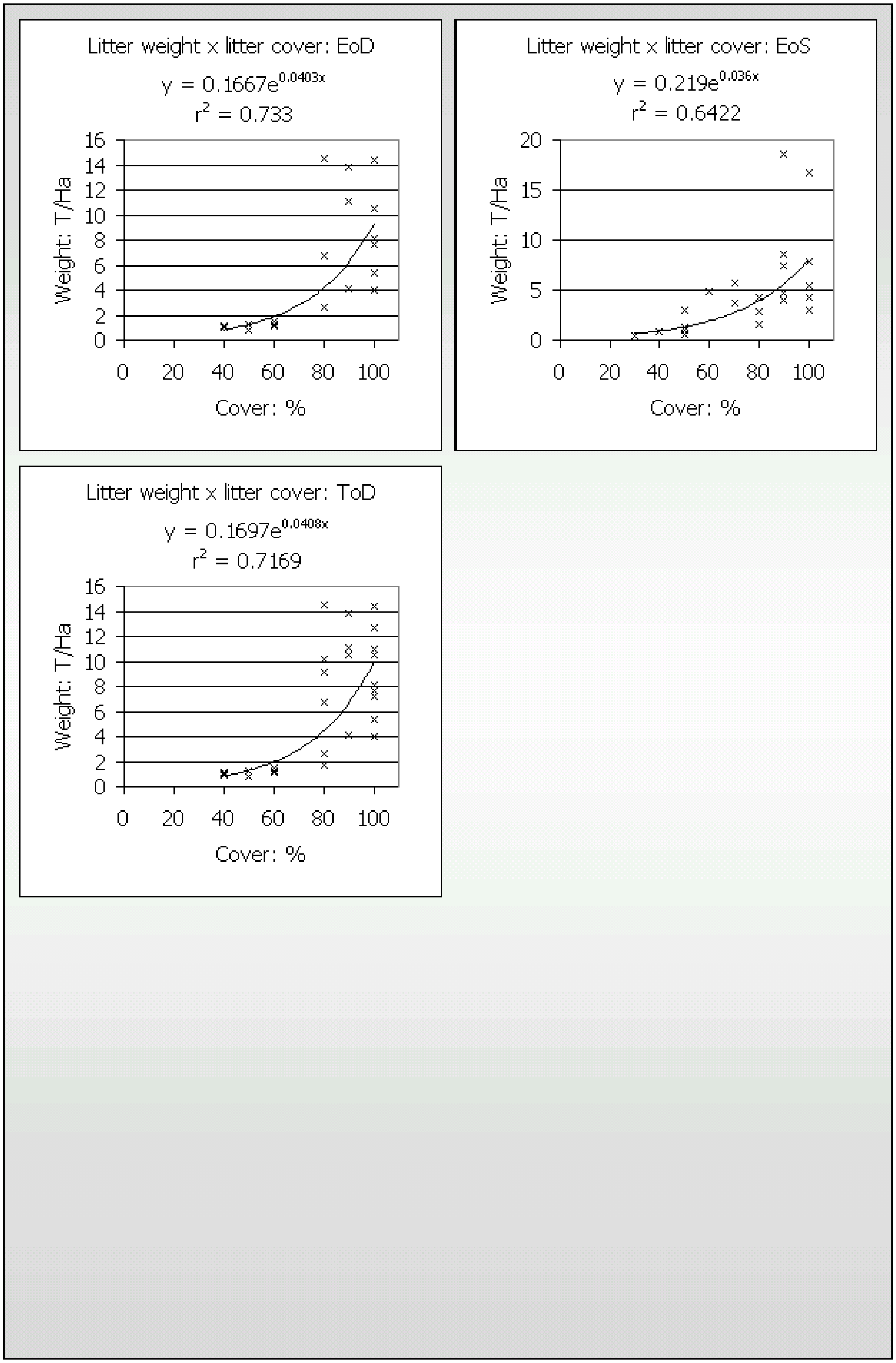


Figure 75: Litter weight relationship to litter cover: geology ordering

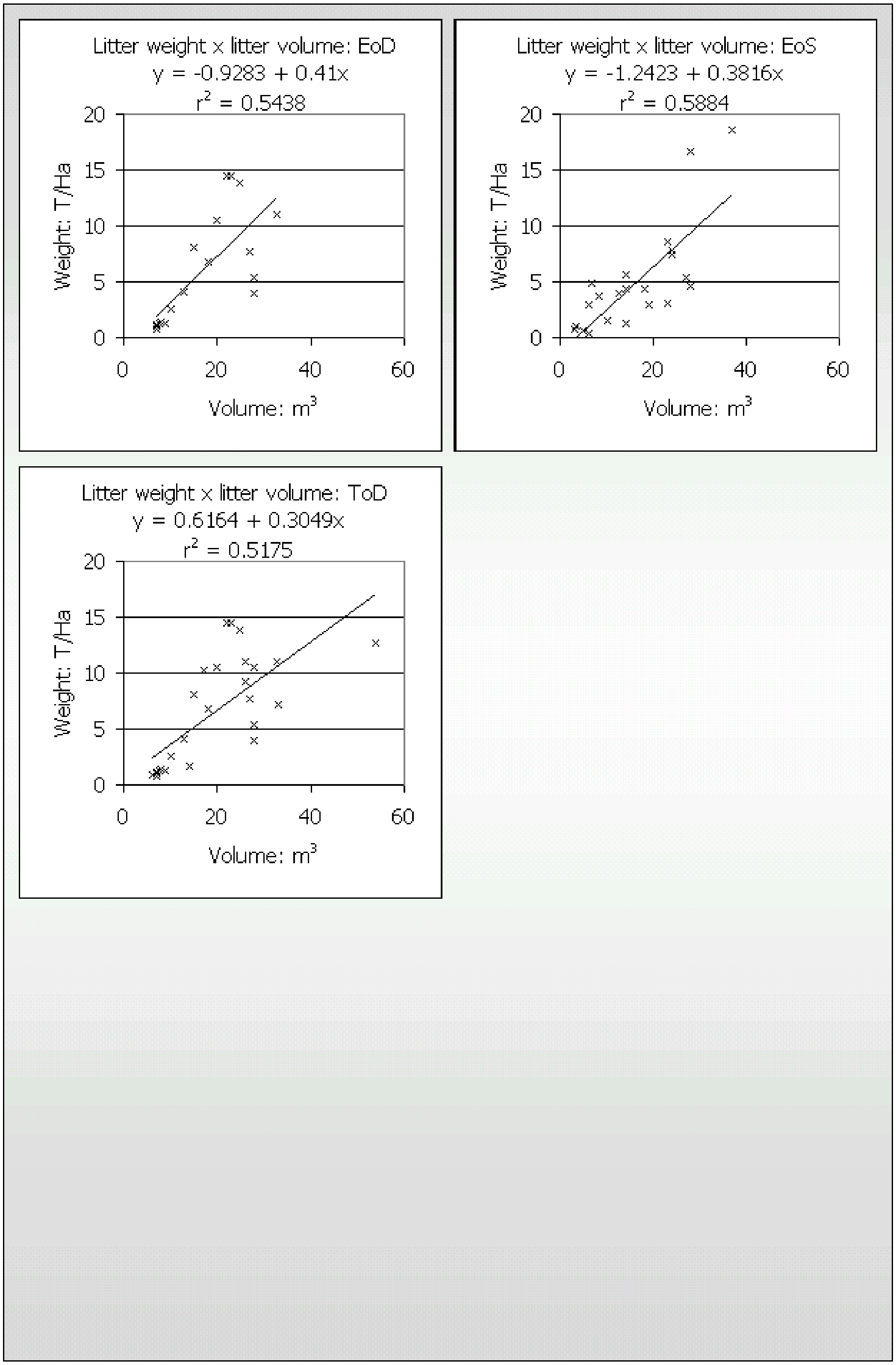


Figure 76: Litter weight relationship to litter volume: geology ordering

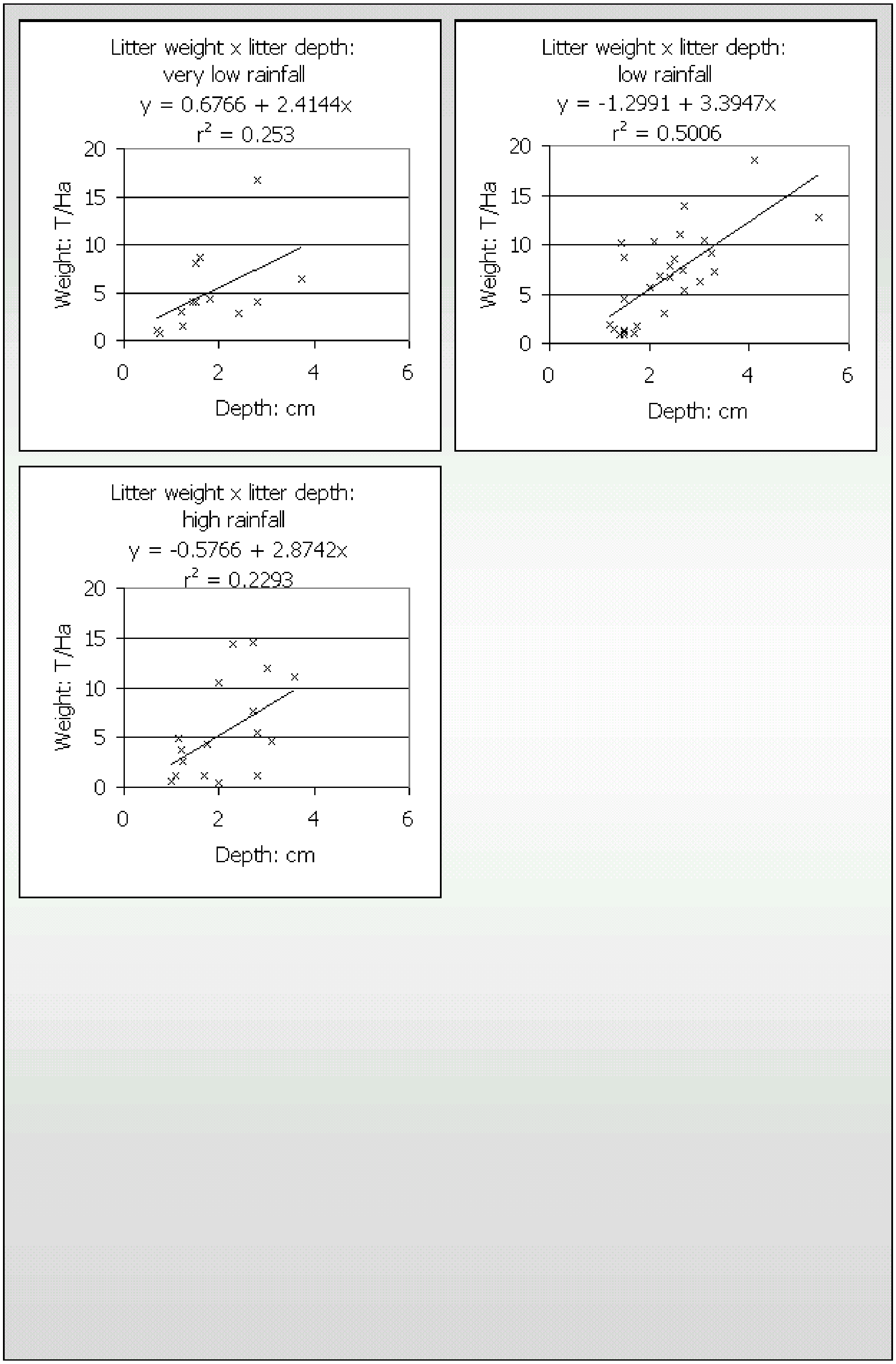


Figure 77: Litter weight relationship to litter depth: rainfall class ordering

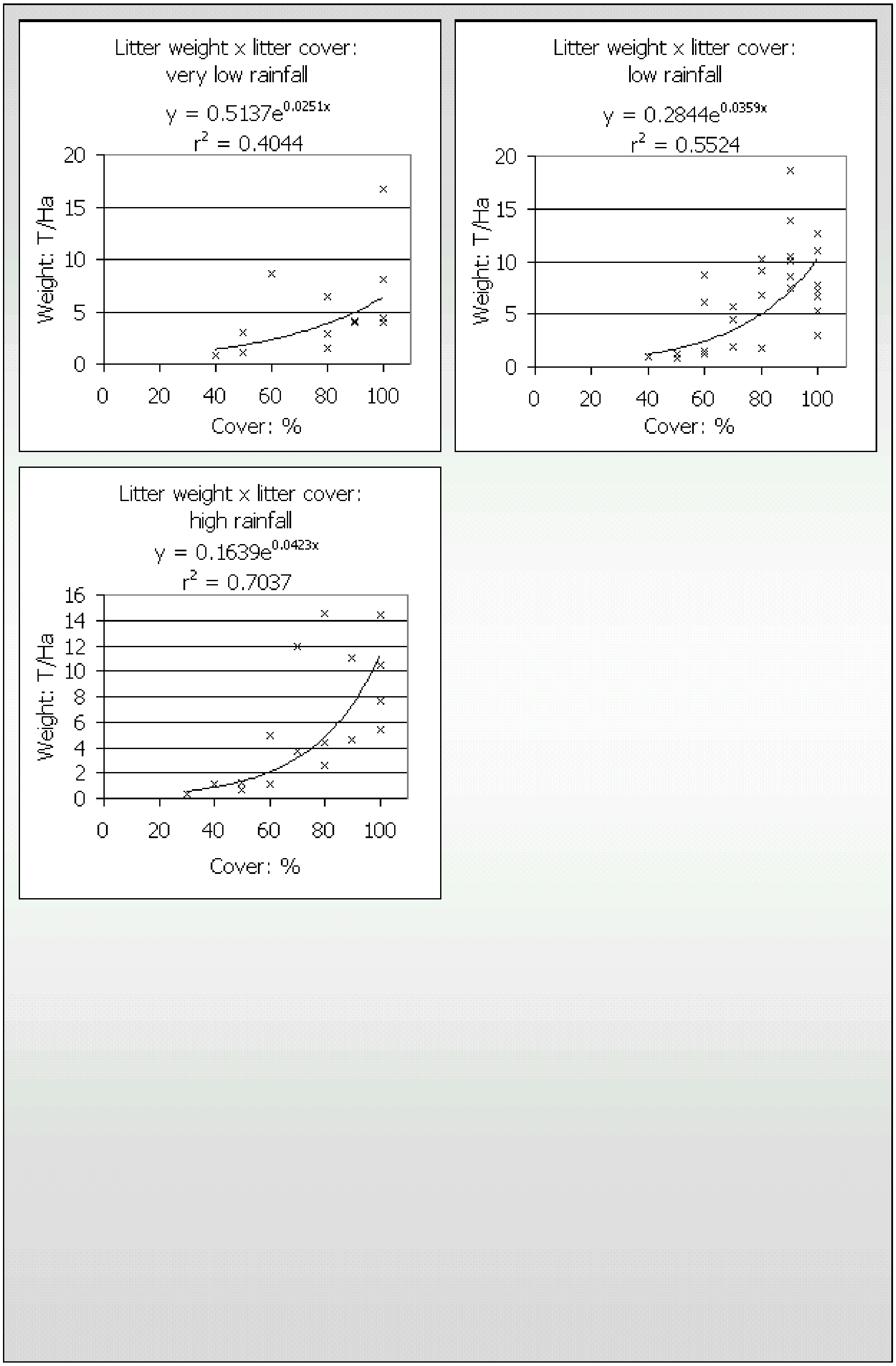


Figure 78: Litter weight relationship to litter cover: rainfall class ordering

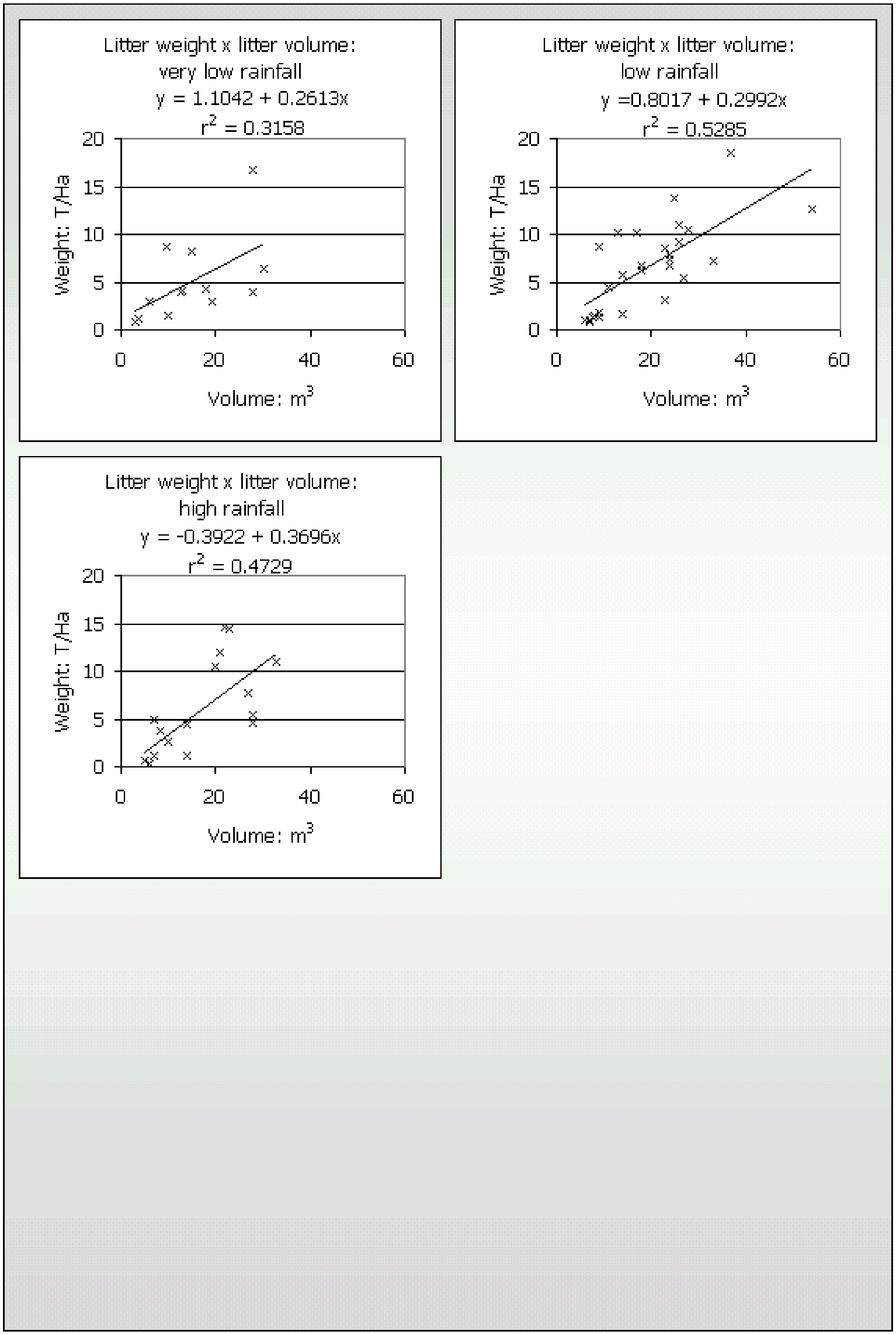


Figure 79: Litter weight relationship to litter volume: rainfall class ordering

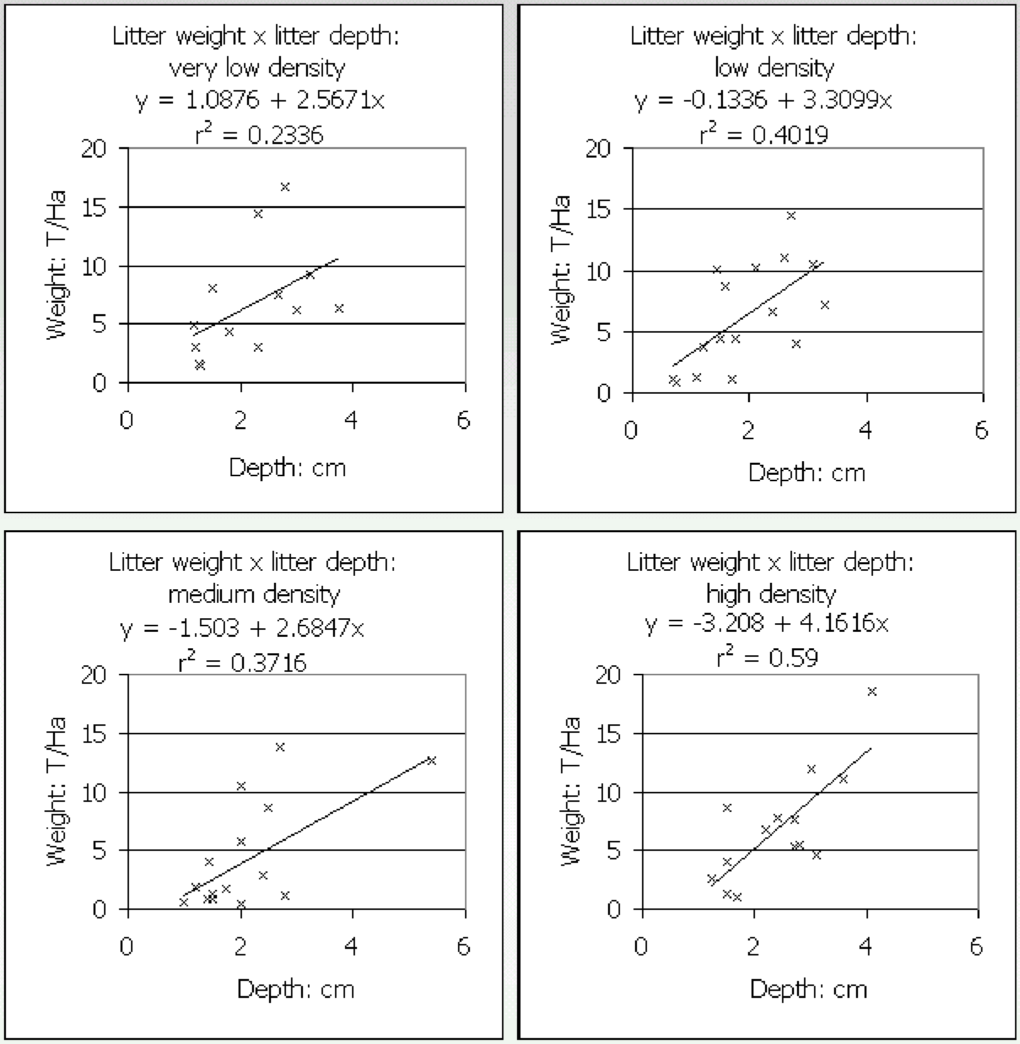


Figure 80: Litter weight relationship to litter depth: canopy tree density ordering

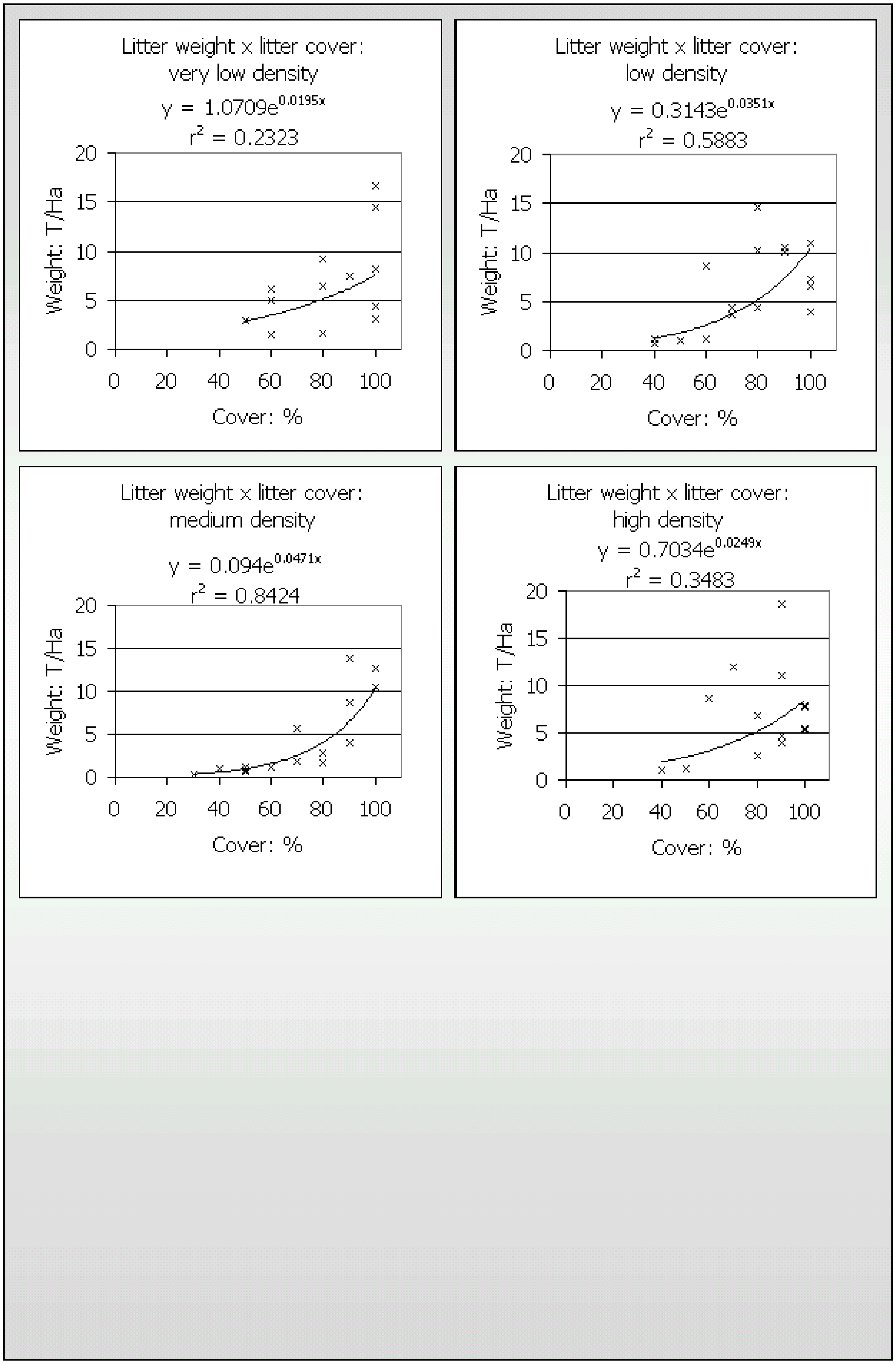


Figure 81: Litter weight relationship to litter cover: canopy tree density ordering

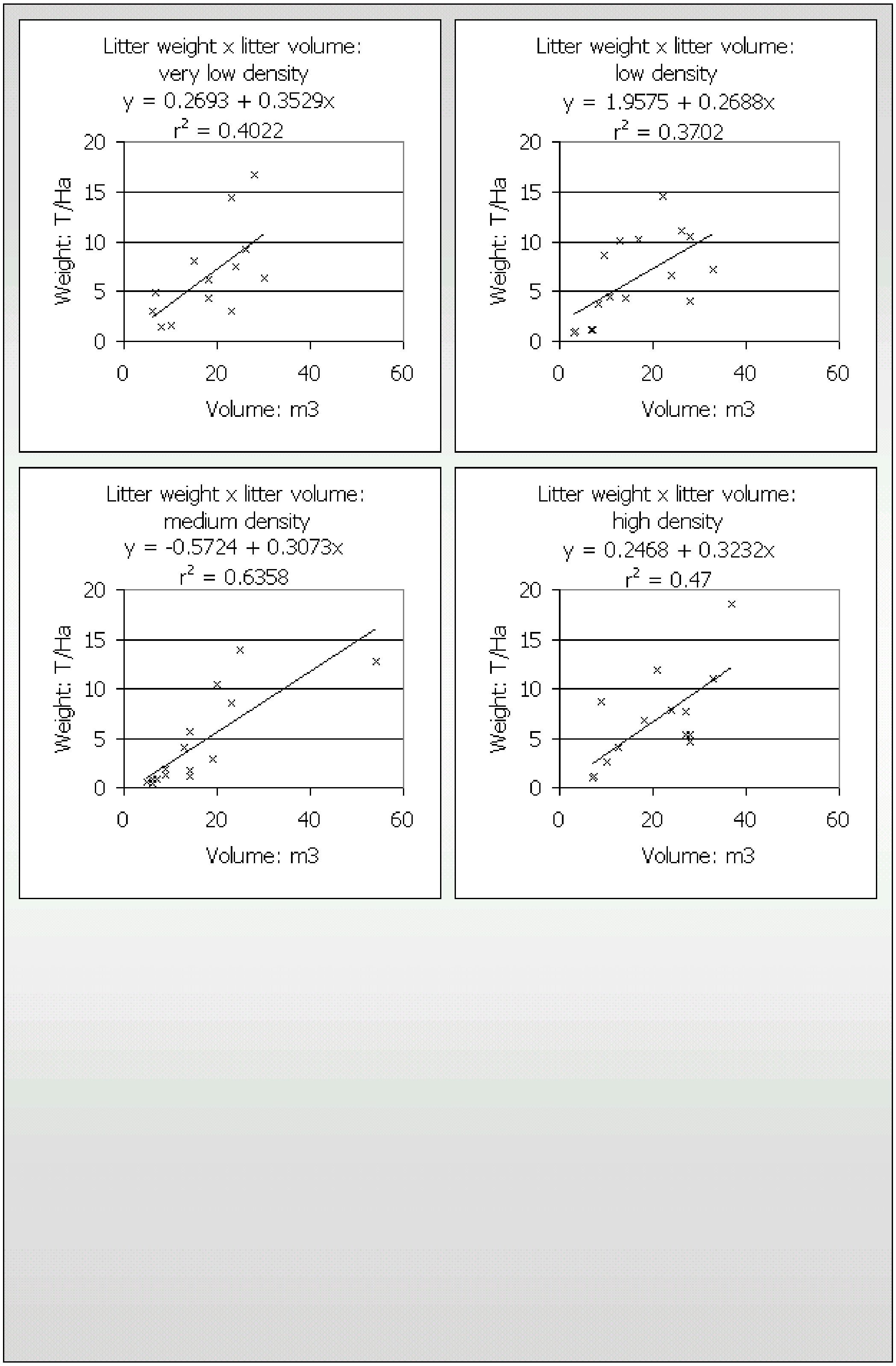


Figure 82: Litter weight relationship to litter volume: canopy tree density ordering

The relationship of litter weight to litter cover, litter depth and litter volume is variable, but for the most part the regression r^2 values presented in Figure 71 to Figure 82 indicate a greater than 40% explanatory power. The only category to exhibit no clear relationship for litter weight is canopy class *Eucalyptus tenuiramis*, with r^2 values of 0.04, 0.00 and 0.02 for litter depth, cover and volume respectively. For this reason, the *E. tenuiramis* class was deleted from further investigations.

Predicting total weight from litter field characteristics

Given the clear relationship between litter fuel weight and total fuel weight, and the relationships between litter weight and litter depth, cover and volume, there is the potential to derive total fuel loads from the litter field characteristics. The relationships between total fuel weight and litter depth, cover and volume are shown in Figure 82 to Figure 94, below.

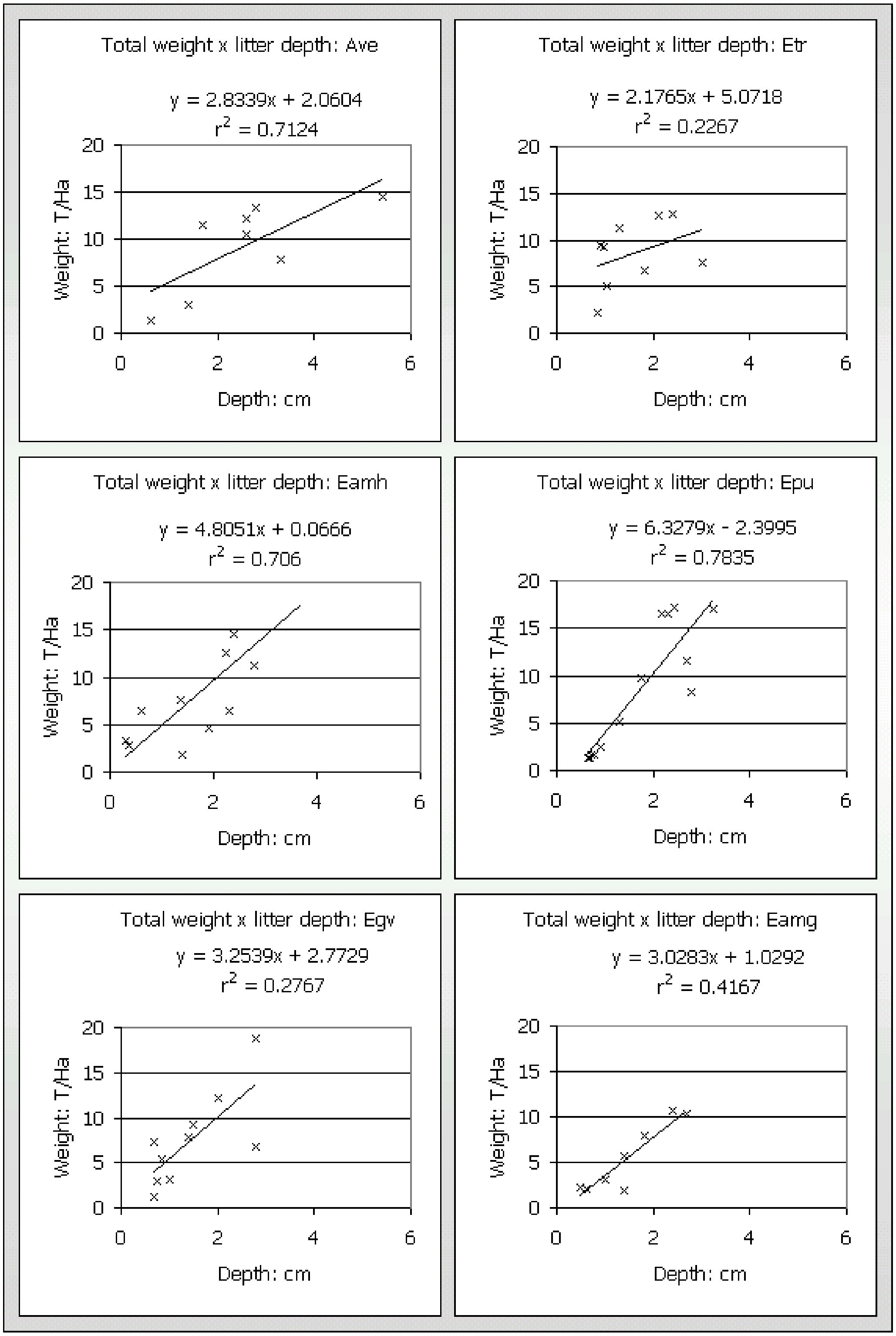


Figure 83: Total weight relationship to litter depth: canopy ordering

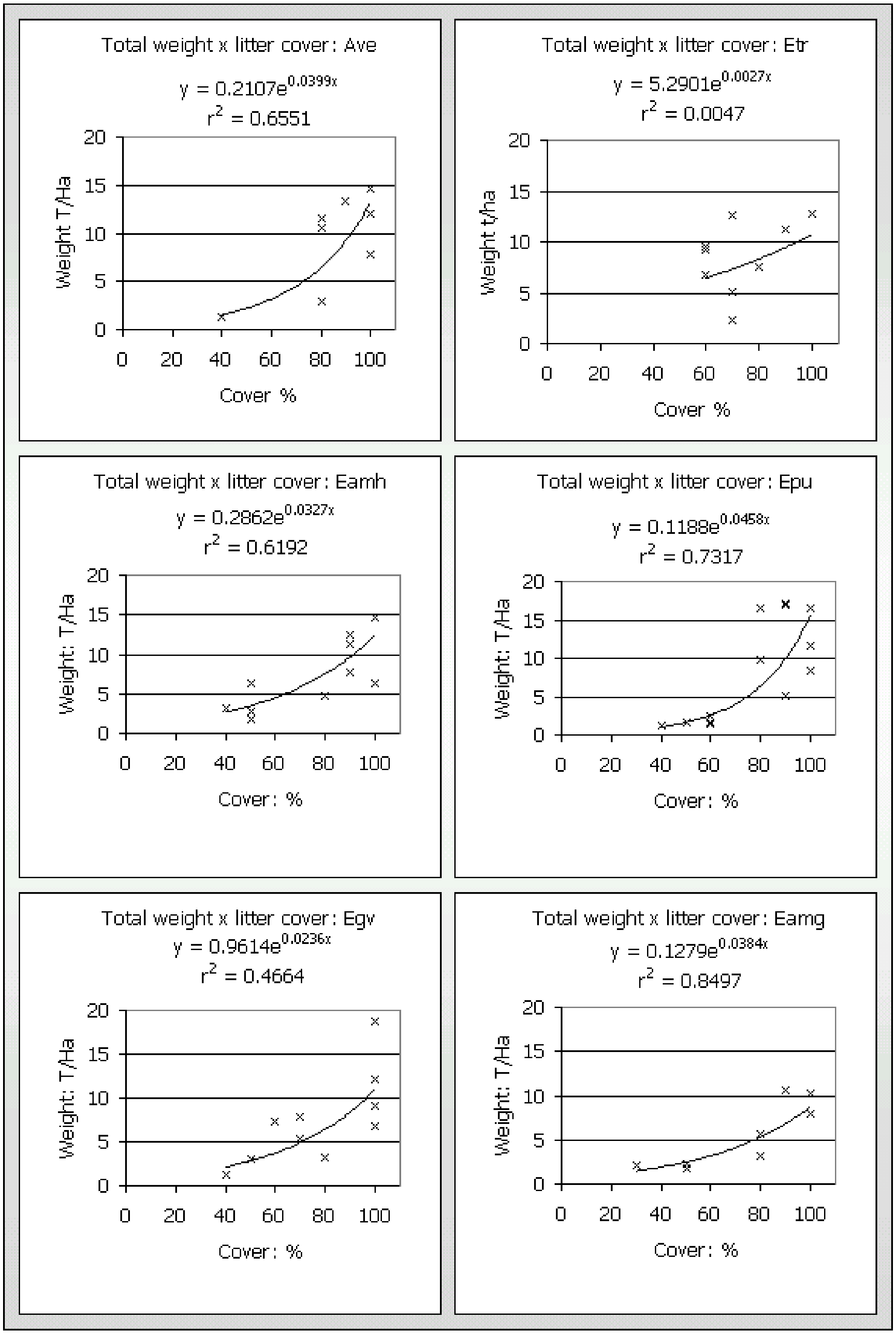


Figure 84: Total weight relationship to litter cover: canopy ordering

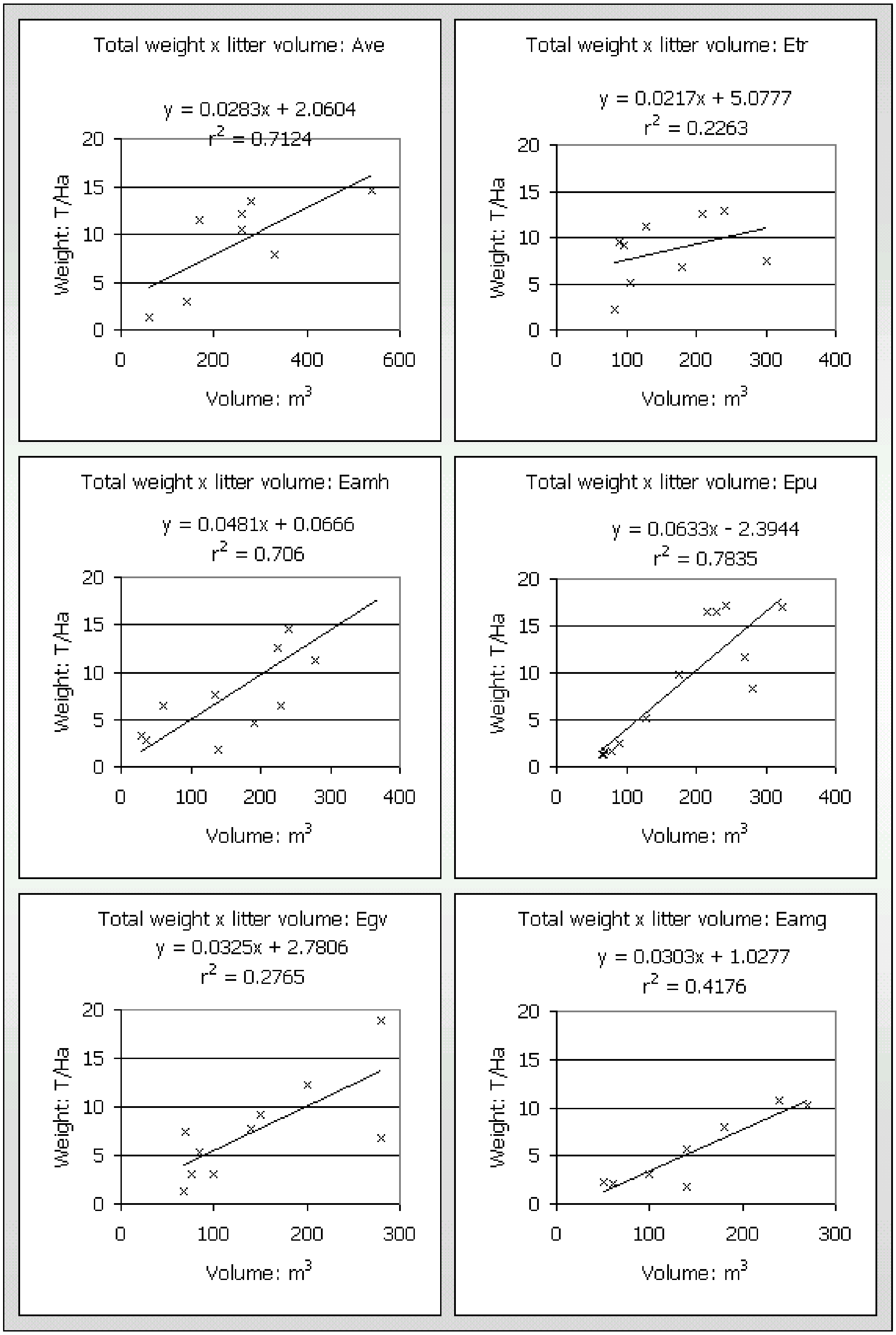


Figure 85: Total weight relationship to litter volume: canopy ordering

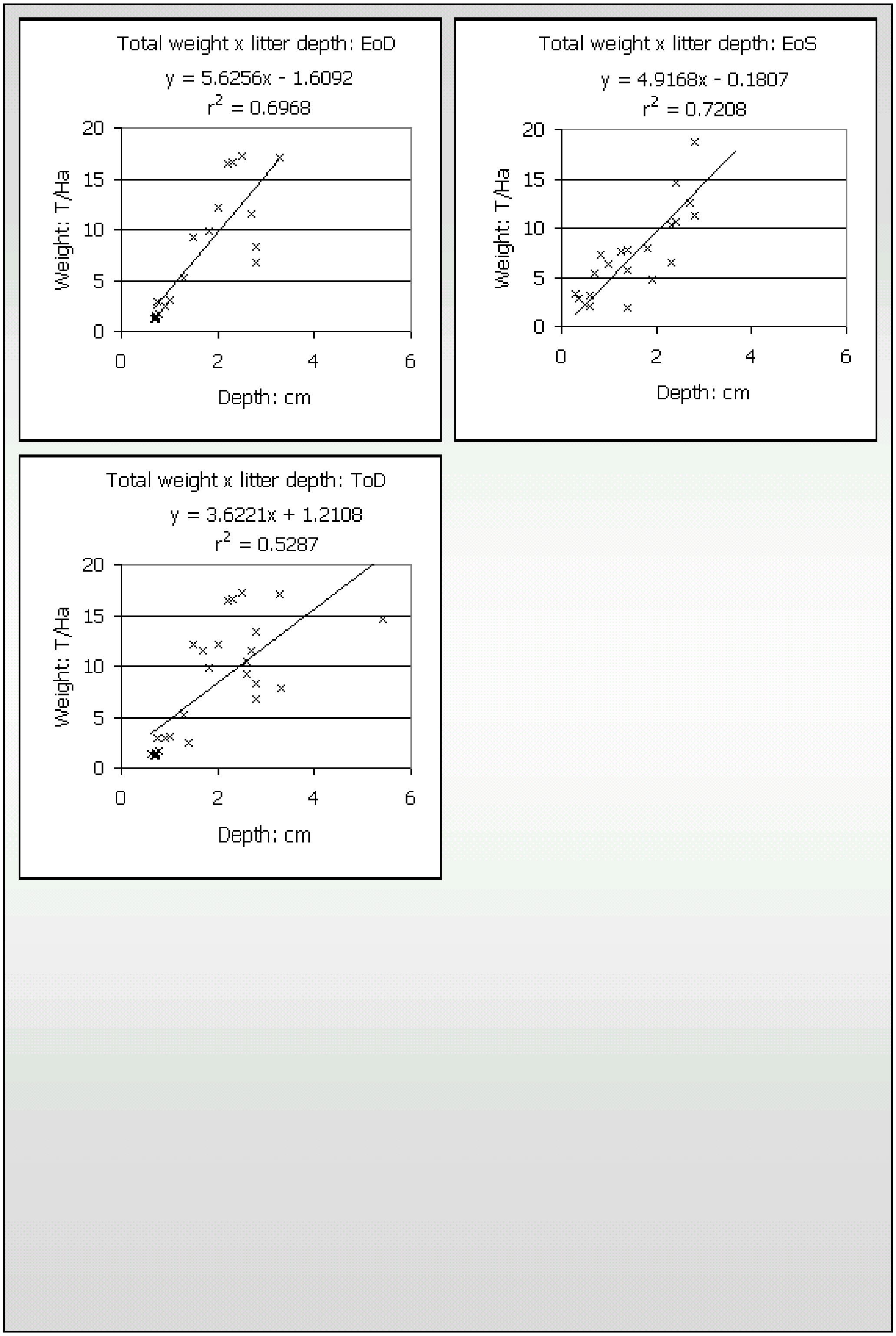


Figure 86: Total weight relationship to litter depth: geology ordering

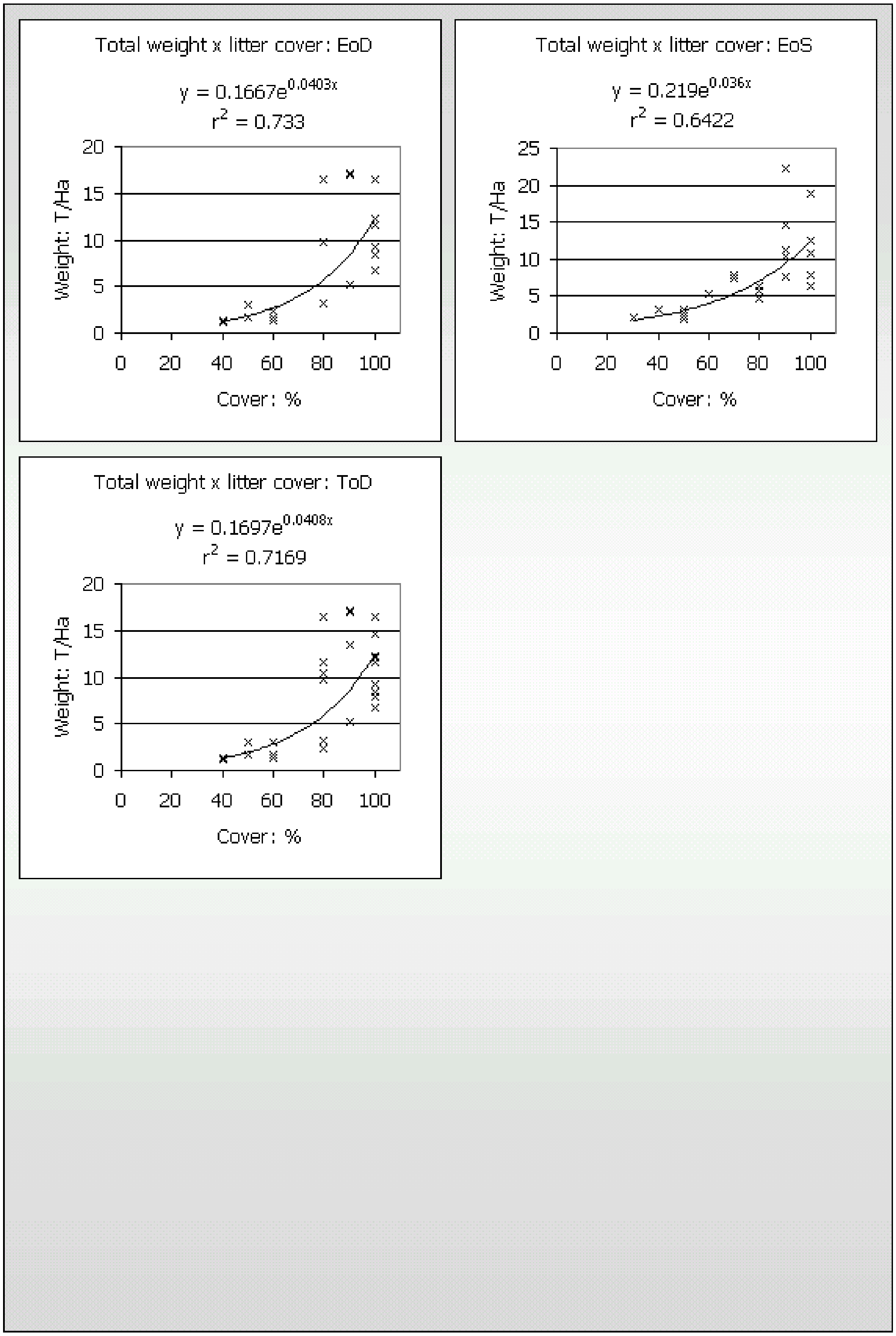


Figure 87: Total weight relationship to litter cover: geology ordering

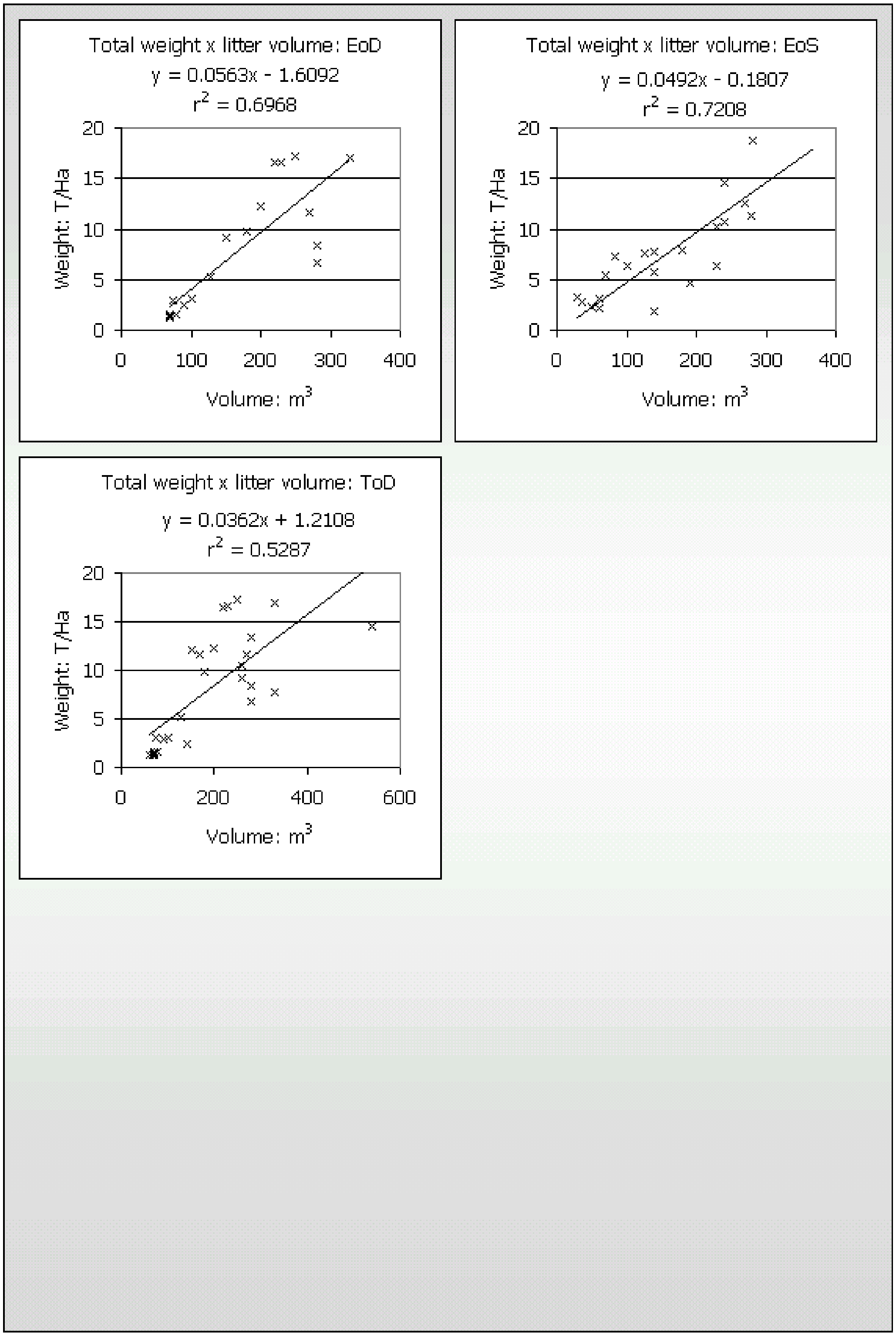


Figure 88: Total weight relationship to litter volume: geology ordering

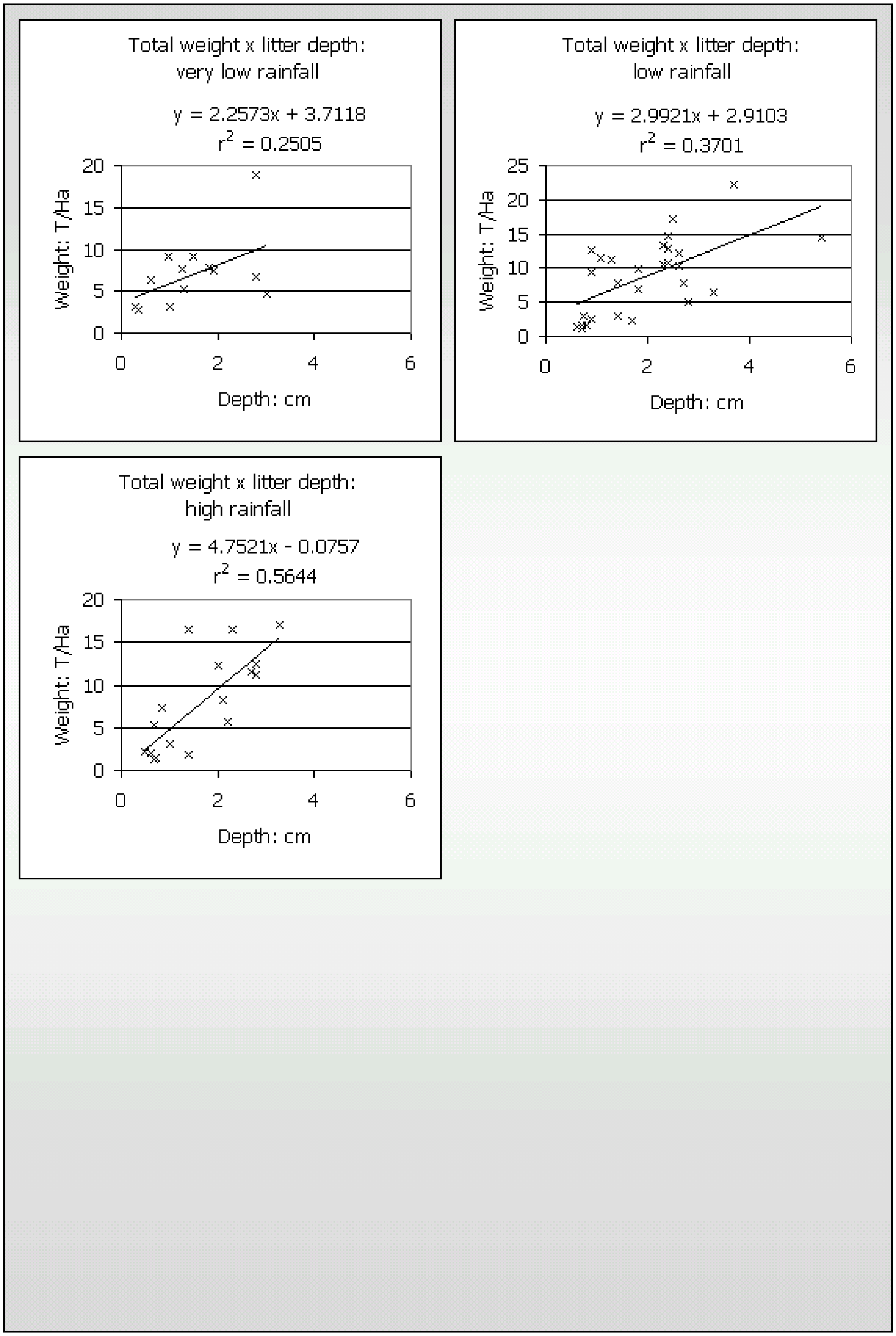


Figure 89: Total weight relationship to litter depth: rainfall ordering

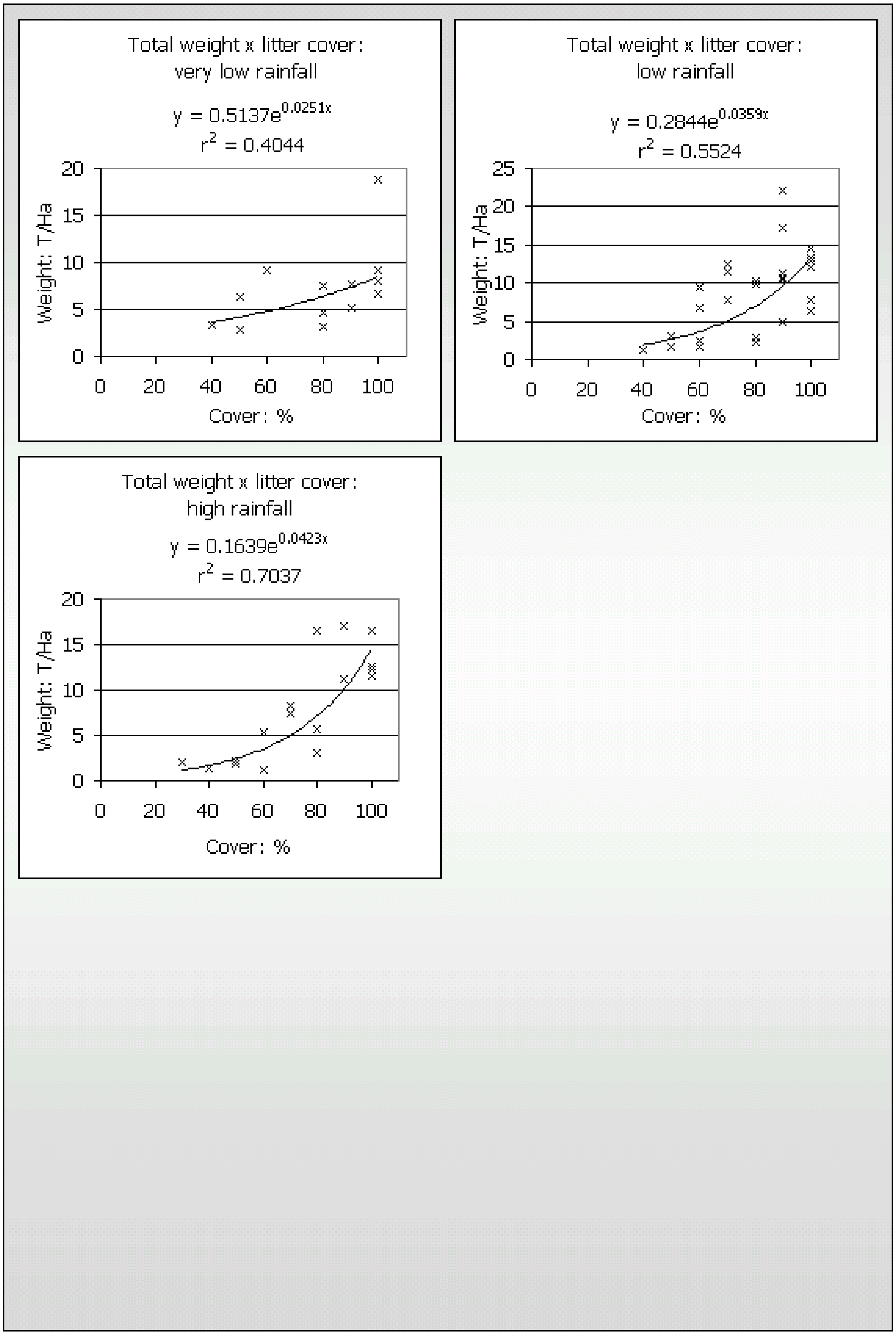


Figure 90: Total weight relationship to litter cover: rainfall ordering

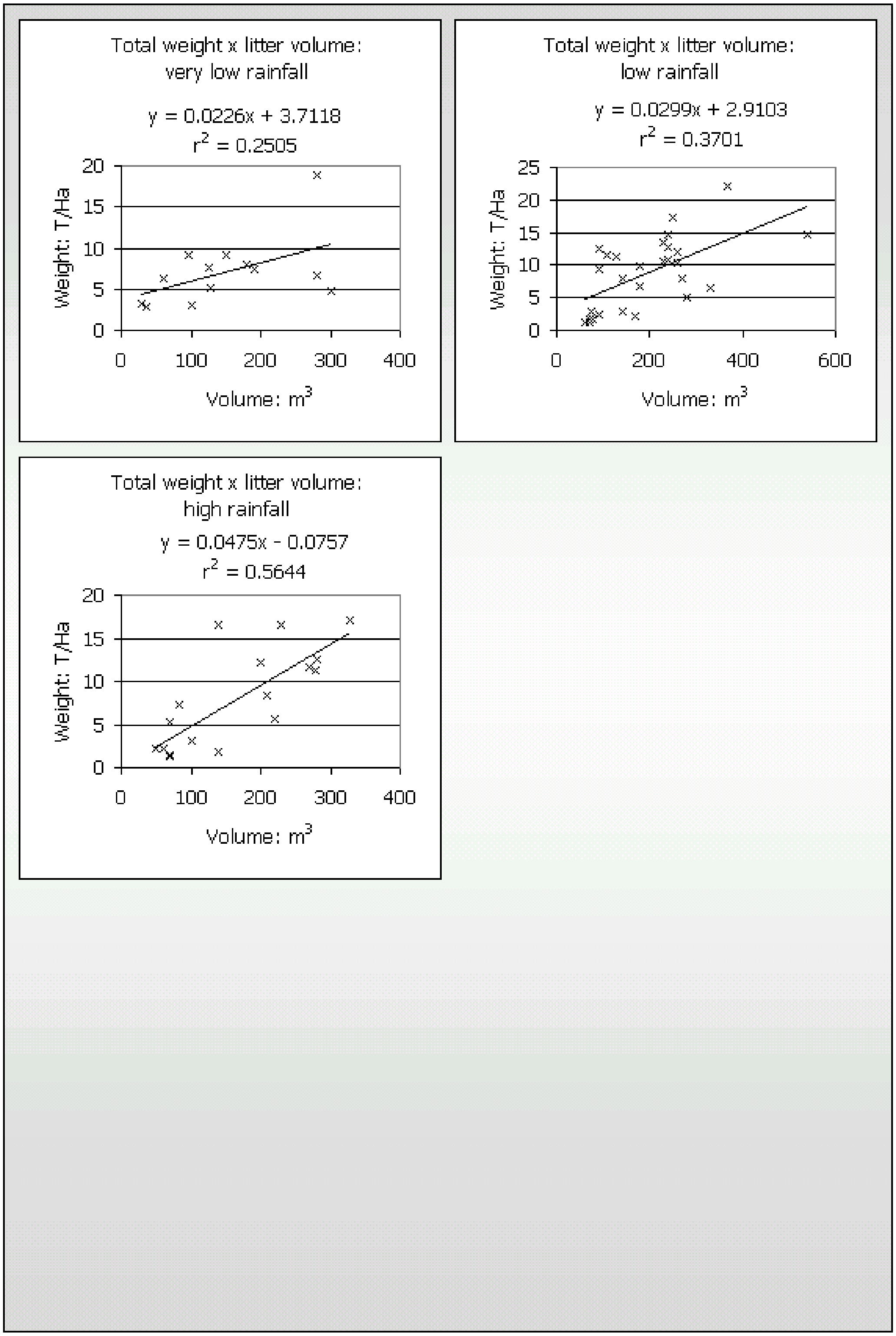


Figure 91: Total weight relationship to litter volume: rainfall ordering

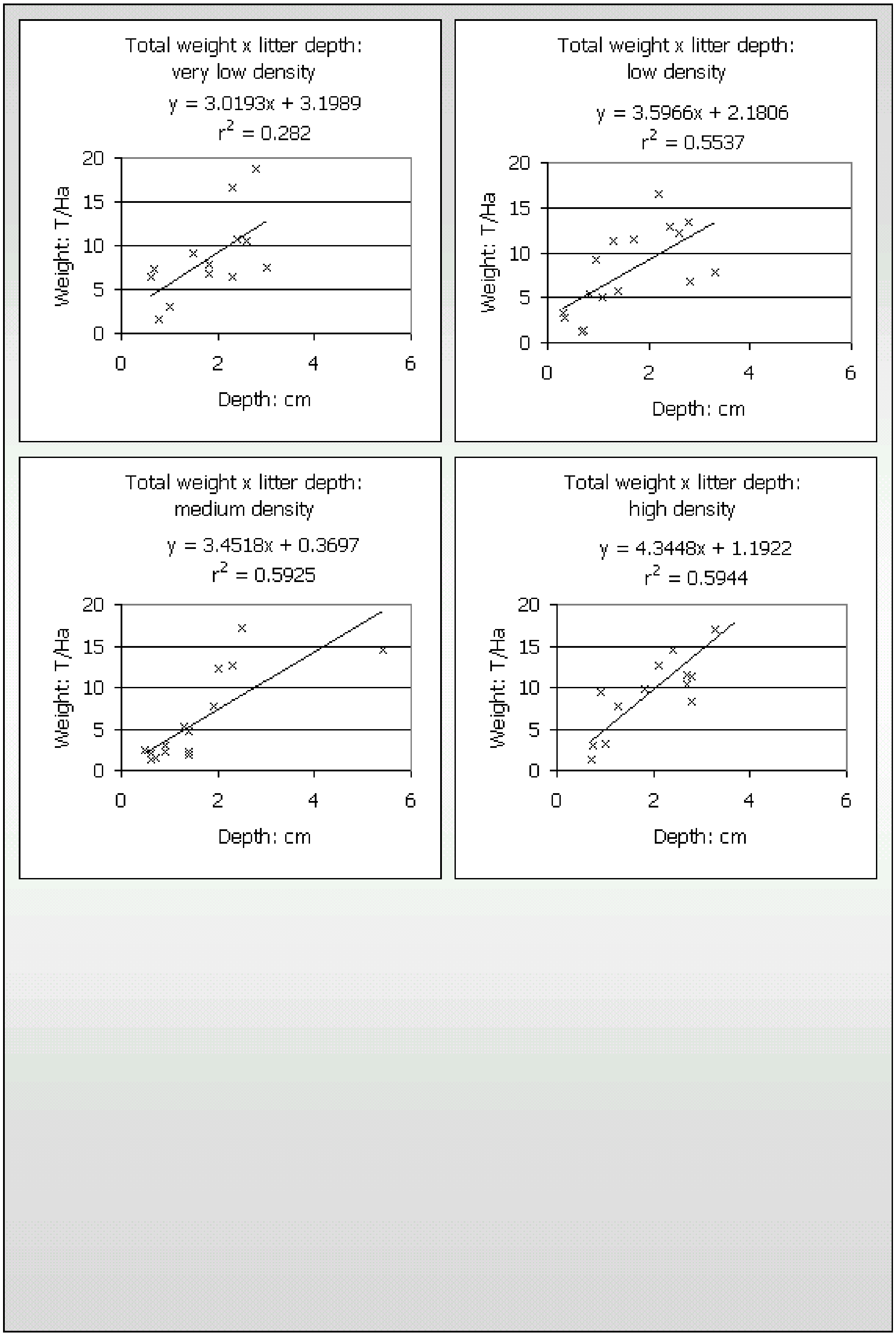


Figure 92: Total weight relationship to litter depth: tree density ordering

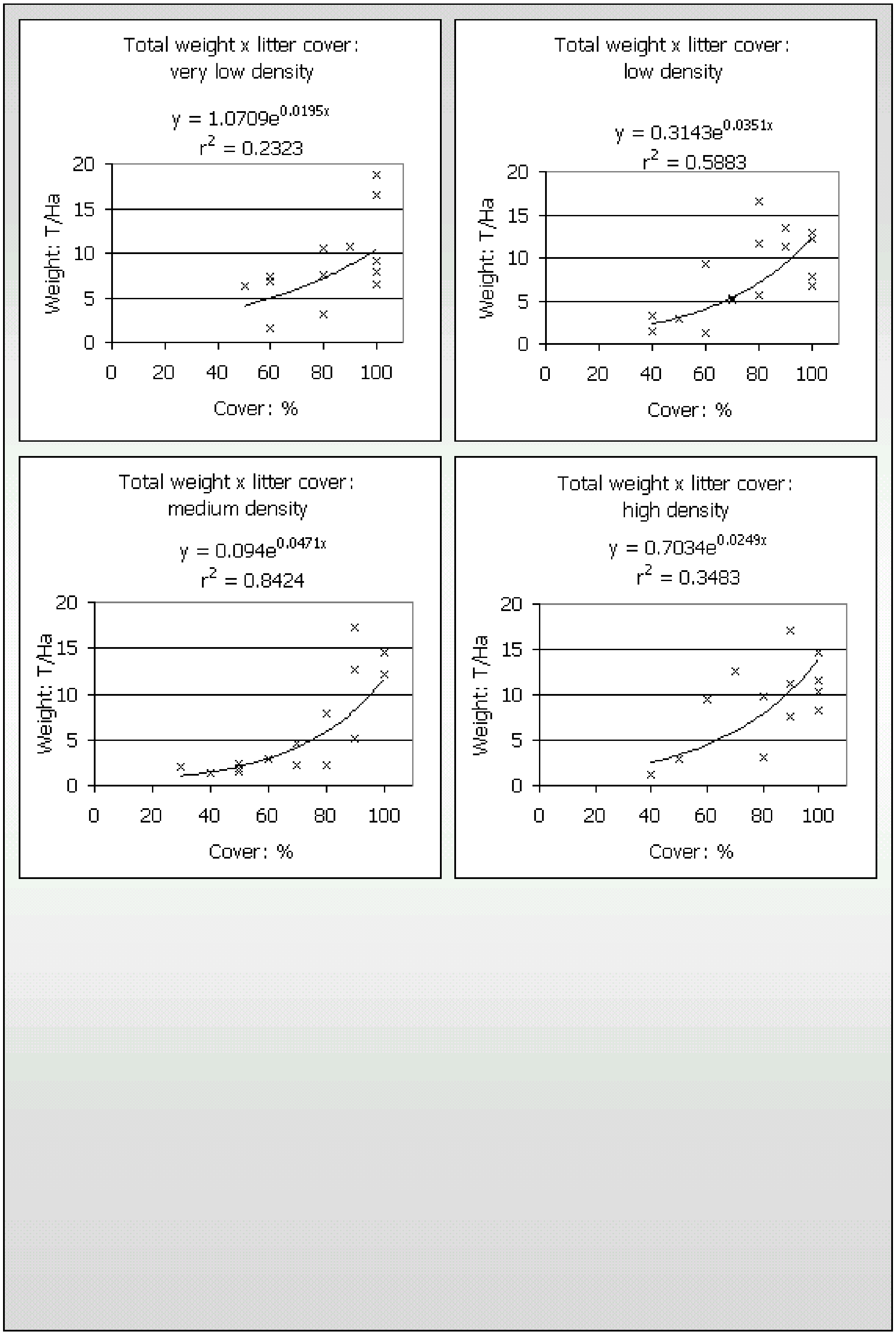


Figure 93: Total weight relationship to litter cover: tree density ordering

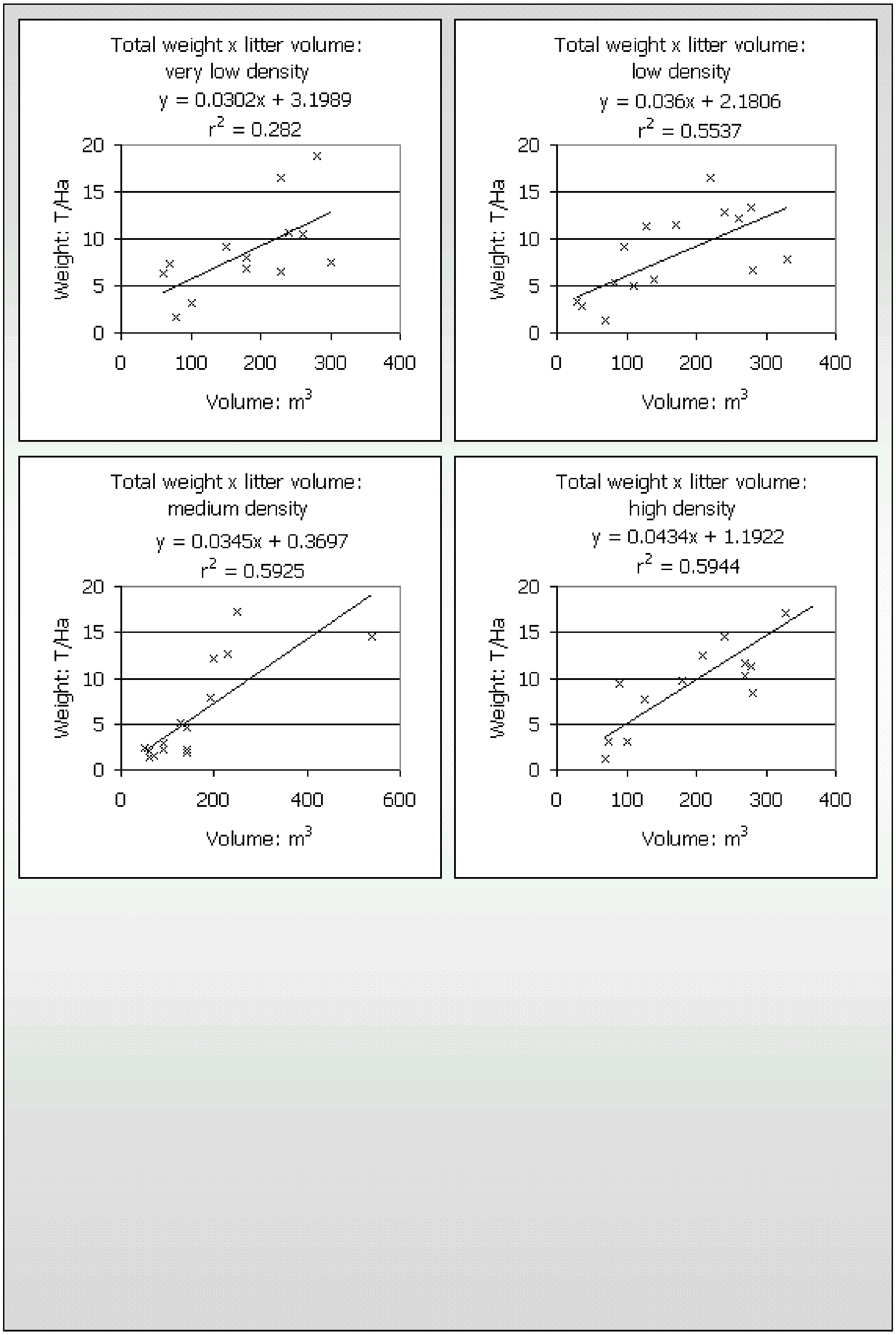


Figure 94: Total weight relationship to litter volume: tree density ordering

The relationships between total fuel weight and the litter field measures are not as strong as with litter fuel weight and the same field measures, which makes logical sense. Nevertheless, the explanatory power of the regression equations can be used to provide a means of developing a fast and reasonably accurate field estimation tool. The simplest, and therefore most widely understood method of presenting information of this nature is in the form of a look-up chart, which is presented in Table 31. This look-up chart provides an estimation method for fuel weight that is independent of laboratory processing and requires only low-level understanding of ecological principles.

A suggested field weight estimation method

A simple method of estimating total flash-fuel for any dry sclerophyll site conforming to the categories identified in this study would proceed as follows:

Determine the area to be studied.

Determine the site's geology type, canopy dominant tree species, rainfall class and tree density. Rainfall class will require a precipitation map and tree density class will require a Bitterlich wedge measurement block (Mueller-Dombois and Ellenberg 1974).

If the fire age for the site is known, use the chart depicted in Table 30.

Part 2	Rainfall class			Tree density class				Canopy type					
Age	VLR	LR	HR	VLD	LD	MD	HD	Ave	Eah	Eag	Ep	Et&r	Ev&g
2	4.3	4.1	4.7	4.4	6.7	3.3	4.5	7.0	2.9	4.1	3.7	0.0	3.4
3	4.8	5.1	6.1	5.0	8.2	4.5	4.9	9.6	3.9	4.6	5.3	3.8	4.1
4	5.3	6.0	7.3	5.7	9.2	5.6	5.3	10.8	4.8	5.2	6.7	6.1	4.8
5	5.8	6.8	8.3	6.3	9.9	6.7	5.7	11.5	5.6	5.8	8.0	7.5	5.5
6	6.4	7.6	9.2	6.9	10.3	7.6	6.1	11.8	6.3	6.3	9.1	8.3	6.2
7	6.9	8.3	10.0	7.5	10.6	8.5	6.5	11.9	6.9	6.9	10.1	9.0	6.9
8	7.4	9.0	10.7	8.1	10.8	9.2	6.9	12.0	7.4	7.5	11.0	9.4	7.5
9	8.0	9.6	11.4	8.7	10.9	10.0	7.3	12.1	7.9	8.0	11.8	9.7	8.2
10	8.5	10.2	11.9	9.2	11.0	10.6	7.7	12.1	8.3	8.6	12.5	9.9	8.9
11	9.0	10.7	12.3	9.8	11.1	11.2	8.1	12.1	8.6	9.2	13.1	10.1	9.5
12	9.6	11.2	12.8	10.3	11.1	11.8	8.5	12.1	8.9	9.8	13.7	10.2	10.1
13	10.1	11.7	13.1	10.8	11.1	12.3	8.9	12.1	9.1	10.3	14.2	10.3	10.8
14	10.6	12.1	13.4	11.3	11.2	12.8	9.3	12.1	9.3	10.9	14.6	10.4	11.4
15	11.2	12.5	13.7	11.8	11.2	13.2	9.7	12.1	9.5	11.5	15.0	10.4	12.0
16	11.7	12.8	13.9	12.3	11.2	13.6	10.1	12.1	9.6	12.0	15.4	10.4	12.6
17	12.3	13.2	14.1	12.8	11.2	13.9	10.5	12.1	9.7	12.6	15.7	10.5	13.2
18	12.8	13.5	14.3	13.3	11.2	14.2	10.9	12.1	9.9	13.2	16.0	10.5	13.8
19	13.4	13.8	14.5	13.7	11.2	14.5	11.3	12.1	9.9	13.7	16.2	10.5	14.4
20	13.9	14.0	14.6	14.1	11.2	14.8	11.7	12.1	10.0	14.3	16.4	10.5	15.0
21	14.4	14.3	14.7	14.6	11.2	15.1	12.1	12.1	10.1	14.9	16.6	10.5	15.6
22	15.0	14.5	14.8	15.0	11.2	15.3	12.5	12.1	10.2	15.4	16.8	10.5	16.2
23	15.5	14.7	14.9	15.4	11.2	15.5	12.9	12.1	10.2	16.0	17.0	10.6	16.7
24	16.1	14.9	15.0	15.8	11.2	15.7	13.3	12.1	10.2	16.6	17.1	10.6	17.3
25	16.6	15.1	15.1	16.2	11.2	15.9	13.7	12.1	10.3	17.2	17.3	10.6	17.9
26	17.2	15.2	15.1	16.5	11.2	16.0	14.1	12.1	10.3	17.7	17.4	10.6	18.4
27	17.7	15.4	15.2	16.9	11.2	16.2	14.5	12.1	10.3	18.3	17.5	10.6	19.0
28	18.3	15.5	15.2	17.2	11.2	16.3	14.8	12.1	10.4	18.9	17.6	10.6	19.5
29	18.8	15.7	15.3	17.6	11.2	16.4	15.2	12.1	10.4	19.4	17.6	10.6	20.0
30	19.4	15.8	15.3	17.9	11.2	16.5	15.6	12.1	10.4	20.0	17.7	10.6	20.6

Table 30: Look-up chart for determining fuel loads in sites with known fire age

If the fire age is not known, the relationship between litter weight and litter depth can be employed to gain an estimate. Using a metre rule, range across the site randomly measuring litter depth, recording a zero for bare ground or rock. The recording of zero values permits the use of litter volume as the predictive element in the lookup chart, as this is shown to have the best predictive strength (see Table 32). Take a minimum of ten measurements and find the average values. For each depth measurement, find the average value from Table 31.

Part 3	Rainfall class			Tree density class				Canopy type				
Depth	VLR	LR	HR	VLD	LD	MD	HD	Ave	Eah	Eag	Ep	Ev&g
0.8	5.4	4.8	4.2	5.1	5.9	2.5	5.7	3.3	4.3	2.8	3.5	4.7
1	5.9	5.5	5.1	5.8	6.9	4.0	6.4	4.7	5.2	3.6	4.6	5.6
1.2	6.4	6.2	5.9	6.5	7.6	5.3	7.1	5.7	6.1	4.4	5.7	6.4
1.4	6.8	6.9	6.7	7.2	8.3	6.4	7.8	6.7	6.9	5.2	6.8	7.3
1.6	7.3	7.6	7.6	7.9	8.8	7.3	8.5	7.5	7.8	6.0	7.8	8.1
1.8	7.8	8.2	8.4	8.6	9.3	8.1	9.2	8.2	8.7	6.8	8.9	9.0
2	8.3	8.9	9.2	9.3	9.8	8.8	9.9	8.8	9.5	7.6	10.0	9.9
2.2	8.8	9.6	10.0	10.0	10.2	9.5	10.6	9.4	10.4	8.4	11.1	10.7
2.4	9.3	10.3	10.9	10.7	10.5	10.1	11.3	9.9	11.3	9.2	12.2	11.6
2.6	9.8	11.0	11.7	11.4	10.9	10.7	12.1	10.4	12.1	10.0	13.3	12.4
2.8	10.3	11.6	12.5	12.1	11.2	11.2	12.8	10.8	13.0	10.8	14.4	13.3
3	10.8	12.3	13.4	12.8	11.5	11.7	13.5	11.2	13.9	11.6	15.5	14.2
3.2	11.3	13.0	14.2	13.5	11.7	12.1	14.2	11.6	14.7	12.4	16.6	15.0
3.4	11.8	13.7	15.0	14.2	12.0	12.5	14.9	12.0	15.6	13.2	17.7	15.9
3.6	12.3	14.4	15.9	14.9	12.2	12.9	15.6	12.3	16.5	14.0	18.8	16.7
3.8	12.7	15.0	16.7	15.6	12.5	13.3	16.3	12.7	17.3	14.8	19.8	17.6
4	13.2	15.7	17.5	16.3	12.7	13.6	17.0	13.0	18.2	15.6	20.9	18.5
4.2	13.7	16.4	18.3	17.0	12.9	14.0	17.7	13.3	19.1	16.4	22.0	19.3
4.4	14.2	17.1	19.2	17.7	13.1	14.3	18.5	13.5	19.9	17.2	23.1	20.2
4.6	14.7	17.8	20.0	18.4	13.3	14.6	19.2	13.8	20.8	18.0	24.2	21.0
4.8	15.2	18.4	20.8	19.1	13.4	14.9	19.9	14.1	21.7	18.9	25.3	21.9
5	15.7	19.1	21.7	19.8	13.6	15.2	20.6	14.3	22.5	19.7	26.4	22.8
5.2	16.2	19.8	22.5	20.5	13.8	15.5	21.3	14.6	23.4	20.5	27.5	23.6
5.4	16.7	20.5	23.3	21.2	13.9	15.7	22.0	14.8	24.3	21.3	28.6	24.5
5.6	17.2	21.2	24.2	21.9	14.1	16.0	22.7	15.0	25.1	22.1	29.7	25.3
5.8	17.7	21.8	25.0	22.6	14.2	16.2	23.4	15.2	26.0	22.9	30.8	26.2
6	18.2	22.5	25.8	23.3	14.4	16.5	24.1	15.4	26.9	23.7	31.9	27.1

Table 31: Look-up chart for determining fuel loads in sites with unknown fire age

Lastly, average the predictions, whether age-based or measurement-based, gained through the different ordering categories to arrive at a single estimate. The use of all orderings for a single prediction will produce an estimate that takes into account the effects of canopy type, geology type, tree density and rainfall class for any site being assessed.

Discussion

The field assessment methods outlined above are not intended to replace the use of fuel accumulation curves based on sampling and weighing methods. These field methods are as an adjunct to the fuel accumulation curves themselves and as a tool of initial examination or rapid assessment. The explanatory power of the field method is not as strong as the age-based predictions from the fuel curves (see chapters 4, 5 and 6), and so this method is suited to being used only on sites where age is not known. Table 32 and Table 33 show the predictive power and relative strength of the field prediction method.

		depth	r^2 values	cover	r^2 values	volume	r^2 values
Canopy	Etr	-1.2 ± 3.6	0.06	2.1 ± 3.4	0.19	-0.2 ± 3.3	0.13
	Epu	-2.4 ± 3.5	0.73	2.9 ± 5	0.45	-0.1 ± 3.2	0.77
	Ave	-0.9 ± 3.4	0.5	2 ± 3.8	0.42	0 ± 3.3	0.54
	Egv	-1.1 ± 4.2	0.36	0.8 ± 3.5	0.53	0 ± 3.6	0.55
	Eamg	-1.6 ± 3.3	0.43	2.5 ± 2.1	0.77	0 ± 1.8	0.84
	Eamh	-4.6 ± 4.4	0.49	4.3 ± 5	0.39	0 ± 3.5	0.68
Geology	EoD	-2 ± 3.8	0.61	2.6 ± 4.6	0.4	0 ± 3.3	0.54
	EoS	-2.2 ± 4.2	0.41	3.6 ± 4.1	0.49	0 ± 3	0.68
	ToD	-1.2 ± 4.1	0.48	2.4 ± 4.3	0.43	0 ± 3.8	0.7
Rainfall	High	-2.3 ± 4.8	0.33	2.8 ± 4.1	0.5	0.1 ± 3.4	0.66
	Low	-1.2 ± 4	0.48	2.8 ± 4	0.44	0 ± 3.6	0.57
	Very Low	-0.6 ± 3.6	0.24	3 ± 3.5	0.28	0 ± 3.4	0.32
Tree Density	High	-1.6 ± 3.1	0.74	4.3 ± 4.9	0.26	0 ± 3	0.73
	Medium	-2 ± 4.4	0.33	2.1 ± 3.1	0.7	0 ± 3.4	0.69
	Low	-1.1 ± 3.6	0.4	2.4 ± 3.8	0.34	0.1 ± 3.6	0.42
	Very Low	-1.2 ± 4.3	0.22	3 ± 4	0.38	-0.2 ± 3.7	0.44

Table 32: Field predictions in tonnes per hectare as trialled against original field data

The use of litter cover alone as a surrogate for estimating fuel weight appears to over-predict fuel loads by 2-3 t/ha and has an error band of 4 t/ha about this. Litter depth will generally under-predict fuel loads by 1-2 t/ha, with an error band of 3-4 t/ha above and below the mean. Litter volume, which is calculated from litter cover and depth, appears to have a mean predictive error of zero and a 1-3 t/ha error band. In fuel weight prediction terms, the use of only litter depth or litter cover will give an initial estimate error of approximately two tonnes before the variability about the estimate is taken into account. This may lead to as much as a 5 or 6 t/ha error in the estimation, which is significant in management terms.

As litter volume has a zero mean predictive error, this makes the use of litter volume as a predictive tool slightly stronger than litter cover or litter depth. The error likely in any prediction is in the order of 1-3 t/ha only, which is acceptable for field estimation.

The r^2 values also indicate that the use of litter volume is slightly stronger than litter depth or litter cover across the whole data set. Classes are generally in the order of 40% to 70% explainable through the field method, although class Etr (Canopy ordering, *Eucalyptus* *tenuiramis*) is only 13% explained. For this reason, fuel weights for sites dominated by *Eucalyptus tenuiramis* cannot be accurately predicted by canopy class.

Ordering	Mean residuals and SD	r^2 values
Canopy	-0.03 ± 3.07	0.63
Geology	0 ± 3.41	0.61
Rainfall	-0.01 ± 3.45	0.57
Tree Density	0 ± 3.33	0.59
Mean- all	-0.01 ± 3.12	0.65

Table 33: Mean residuals and standard deviations in tonnes per hectare for field predictions across all sites.

Table 33 shows the predictive power of the fuel weight prediction method using the four different classification schemes on all 59 sites of the original fuel load and environmental data. The rationale for averaging the predictions from as many of the classification schemes as possible is that this process allows for more of the environmental factors that determine fuel load to be incorporated. In general, a slightly stronger prediction is gained using all classification schemes when compared to using any one single classification. The use of all classifications gives an estimate with a similar mean residual and a slightly narrower standard deviation when compared to the single classifications, however the r^2 value for the single classifications are slightly lower than using all classifications for the one estimate.

Canopy ordering appears to have a stronger predictive power than the other three classification schemes but does not permit predictions to be made for *Eucalyptus risdonii* and *Eucalyptus tenuiramis* dominated sites. These sites can still be estimated using tree density or rainfall ordering classifications and still return acceptable results.

The method discussed above was collated and developed into a guidebook format (Bresnehan and Pyrke 1998) and trialled successfully by both students and professional field operatives. The guidebook text and pertinent information is included as Appendix 2. The guidebook has also been trialled by three classes of third-year vegetation management students during 1998 and 1999 on sites of known fuel loads. The results from this trial have shown if sufficient care and attention to the method is paid, estimations within 3 tonnes per hectare of the actual fuel loads can be reliably and repeatably gained.

Technique developments- litter density

This study relied on calculating litter density from litter volume and litter weight. As such, any correlation between litter density and litter weight, cover, volume and depth would be reflecting the method of calculation and not the actual litter density. The reliability of the field assessment methods would be greatly enhanced was there to be a technique for litter density to be measured developed that was independent of measures of litter depth and cover.

Litter compaction may be a viable surrogate for litter density, and if so, brings the possibility of developing a simple hand-tool based method for assessing litter density. The measurement tool outlined in McCarthy *et al*. (1999), a simple sliding disc on a ruler, may lend itself to just such a purpose.

9. Conclusion

This study has shown that fuel curve modeling is a suitable tool for fire management planning if the techniques and modeling equation are suitably rigorous. The previously published equation form has been modified to better explain the immediate after-fire fuel dynamics while retaining the basic process model structure, keeping its original usefulness as a model in which the coefficients are recognizable field variables. Pre- and post-hoc data checking techniques have demonstrated the statistical reliability of the accumulation curves developed with the refined model, leading to a greater confidence in the results than previous studies have had.

The traditional classification of sites by the canopy dominant species has been shown to be of equal or greater usefulness than other logical classification criteria. This includes both simple environmental factors and combinations of factors in an approximation of a ‘productivity score’ rating. Further investigation along these lines may well produce a more robust and efficient scheme by which sites can be classified, but in practical terms the curves presented in this study are perfectly acceptable management tools.

The potential for using the results of the fuel curve fitting process to develop a fast field assessment tool was recognized as a practical benefit to this study. It has been demonstrated that, while of lesser reliability than the traditional fuel drying procedure, the results are more consistently within an acceptable range of the site fuel weight than other currently accepted methods.

This study has shown the growth of computer statistical processing power has provided a considerably greater scope for data investigation and the discovery of patterns within very complex biological systems than was previously possible. It is expected this processing power will continue to increase, and as statistical and spatial mapping systems become more integrated, new insights may be gained from the data generated in this study.

10. References

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Appendices

Appendix 1: Data

Site	Geology	Tw_class	Rain_class	Tree_densi	Land_zone	Canopy	X_coord	Y_coord	fire-age
1	Mudstone	4	low	low	m1	*E tenuiramis/risdonii*	527552	5242583	29.5
2	Mudstone	4	low	high	m1	*E tenuiramis/risdonii*	520514	5258423	17.5
3	Mudstone	4	low	low	m1	*E tenuiramis/risdonii*	518464	5258781	14
4	Mudstone	4	very low	low	m1	*E tenuiramis/risdonii*	514816	5270714	12
5	Mudstone	4	low	very low	m1	*E tenuiramis/risdonii*	532060	5255867	12
6	Mudstone	5	high	high	m1	*E tenuiramis/risdonii*	523604	5249573	8
7	Mudstone	4	very low	very low	m1	*E tenuiramis/risdonii*	534048	5250534	6
8	Mudstone	4	low	low	m1	*E tenuiramis/risdonii*	517516	5262662	3.5
9	Mudstone	1	low	medium	m1	*E tenuiramis/risdonii*	519332	5258718	2.5
10	Dolerite	3	high	high	d1	*E pulchella*	523282	5248255	28.1
11	Dolerite	3	low	medium	d1	*E pulchella*	526572	5247944	28
12	Dolerite	2	high	low	d1	*E pulchella*	527144	5248152	12
13	Dolerite	2	high	very low	d1	*E pulchella*	527372	5247904	12
14	Dolerite	2	low	high	d1	*E pulchella*	527964	5247100	11
15	Dolerite	3	high	high	d1	*E pulchella*	523848	5251552	8
16	Dolerite	3	high	high	d1	*E pulchella*	523912	5248391	7
17	Dolerite	3	very low	medium	d1	*E pulchella*	532568	5253571	3.5
18	Dolerite	3	low	medium	d1	*E pulchella*	525932	5249344	1.5
19	Dolerite	3	low	medium	d1	*E pulchella*	525932	5249344	0.9
20	Dolerite	1	low	very low	d1	*E pulchella*	526348	5249308	0.3
21	Dolerite	2	high	low	d1	*E pulchella*	527420	5248076	0.1
22	Dolerite	2	high	low	d1	*E pulchella*	527168	5248340	0.1
23	Dolerite	2	low	medium	d1	*A verticillata*	526687	5253904	27
24	Dolerite	2	low	low	d1	*A verticillata*	526609	5254217	13
25	Dolerite	3	low	very low	d1	*A verticillata*	526876	5248200	10
26	Dolerite	2	low	low	d1	*A verticillata*	526574	5254435	5.5
27	Dolerite	2	low	low	d1	*A verticillata*	525791	5254470	4.5
28	Dolerite	2	low	low	d1	*A verticillata*	526057	5254513	3
29	Dolerite	1	low	medium	d1	*A verticillata*	525736	5249260	1.5
30	Dolerite	1	low	medium	d1	*A verticillata*	525736	5249260	0.8
31	Sandstone	4	very low	very low	s1	*E globulus/viminalis*	527937	5261274	28.4
32	Dolerite	1	very low	very low	d1	*E globulus/viminalis*	520516	5283581	13
33	Dolerite	2	high	medium	d2	*E globulus/viminalis*	518805	5258100	10
34	Sandstone	3	low	medium	d1	*E globulus/viminalis*	529056	5246740	6
35	Dolerite	1	very low	low	d1	*E globulus/viminalis*	514960	5284993	4
36	Dolerite	3	high	high	d2	*E globulus/viminalis*	518928	5258295	2.5
37	Sandstone	1	high	very low	s1	*E globulus/viminalis*	528026	5262079	1.6
38	Sandstone	1	high	low	s1	*E globulus/viminalis*	527986	5261819	1.6
39	Dolerite	3	low	high	d1	*E globulus/viminalis*	525660	5248804	1.2
40	Dolerite	3	low	high	d1	*E globulus/viminalis*	525764	5248736	0.2
41	Sandstone	5	low	very low	s1	*E amygdalina* grassy	524448	5251215	19
42	Sandstone	1	high	low	s1	*E amygdalina* grassy	532053	5255582	12
43	Sandstone	1	low	high	s1	*E amygdalina* grassy	524510	5251879	10
44	Sandstone	2	very low	very low	s1	*E amygdalina* grassy	520488	5283510	7
45	Sandstone	2	very low	very low	s1	*E amygdalina* grassy	528618	5256395	3
46	Sandstone	5	high	medium	s2	*E amygdalina* grassy	521211	5228274	1.5
47	Sandstone	5	high	medium	s2	*E amygdalina* grassy	521211	5228274	1
48	Sandstone	5	high	medium	s2	*E amygdalina* grassy	521211	5228274	0.2
49	Sandstone	5	low	high	s1	*E amygdalina* heathy	524459	5251431	29
50	Sandstone	5	low	high	s1	*E amygdalina* heathy	525526	5240771	19
51	Sandstone	5	high	high	s2	*E amygdalina* heathy	521078	5228302	18
52	Sandstone	4	low	medium	s1	*E amygdalina* heathy	524301	5251782	10
53	Sandstone	4	very low	high	s1	*E amygdalina* heathy	533955	5254800	6
54	Sandstone	4	very low	medium	s1	*E amygdalina* heathy	534037	5250366	6
55	Sandstone	4	low	very low	s1	*E amygdalina* heathy	524652	5251717	5
56	Sandstone	5	very low	very low	b	*E amygdalina* heathy	540356	5240472	3
57	Sandstone	5	very low	low	s1	*E amygdalina* heathy	551832	5254316	0.8
58	Sandstone	5	very low	low	s1	*E amygdalina* heathy	551832	5254316	0.5
59	Sandstone	5	high	medium	s2	*E amygdalina* heathy	521203	5228594	0.2

Site	topo pos	mean rain	solar	tot.f	tot.l	tot.d	s.d	s.l	ns.d	ns.l	e.d	e.l
1	2	650	5	12.8	4.77	8.05	6.64	0.52	0.22	0.53	1.18	3.71
2	3	650	5.25	9.48	0.71	8.77	8.64	0.19	0.07	0.13	0.05	0.38
3	3	650	5.25	11.27	0.98	10.29	10.12	0.23	0.04	0.22	0.12	0.53
4	3	550	5.25	9.21	0.39	8.81	8.66	0.11	0.1	0.11	0.05	0.16
5	3	650	5.25	6.77	0.45	6.32	6.18	0.11	0.11	0.19	0.02	0.15
6	2	750	5.25	12.56	0.57	11.98	11.95	0.18	0.03	0.15	0	0.24
7	2	550	5.25	7.5	0.61	6.89	6.37	0.17	0.38	0.22	0.13	0.2
8	3	650	5	5.01	0.52	4.48	4.43	0.19	0.03	0.25	0.01	0.07
9	3	650	4.25	2.25	0.12	2.13	1.84	0.05	0.07	0.02	0.21	0.03
10	1	850	4.5	17	3.3	13.7	11.06	0.62	2.59	1.22	0.04	1.45
11	3	650	5	17.22	2.91	14.31	13.85	2.08	0.38	0.28	0.08	0.53
12	3	750	5	16.53	1.55	14.98	14.55	1	0.04	0.23	0.02	0.31
13	3	750	4.5	16.55	1.59	14.95	14.45	0.97	0.44	0.29	0.05	0.32
14	2	650	4.5	9.81	2.22	7.58	6.76	0.57	0.82	0.6	0	1.04
15	2	750	4.5	8.34	2.67	5.66	5.4	1.15	0.24	0.85	0.02	0.66
16	3	750	5	11.6	3.77	7.83	7.66	2.96	0.15	0.65	0.01	0.15
17	2	550	4.75	5.2	0.71	4.49	4.06	0.38	0.11	0.29	0.31	0.02
18	3	650	5.25	2.43	0.99	1.43	1.24	0.88	0.14	0.11	0.04	0
19	3	650	5.25	1.6	0.61	0.99	0.83	0.6	0.11	0	0.04	0
20	3	650	5	1.62	0	1.62	1.47	0	0.01	0	0.13	0
21	3	750	4.5	1.29	0.01	1.28	1.15	0.01	0.07	0	0.05	0
22	3	750	5	1.39	0	1.39	1.18	0	0.16	0	0.03	0
23	3	650	4	14.56	1.6	12.96	12.69	0.93	0.21	0.38	0.04	0.28
24	2	650	4.75	12.12	1.05	11.07	11.02	0.64	0.02	0.21	0.01	0.2
25	3	650	5	10.5	1.14	9.35	9.18	0.52	0.05	0.26	0.11	0.34
26	4	650	5	7.82	0.5	7.32	7.24	0.27	0.06	0.09	0.01	0.13
27	3	650	2.25	13.4	1.29	12.1	10.46	0.74	1.63	0.32	0.01	0.22
28	2	650	4.75	11.55	1.22	10.32	10.22	0.78	0.09	0.1	0	0.34
29	3	650	5.25	2.97	1.09	1.88	1.72	0.32	0.07	0.76	0.08	0
30	3	650	5.25	1.31	0.24	1.06	0.93	0.19	0.07	0.05	0.05	0
31	2	550	5	18.8	1.49	17.3	16.69	0.26	0.58	0.66	0.02	0.56
32	4	550	5	9.17	0.87	8.3	8.12	0.26	0.09	0.21	0.09	0.41
33	2	750	5.25	12.21	1.49	10.72	10.47	0.3	0.2	0.39	0.05	0.8
34	3	650	4.5	7.82	1.39	6.43	5.7	0.23	0.65	0.3	0.06	0.85
35	2	550	5	6.72	2.36	4.37	4	0.15	0.34	2.03	0.03	0.18
36	4	750	5.25	3.13	0.41	2.72	2.62	0.16	0.03	0.23	0.07	0.02
37	2	700	4.8	5.36	0.34	5.01	4.91	0.2	0.01	0.14	0.08	0
38	2	700	4.5	7.34	3.41	3.93	3.72	0.22	0.12	3.18	0.08	0
39	3	650	4.5	3	1.24	1.75	1.23	1.11	0.33	0.12	0.18	0
40	3	650	4.5	1.25	0.01	1.24	1.01	0.01	0.15	0	0.07	0
41	2	650	4	10.7	1.76	8.94	7.43	0.41	1.2	1	0.3	0.34
42	4	750	4.5	5.71	1.3	4.41	4.35	0.47	0.04	0.36	0.01	0.46
43	3	650	4.5	10.29	3.94	6.35	5.37	1.64	0.69	1.84	0.28	0.45
44	4	550	5	7.92	2.87	5.05	4.32	1.34	0.59	0.96	0.13	0.55
45	3	550	4.25	3.12	1.15	1.96	1.54	0.72	0.22	0.39	0.19	0.03
46	4	700	5	2.25	1.36	0.88	0.64	0.73	0.08	0.51	0.14	0.11
47	4	700	5	2.11	1.3	0.81	0.38	0.76	0.21	0.53	0.21	0
48	4	700	5	1.85	0.01	1.83	1.22	0.01	0.36	0	0.23	0
49	1	650	4.8	22.19	1.35	20.83	18.6	0.13	2.18	0.91	0.04	0.3
50	1	650	4.6	14.59	4.03	10.55	7.82	1.28	2.42	2.08	0.3	0.66
51	2	700	4.8	11.27	4.21	7.05	4.67	0.8	2.37	2.72	0	0.69
52	3	650	5	12.57	2.54	10.02	8.62	0.99	1.31	0.99	0.08	0.55
53	3	550	4.5	7.65	3.1	4.55	4	0.75	0.22	1.52	0.31	0.82
54	3	550	4.5	4.7	1.59	3.1	2.89	0.81	0.14	0.34	0.06	0.43
55	2	650	4.8	6.43	2.75	3.67	3.06	0.62	0.56	0.61	0.04	1.51
56	3	550	5	6.38	2.77	3.61	2.99	0.52	0.05	2.25	0.56	0
57	1	550	4.8	3.26	1.91	1.35	0.8	0.51	0.05	1.4	0.49	0
58	1	550	4.8	2.82	1.36	1.46	1.07	0.45	0.06	0.91	0.31	0
59	4	700	5	1.85	0.01	1.83	1.22	0.01	0.36	0	0.23	0

Site	non.l	lit.vol	lit.dens	lit.cov	lit.dep	slope	aspect	tree dens
1	6.16	240	276.9	100	2.4	3	2	13
2	0.82	90	960	60	1.5	3	1	22
3	1.14	129	780.8	90	1.4	2	1	13
4	0.53	96	902.2	60	1.6	3	1	14
5	0.58	180	343.8	60	3	3	2	12
6	0.6	210	569.22	70	3	3	2	23
7	1.1	300	212.3	80	3.7	3	1	11
8	0.55	109	403.9	70	1.6	3	2	14
9	0.38	90	204.5	70	1.2	3	4	17
10	5.92	329	335.24	90	3.6	1	5	25
11	3.35	249	554	90	2.7	1	2	17
12	1.6	220	661.5	80	2.7	2	2	14
13	2.07	230	628.3	100	2.3	2	3	12
14	3.03	180	375.9	80	2.2	1	3	19
15	2.92	280	192.9	100	2.8	1	4	21
16	3.92	270	283.7	100	2.7	2	1	24
17	1.11	129	313.3	90	1.4	1	3	17
18	1.17	90	138.6	60	1.5	3	1	15
19	0.75	70	119.7	50	1.4	3	1	15
20	0.14	79	183.7	60	1.3	3	2	11
21	0.13	70	165.6	40	1.7	1	3	13
22	0.19	69	169.9	60	1.1	2	2	14
23	1.84	540	235.1	100	5.4	3	5	17
24	1.08	260	424.1	100	2.6	1	3	14
25	1.28	260	353.3	80	3.2	2	1	12
26	0.56	330	219.65	100	3.3	2	2	14
27	2.92	279	373.7	90	3.1	2	2	14
28	1.31	170	601.6	80	2.1	1	3	13
29	1.23	140	123.3	80	1.8	3	1	15
30	0.36	60	156.2	40	1.5	3	1	15
31	2.08	280	569.3	100	2.8	1	1	12
32	1.06	150	541.3	100	1.5	3	2	9
33	1.74	200	523.4	100	2	2	1	17
34	2.09	140	407.5	70	2	3	4	15
35	2.73	280	142.9	100	2.8	1	2	13
36	0.51	100	261.6	80	1.2	3	1	19
37	0.43	69	706.7	60	1.2	1	3	11
38	3.6	84	443.2	70	1.2	3	3	13
39	1.74	75	164.9	50	1.5	3	3	21
40	0.23	70	145.3	40	1.7	3	3	21
41	3.25	240	309.9	90	2.7	3	4	8
42	1.34	140	311.1	80	1.8	1	4	13
43	4.9	270	198.9	100	2.7	3	3	18
44	3.57	180	240.5	100	1.8	3	2	10
45	1.55	100	154.5	80	1.2	2	4	8
46	1.57	50	129.8	50	1	1	1	15
47	1.71	60	63.6	30	2	1	1	15
48	0.6	140	87.8	50	2.8	1	1	15
49	3.56	369	502.9	90	4.1	0	2	23
50	6.74	240	326.1	100	2.4	0	4	29
51	6.58	279	166.9	90	3.1	1	2	18
52	3.92	230	375.1	90	2.5	1	1	15
53	3.62	126	318.2	90	1.5	2	4	19
54	1.78	192	150.7	80	2.4	2	4	17
55	3.34	230	133.4	100	2.3	1	3	8
56	3.38	60	498.4	50	1.2	1	2	12
57	2.45	30	267.8	40	0.7	0	1	13
58	1.73	35	307.5	50	0.7	0	2	13
59	0.6	140	87.8	50	2.8	1	1	15

Appendix 2: Field guide book

Introduction

This guidebook has been written with the aim of providing a quick method for estimating the available flash fuel in dry bushland in Southeast Tasmania. Flash fuel is made up of smaller material like leaves, bark and twigs; it is the fuel that supports the fire front. The research and statistics behind this guidebook are based on the report "An assessment of fuel characteristics and fuel loads in dry sclerophyll forests in Southeast Tasmania" (Bresnehan, 1998).

This guidebook is not intended to replace the current methods of fuel weight estimation. Sampling, oven-drying and weighing procedures will give a more reliable estimation of fuel weight for any site. The intention of this book is to provide a quick field-based method requiring few tools and no laboratory or oven-drying time.

This guidebook was developed on the six most common dry bush vegetation types for South-east Tasmania. These are:

White peppermint (*Eucalyptus pulchella*),

Black peppermint (*E. amygdalina*) with grassy understorey,

Black peppermint (*E. amygdalina*) with heathy understorey,

Silver and Risdon peppermints (*E. tenuiramis* & *E. risdonii*),

White gum and Bluegum (*E. viminalis* & *E. globulus*),

She-oak (Allocasuarina verticillata).

How to use this guide.

To easily use this guide, the following items are required: a copy of the worksheet on page 12 of this booklet, a measuring stick built to the description in the appendix (page 11), and a pen or pencil.

When estimating the fuel load for a site, follow this procedure:

Determine the extent of the site- make sure you do not cross into different canopy or geology types, or cross fire boundaries.

Write the site identification at the top of the worksheet. This can be a name or map grid reference. Write the date the estimates were made next to the site identification.

Define the site according to Part 1 of this guide. Write the results in the Part 1 section of the worksheet.

If the time since the last fire is known or can be reliably determined in the field, use the charts in Part 2 to estimate the fuel load. Write the estimates in the Part 2 section of the worksheet.

If the time since the last fire is not known, use Part 3 of this guide. Follow the method and calculate the fuel load using the Part 3 section of the worksheet.

Whether you use Part 2 or Part 3, there will be three separate estimates of fuel load, one for each of the major site characteristics. Average these to arrive at a general field estimate for the site. Write this in the Part 4 section of the worksheet. File the completed worksheet for later use and comparisons.

The charts throughout this guide use shortened titles for the site characteristics. They are as follows:

Canopy types

She-oaks:	SO
Heathy Black Peppermint:	H BP
Grassy Black Peppermint:	G BP
White Peppermint:	WP
Silver and Risdon Peppermints:	S&RP
White gum and Bluegum:	W&BG

Tree Density classes

Very low tree density:	VLD
Low tree density:	LD
Medium tree density:	MD
High tree density:	HD

Rainfall classes

Very low rainfall:	VLR
Low rainfall:	LR
High rainfall:	HR

Part 1: Defining the site.

The method for defining the site to be assessed is based on three major factors: the type of canopy tree, the density of the canopy trees and the amount of rainfall the site receives. Write the assessment results on the worksheet.

Canopy type.

The following key, simplified from that presented by Duncan (1996), should be used to determine to which of the six communities a site belongs.

1a. Small to medium sized trees with long thin droopy needle-like green foliage: She-Oak category.

1b. Medium to tall trees with well-defined leaves ranging from 5 to 12cm long: Eucalypts. Go to 2.

2a. Leaf length generally over 7-10cm. Bark generally smooth and white, possibly with a brown flaky 'sock' of thicker bark at the base of the trunk. White gum and Bluegum category.

2b. Leaf length generally less than 8cm. Trunk and limb bark may be smooth or rough. Peppermints. Go to 3.

3a. Trunk bark is generally dark and rough. Black peppermints. Go to 4.

3b. Trunk bark is generally pale and smooth. Go to 5.

4a. Understorey is mostly grasses. Grassy Black Peppermint category.

4b. Understorey is mostly heath, ferns and/or low bushes. Heathy Black Peppermint category.

5a. Leaves very narrow and straight, quite green coloured. White Peppermint category.

5b. Leaves narrow and noticeably bluish/silver in colour or leaves very round in shape and silvery white in colour. Silver Peppermint and Risdon Peppermint category.

Note: Some wetter sites may have stringybarks (*Eucalyptus obliqua*) or ironbarks (*Eucalyptus sieberi*) present. These types of forest fall outside the scope of this booklet.

Tree density- Bitterlich wedge method.

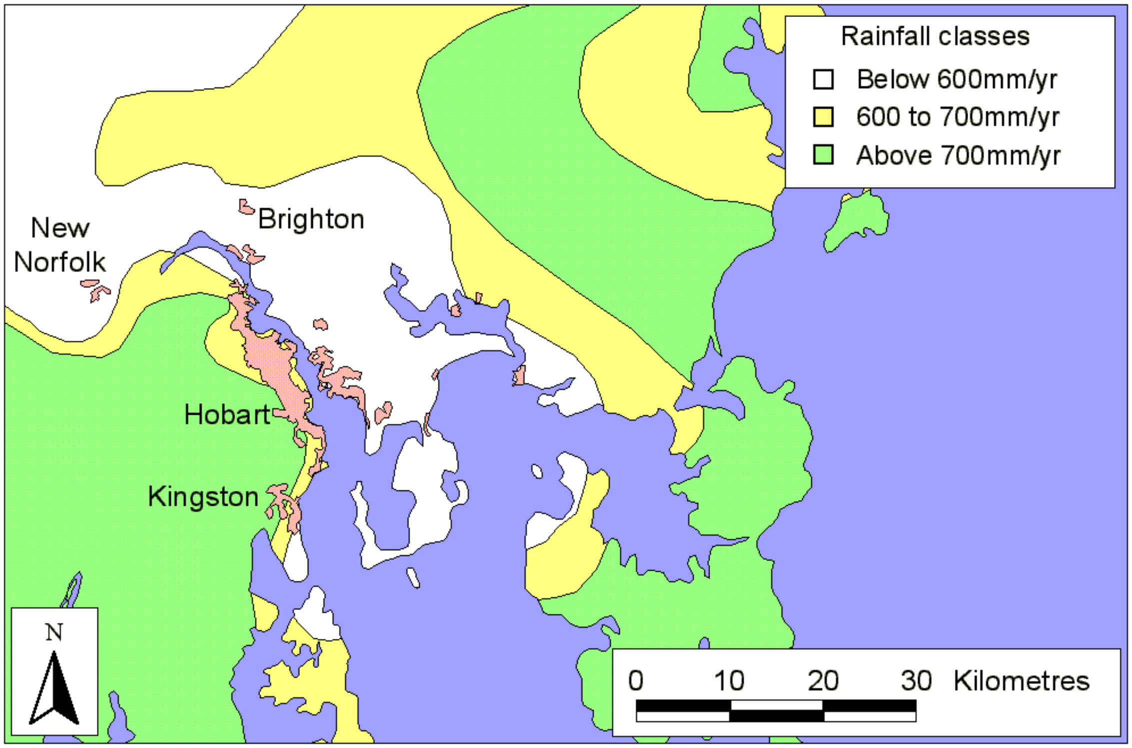
Tree density in square metres of trunk area per hectare of land can be estimated using the Bitterlich method (Mueller-Dombois and Ellenberg 1974).

Using a measuring stick constructed to the specifications outlined in the appendix, stand in the approximate centre of the site and hold the stick up to your eye and parallel to the ground. The sighting block should be at the far end of the stick. Sight down the length of the stick and slowly rotate in a full circle, counting every tree trunk wider than the sighting block. At the end of the circle, the count of tree trunks is equivalent to the tree basal area in square metres per hectare.

Density counts of less than 13 are considered very low density, counts of between 13 and less than 15 are low density, counts of between 15 and less than 18 are medium density and anything at or above 18 square metres per hectare is considered high density.

Rainfall class.

Locate the site on this map to determine rainfall class.



Part 2: Assessing fuel loads for sites of known time since last fire.

This section is for determining fuel loads for sites where there exists reliable information indicating when the last burn occurred.

The approximate date of the last fire can sometimes be determined in the field, using tree-ring counts from *leptospermum* and fire-scarred eucalypts. *Banksia* node counts are another method useful in the field; these understorey trees will put on one extra node of growth each year (Brown and Podger 1982). However, ring and node counting are dating methods requiring both practice and patience and as such, if there is any doubt over the accuracy of a fire age estimate, the part 3 section of this guide should be used instead.

Assess the fuel loads for the site along the relevant categories (canopy, rainfall and tree density) according to the elapsed time since the site was last burnt. Write the relevant information on the worksheet.

Use the Part 2 reckoner charts to estimate the total fuel load.

Part 2	Rainfall class			Tree density class				Canopy type					
Age	VLR	LR	HR	VLD	LD	MD	HD	Ave	Eah	Eag	Ep	Et&r	Ev&g
2	4.3	4.1	4.7	4.4	6.7	3.3	4.5	7.0	2.9	4.1	3.7	0.0	3.4
3	4.8	5.1	6.1	5.0	8.2	4.5	4.9	9.6	3.9	4.6	5.3	3.8	4.1
4	5.3	6.0	7.3	5.7	9.2	5.6	5.3	10.8	4.8	5.2	6.7	6.1	4.8
5	5.8	6.8	8.3	6.3	9.9	6.7	5.7	11.5	5.6	5.8	8.0	7.5	5.5
6	6.4	7.6	9.2	6.9	10.3	7.6	6.1	11.8	6.3	6.3	9.1	8.3	6.2
7	6.9	8.3	10.0	7.5	10.6	8.5	6.5	11.9	6.9	6.9	10.1	9.0	6.9
8	7.4	9.0	10.7	8.1	10.8	9.2	6.9	12.0	7.4	7.5	11.0	9.4	7.5
9	8.0	9.6	11.4	8.7	10.9	10.0	7.3	12.1	7.9	8.0	11.8	9.7	8.2
10	8.5	10.2	11.9	9.2	11.0	10.6	7.7	12.1	8.3	8.6	12.5	9.9	8.9
11	9.0	10.7	12.3	9.8	11.1	11.2	8.1	12.1	8.6	9.2	13.1	10.1	9.5
12	9.6	11.2	12.8	10.3	11.1	11.8	8.5	12.1	8.9	9.8	13.7	10.2	10.1
13	10.1	11.7	13.1	10.8	11.1	12.3	8.9	12.1	9.1	10.3	14.2	10.3	10.8
14	10.6	12.1	13.4	11.3	11.2	12.8	9.3	12.1	9.3	10.9	14.6	10.4	11.4
15	11.2	12.5	13.7	11.8	11.2	13.2	9.7	12.1	9.5	11.5	15.0	10.4	12.0
16	11.7	12.8	13.9	12.3	11.2	13.6	10.1	12.1	9.6	12.0	15.4	10.4	12.6
17	12.3	13.2	14.1	12.8	11.2	13.9	10.5	12.1	9.7	12.6	15.7	10.5	13.2
18	12.8	13.5	14.3	13.3	11.2	14.2	10.9	12.1	9.9	13.2	16.0	10.5	13.8
19	13.4	13.8	14.5	13.7	11.2	14.5	11.3	12.1	9.9	13.7	16.2	10.5	14.4
20	13.9	14.0	14.6	14.1	11.2	14.8	11.7	12.1	10.0	14.3	16.4	10.5	15.0
21	14.4	14.3	14.7	14.6	11.2	15.1	12.1	12.1	10.1	14.9	16.6	10.5	15.6
22	15.0	14.5	14.8	15.0	11.2	15.3	12.5	12.1	10.2	15.4	16.8	10.5	16.2
23	15.5	14.7	14.9	15.4	11.2	15.5	12.9	12.1	10.2	16.0	17.0	10.6	16.7
24	16.1	14.9	15.0	15.8	11.2	15.7	13.3	12.1	10.2	16.6	17.1	10.6	17.3
25	16.6	15.1	15.1	16.2	11.2	15.9	13.7	12.1	10.3	17.2	17.3	10.6	17.9
26	17.2	15.2	15.1	16.5	11.2	16.0	14.1	12.1	10.3	17.7	17.4	10.6	18.4
27	17.7	15.4	15.2	16.9	11.2	16.2	14.5	12.1	10.3	18.3	17.5	10.6	19.0
28	18.3	15.5	15.2	17.2	11.2	16.3	14.8	12.1	10.4	18.9	17.6	10.6	19.5
29	18.8	15.7	15.3	17.6	11.2	16.4	15.2	12.1	10.4	19.4	17.6	10.6	20.0
30	19.4	15.8	15.3	17.9	11.2	16.5	15.6	12.1	10.4	20.0	17.7	10.6	20.6

Part 3: Assessing fuel loads for sites of unknown time since last fire.

Using the measuring stick, wander about the site and take ten random measures of litter depth. Record these measurements on the worksheet. If any of the random depth measurements are bare ground or exposed rock, record a zero.

Add up all measurements and divide this number by ten. This is the average litter depth (in centimetres) for the site.

Use the reckoner charts on the next page to estimate total fuel loads based on the site categories and the average litter depth. Write them in the Part 3 section of the worksheet.

NB: Silver and Risdon peppermint fuel loads cannot be predicted in this manner, as the distribution of the litter is highly variable in these forest types. Calculate fuel loads for these canopy types using tree density and rainfall classes.

Part 3 fuel reckoner chart.

Part 3	Rainfall class			Tree density class				Canopy type				
Depth	VLR	LR	HR	VLD	LD	MD	HD	Ave	Eah	Eag	Ep	Ev&g
0.8	5.4	4.8	4.2	5.1	5.9	2.5	5.7	3.3	4.3	2.8	3.5	4.7
1	5.9	5.5	5.1	5.8	6.9	4.0	6.4	4.7	5.2	3.6	4.6	5.6
1.2	6.4	6.2	5.9	6.5	7.6	5.3	7.1	5.7	6.1	4.4	5.7	6.4
1.4	6.8	6.9	6.7	7.2	8.3	6.4	7.8	6.7	6.9	5.2	6.8	7.3
1.6	7.3	7.6	7.6	7.9	8.8	7.3	8.5	7.5	7.8	6.0	7.8	8.1
1.8	7.8	8.2	8.4	8.6	9.3	8.1	9.2	8.2	8.7	6.8	8.9	9.0
2	8.3	8.9	9.2	9.3	9.8	8.8	9.9	8.8	9.5	7.6	10.0	9.9
2.2	8.8	9.6	10.0	10.0	10.2	9.5	10.6	9.4	10.4	8.4	11.1	10.7
2.4	9.3	10.3	10.9	10.7	10.5	10.1	11.3	9.9	11.3	9.2	12.2	11.6
2.6	9.8	11.0	11.7	11.4	10.9	10.7	12.1	10.4	12.1	10.0	13.3	12.4
2.8	10.3	11.6	12.5	12.1	11.2	11.2	12.8	10.8	13.0	10.8	14.4	13.3
3	10.8	12.3	13.4	12.8	11.5	11.7	13.5	11.2	13.9	11.6	15.5	14.2
3.2	11.3	13.0	14.2	13.5	11.7	12.1	14.2	11.6	14.7	12.4	16.6	15.0
3.4	11.8	13.7	15.0	14.2	12.0	12.5	14.9	12.0	15.6	13.2	17.7	15.9
3.6	12.3	14.4	15.9	14.9	12.2	12.9	15.6	12.3	16.5	14.0	18.8	16.7
3.8	12.7	15.0	16.7	15.6	12.5	13.3	16.3	12.7	17.3	14.8	19.8	17.6
4	13.2	15.7	17.5	16.3	12.7	13.6	17.0	13.0	18.2	15.6	20.9	18.5
4.2	13.7	16.4	18.3	17.0	12.9	14.0	17.7	13.3	19.1	16.4	22.0	19.3
4.4	14.2	17.1	19.2	17.7	13.1	14.3	18.5	13.5	19.9	17.2	23.1	20.2
4.6	14.7	17.8	20.0	18.4	13.3	14.6	19.2	13.8	20.8	18.0	24.2	21.0
4.8	15.2	18.4	20.8	19.1	13.4	14.9	19.9	14.1	21.7	18.9	25.3	21.9
5	15.7	19.1	21.7	19.8	13.6	15.2	20.6	14.3	22.5	19.7	26.4	22.8
5.2	16.2	19.8	22.5	20.5	13.8	15.5	21.3	14.6	23.4	20.5	27.5	23.6
5.4	16.7	20.5	23.3	21.2	13.9	15.7	22.0	14.8	24.3	21.3	28.6	24.5
5.6	17.2	21.2	24.2	21.9	14.1	16.0	22.7	15.0	25.1	22.1	29.7	25.3
5.8	17.7	21.8	25.0	22.6	14.2	16.2	23.4	15.2	26.0	22.9	30.8	26.2
6	18.2	22.5	25.8	23.3	14.4	16.5	24.1	15.4	26.9	23.7	31.9	27.1

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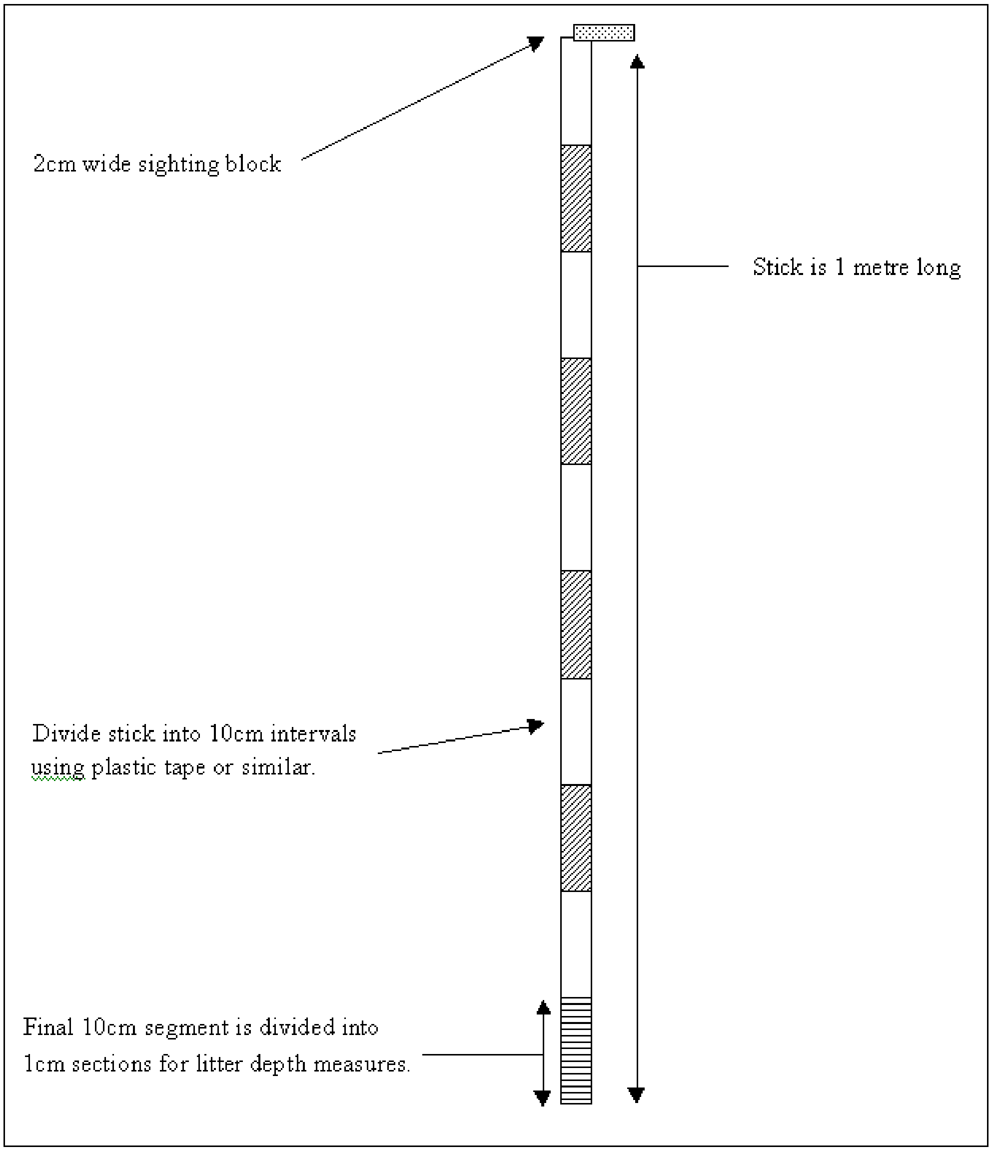
The measuring stick.

The measuring stick is used for determining litter depth and cover, and also for measuring tree density.



Field worksheet.

Site identification and/or name		date
		/ /

Part 1: Defining the site

Canopy type	
Tree density:	
Rainfall class:	

Part 2: For sites of known fire age:

Approximate date of last fire:	
Elapsed time since last fire (years)	

Use the charts for known fire age to estimate fuel loads

Canopy	Tree density	Rainfall class	Mean
t/ha	t/ha	t/ha	t/ha

Part 3: For sites of unknown fire age:

Make ten random measurements of litter depth in centimetres

1	cm	6	cm
2	cm	7	cm
3	cm	8	cm
4	cm	9	cm
5	cm	10	cm

Total	
Average (divide by 10)	cm

Use the reckoner charts for each category to estimate total weight

Canopy	Tree density	Rainfall class	Mean
t/ha	t/ha	t/ha	t/ha

Part 4: Final estimate

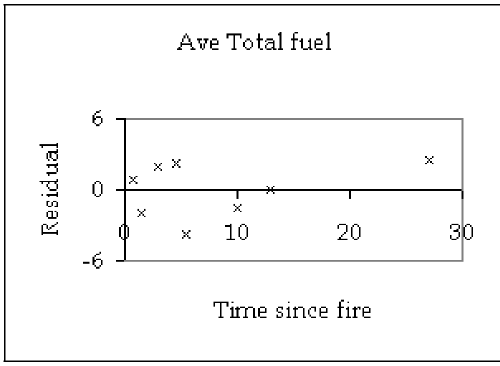
Estimate (part 2 or part 3)	t/ha

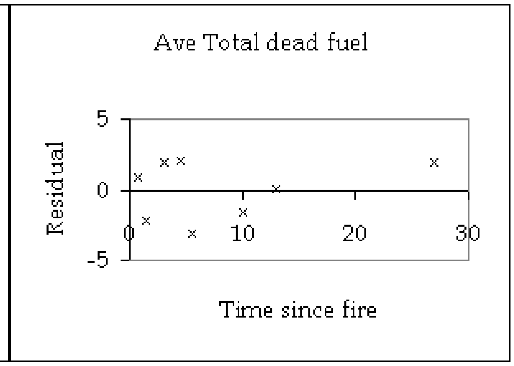
Appendix 3: Residuals plots

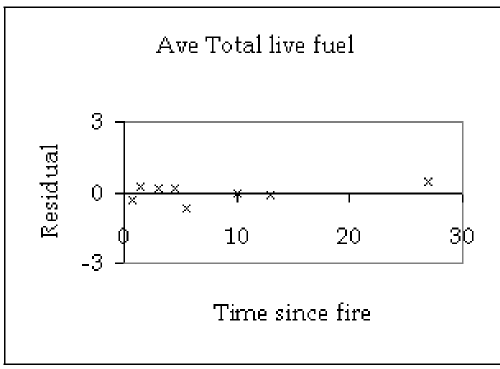
Note: Time since fire is presented here in units of years, and residuals in units of tones per hectare.

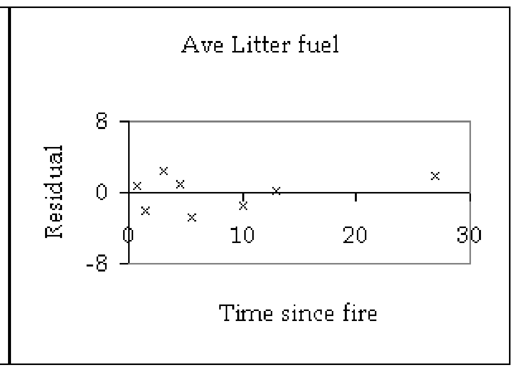
Canopy ordering

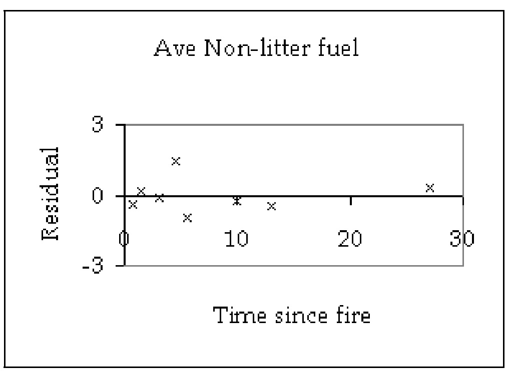
Category Ave: *Allocasuarina verticillata*



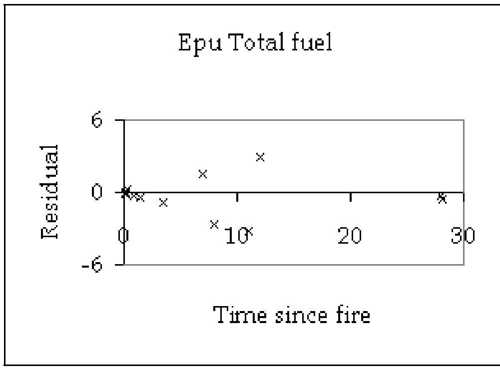


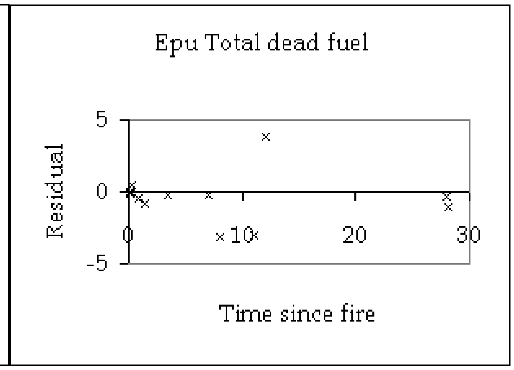


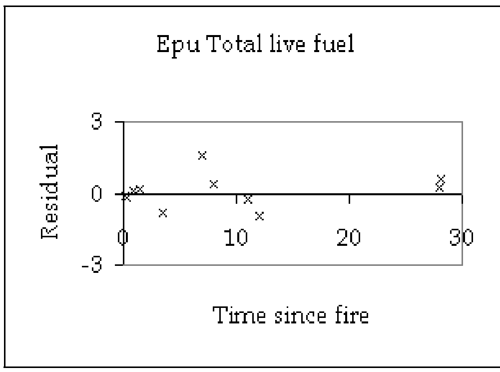


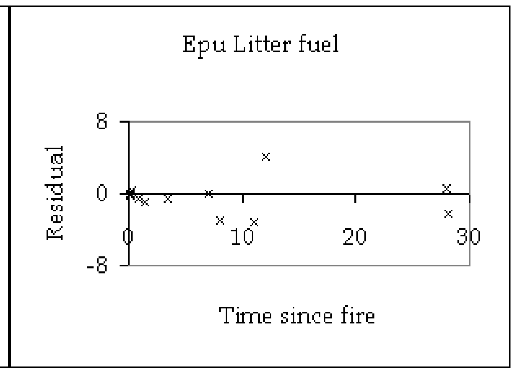


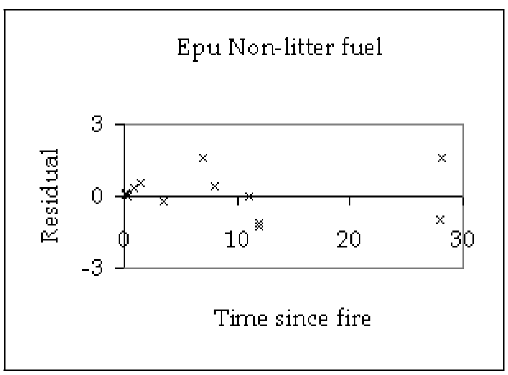
Category Epu: *Eucalyptus pulchella*



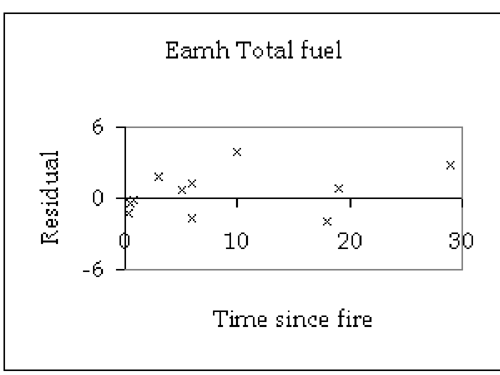


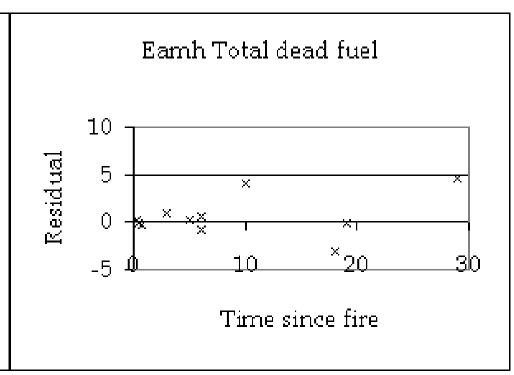


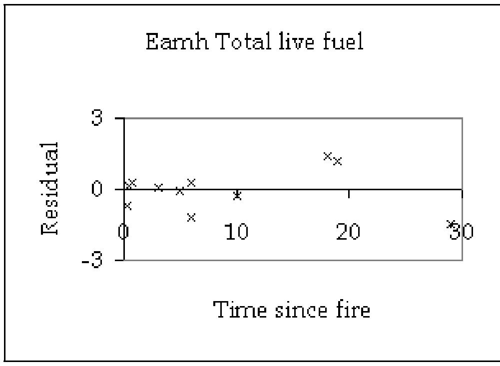


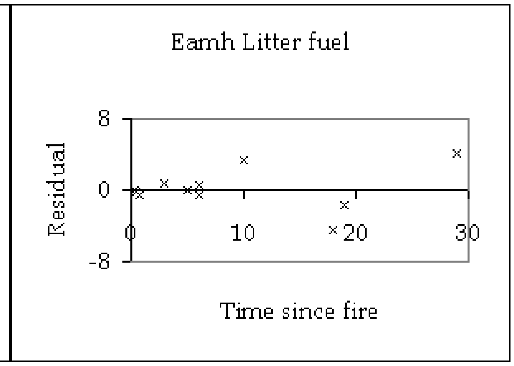


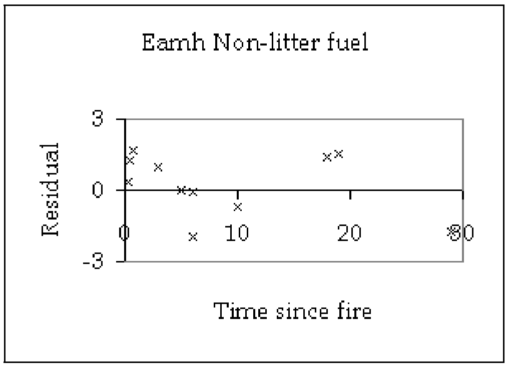
Category Eamh: Heathy *Eucalyptus amygdalina*



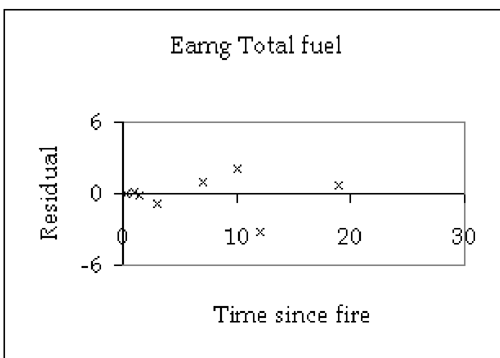


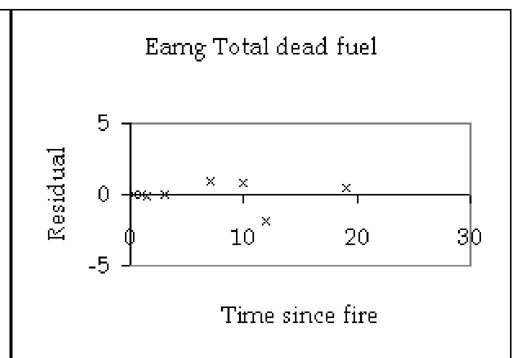


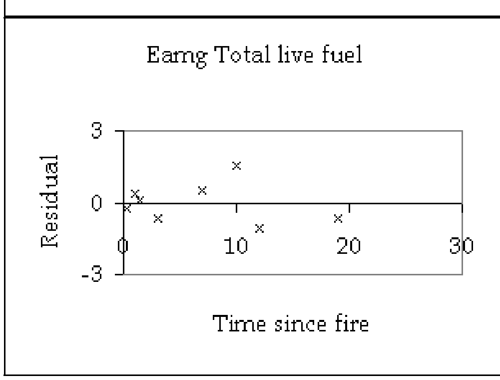


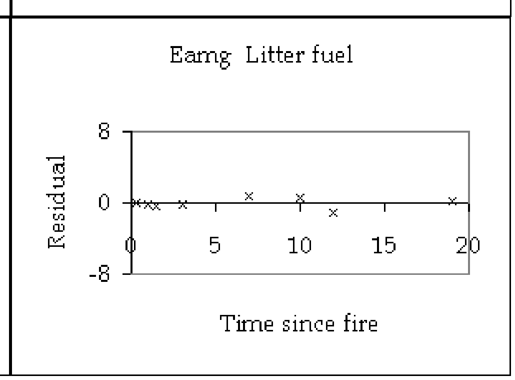


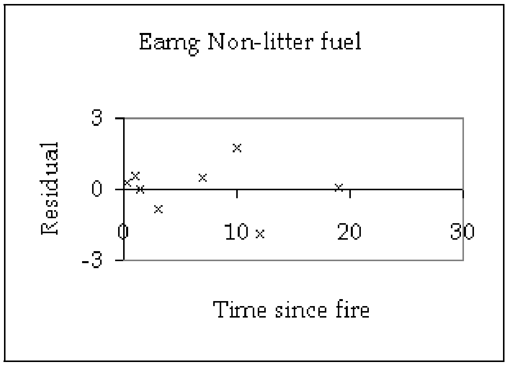
Category Eamg: grassy *Eucalyptus amygdalina*



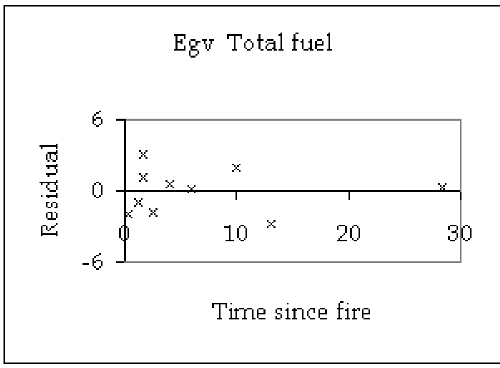


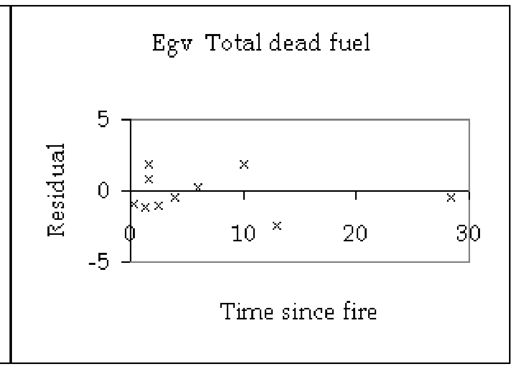


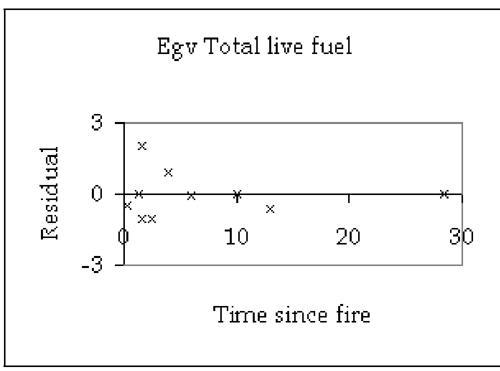


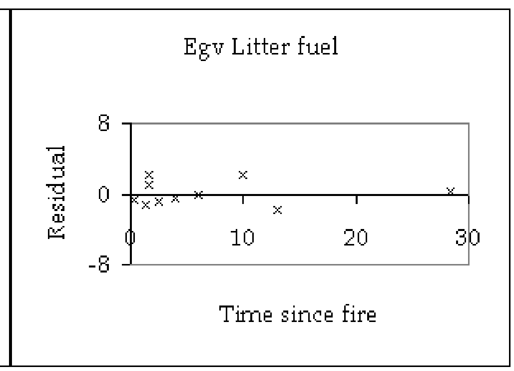


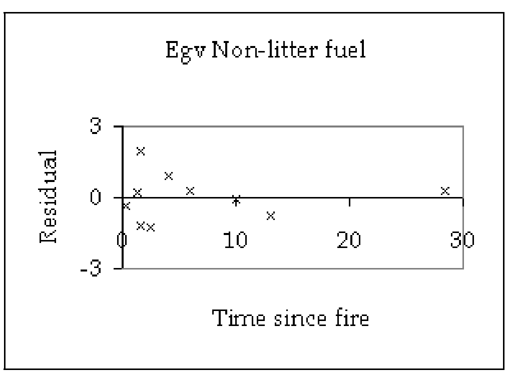
Category Egv: *Eucalyptus globulus/ E. viminalis*



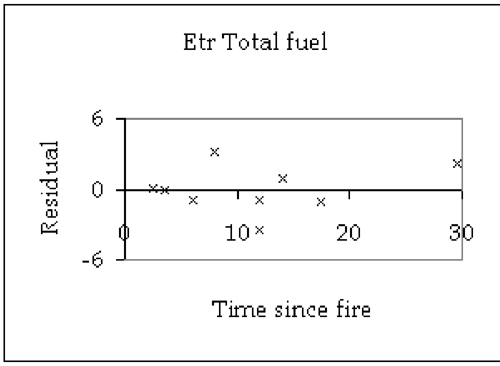


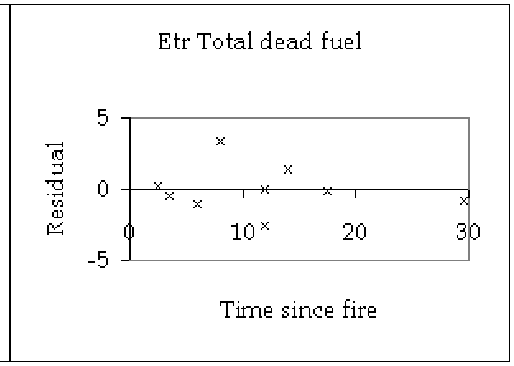


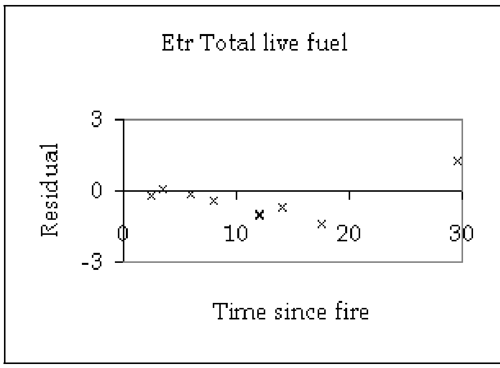


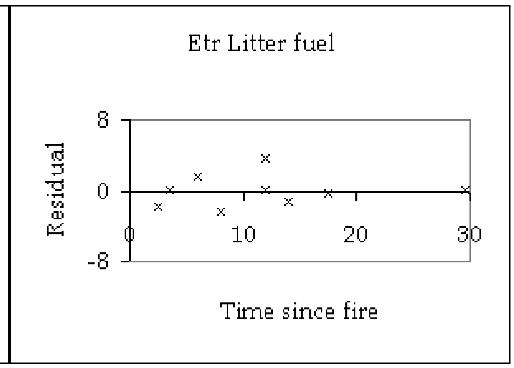


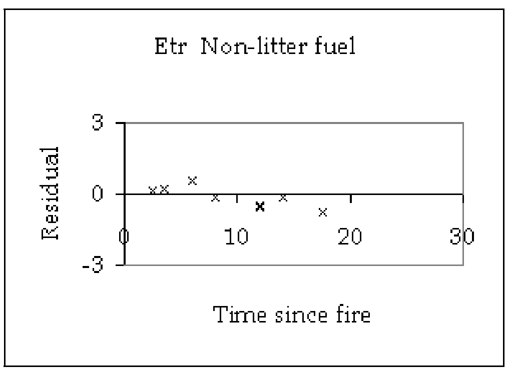
Category Etr: *Eucalyptus tenuiramis*/ *E. risdonii*





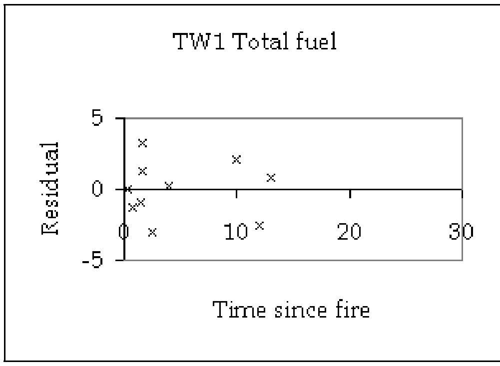


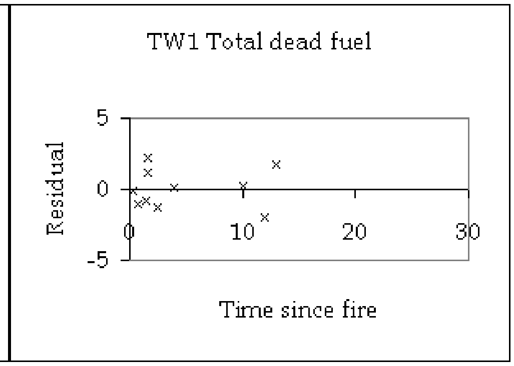


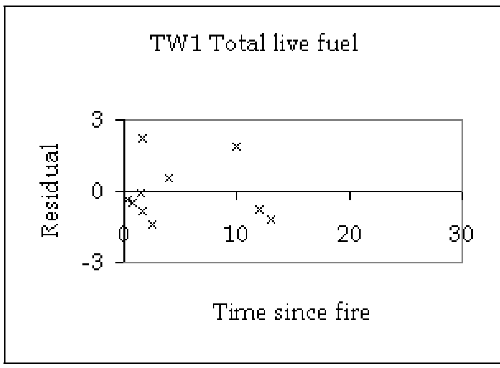


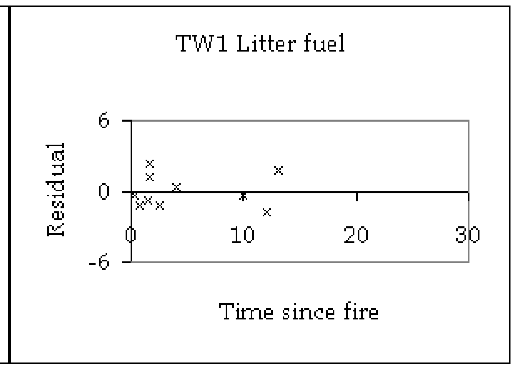
Phytosociological ordering

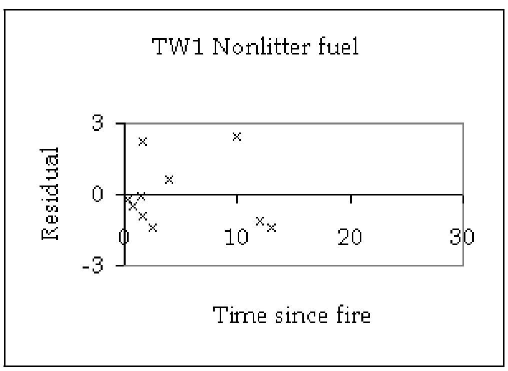
TWINSPAN group 1











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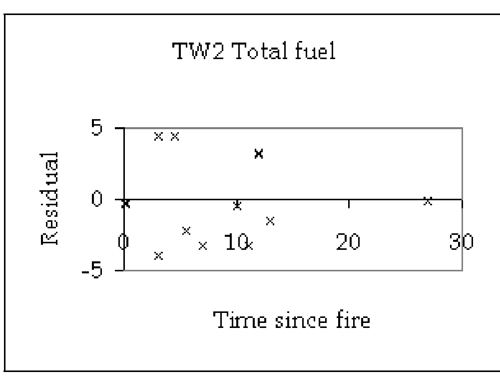

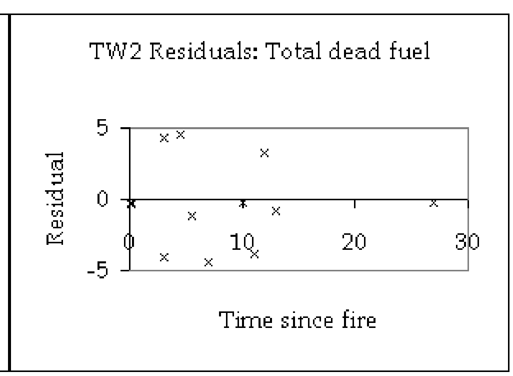

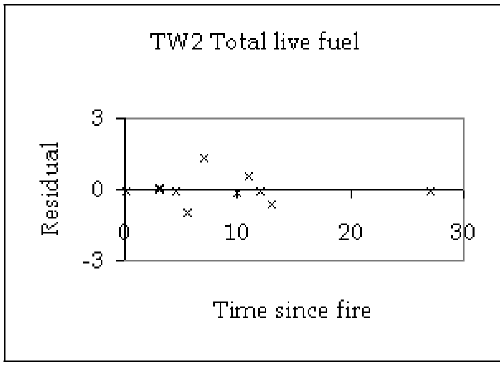

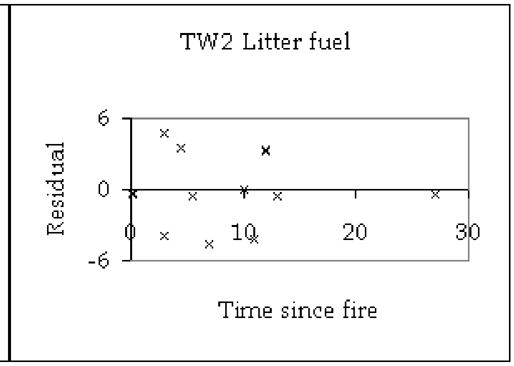

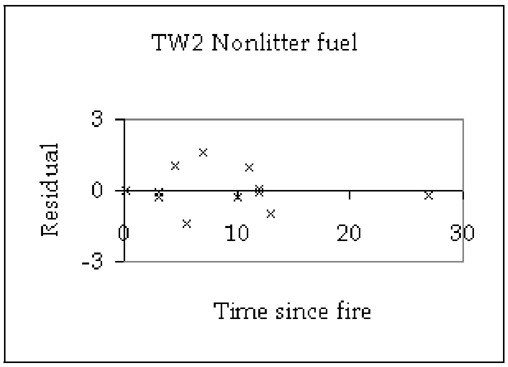

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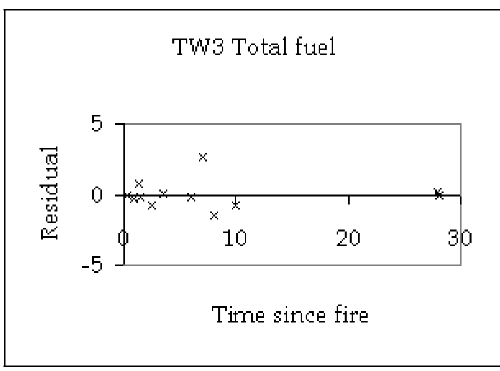

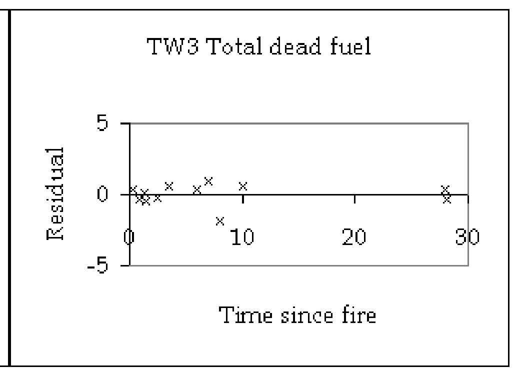

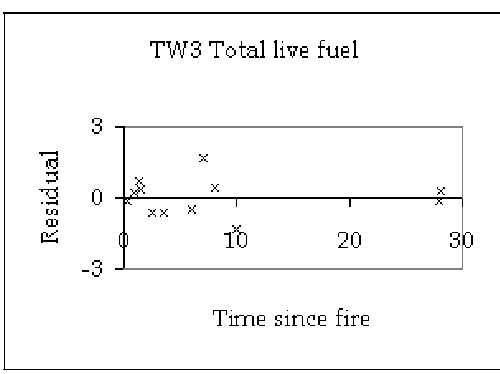

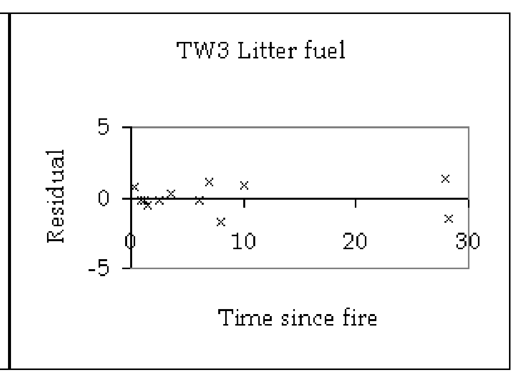

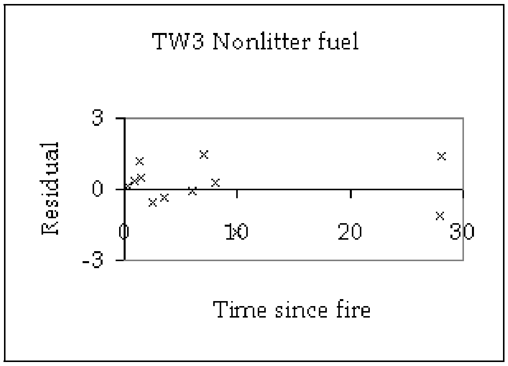

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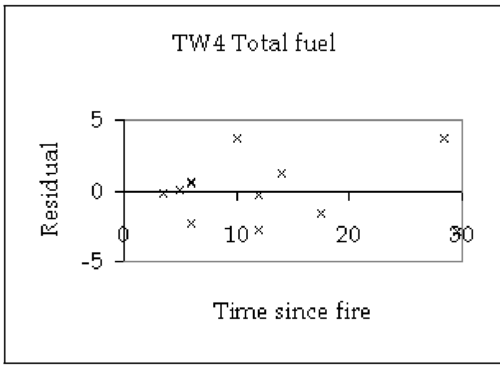
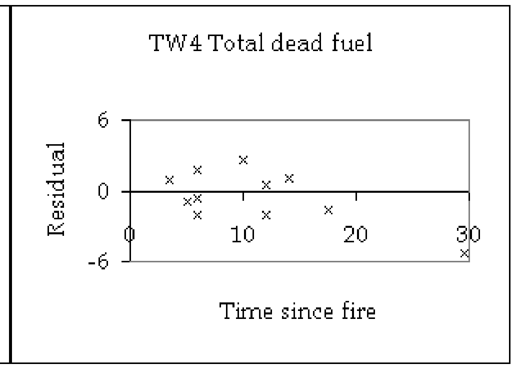
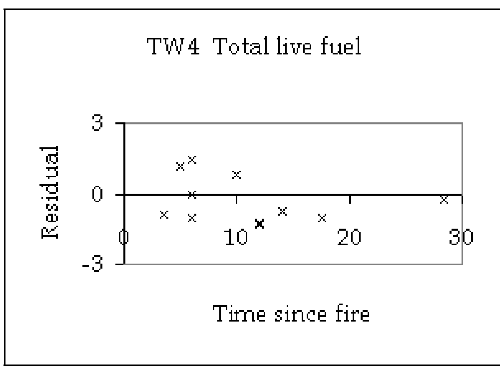
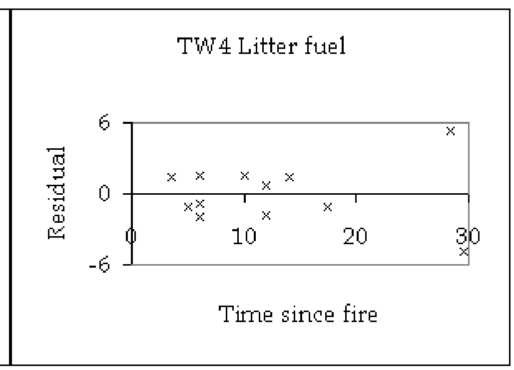
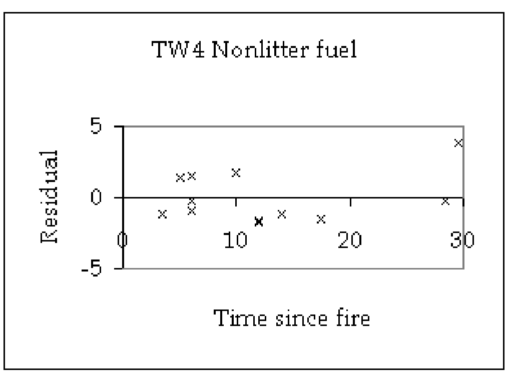


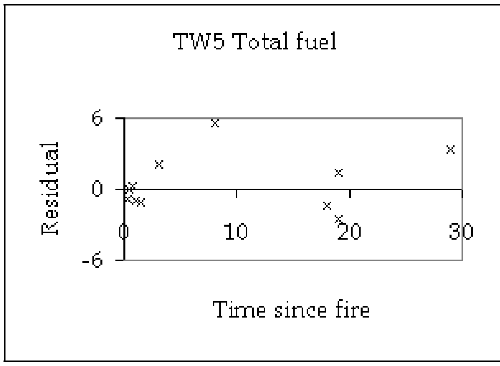


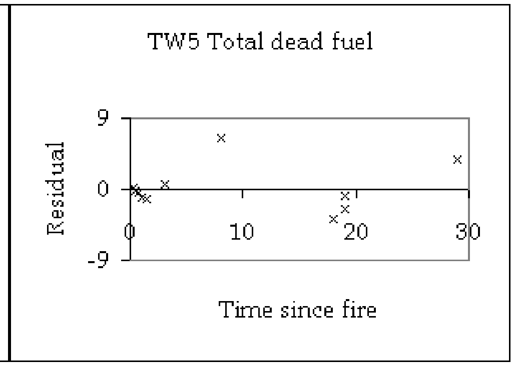


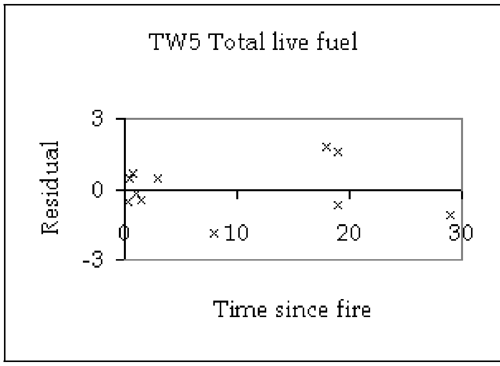


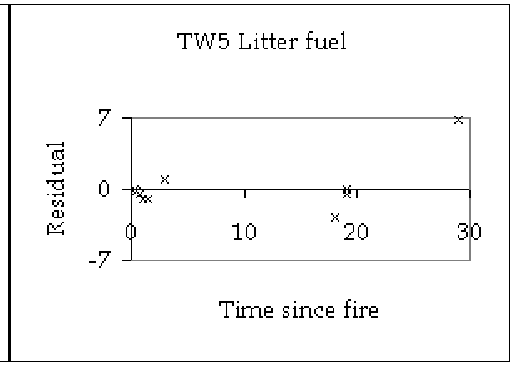


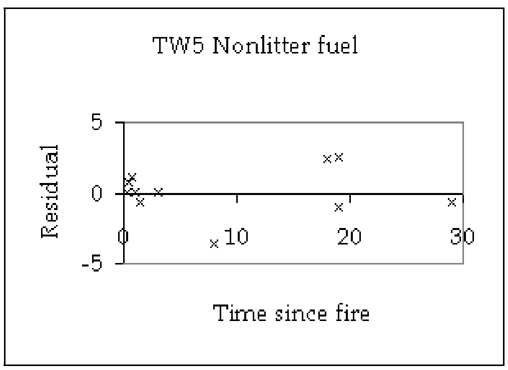
TWINSPAN group 5





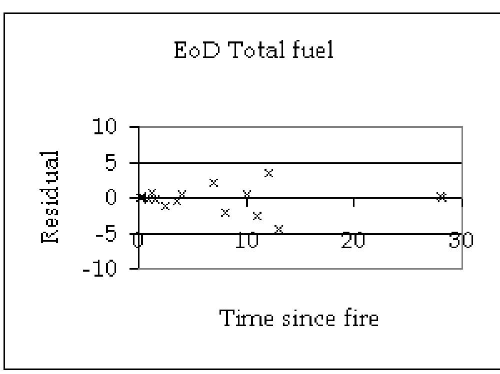


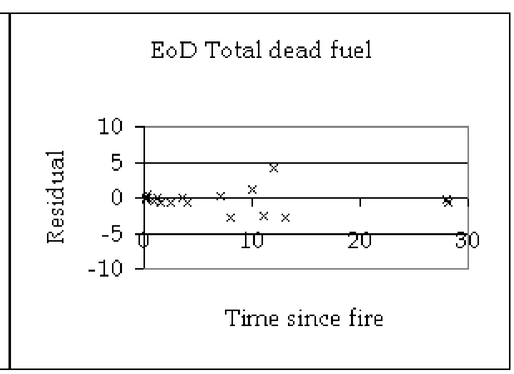


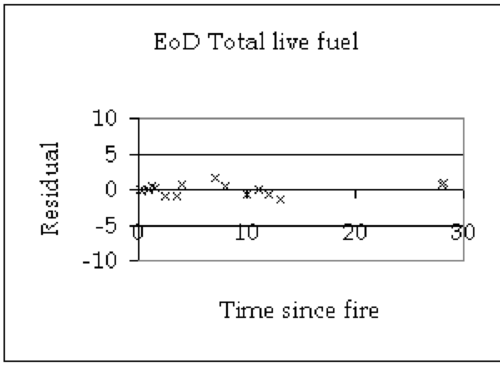


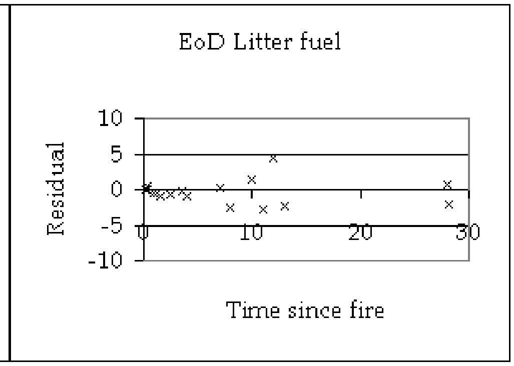
Geology ordering

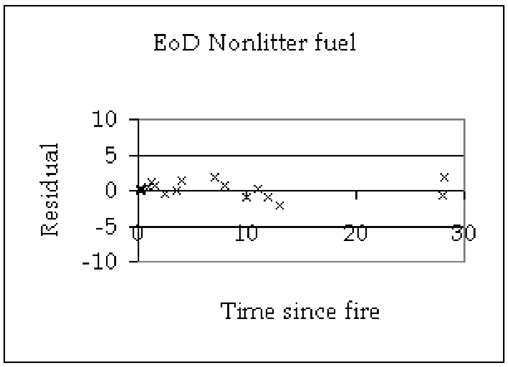
Eucalypts on dolerite



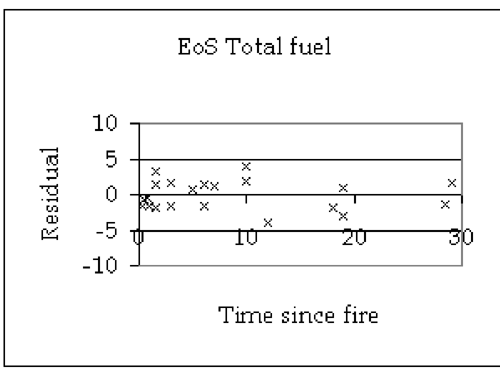


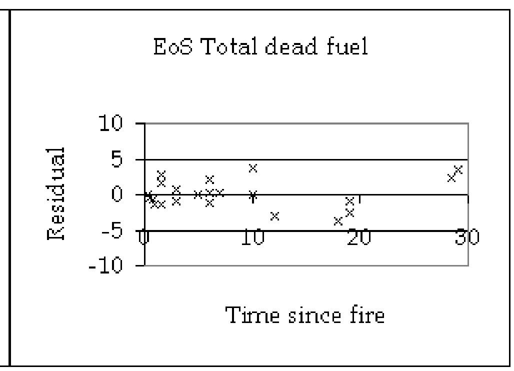


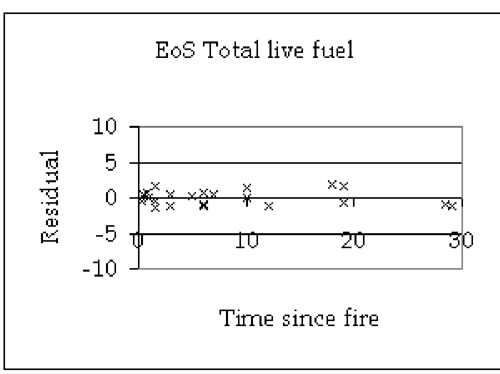


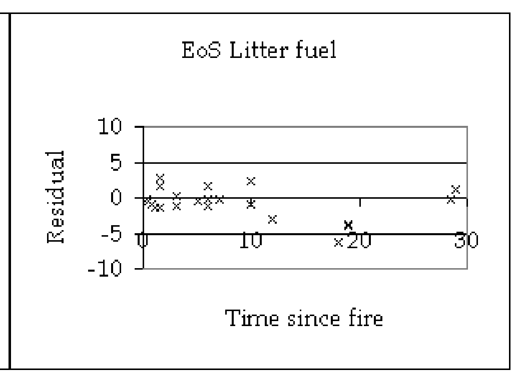


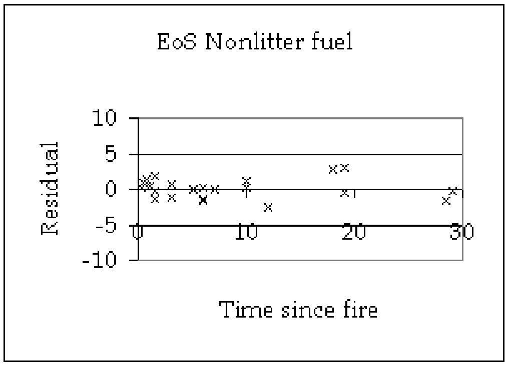
Eucalypts on sandstone



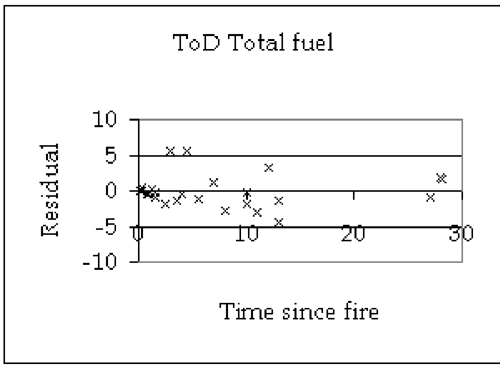


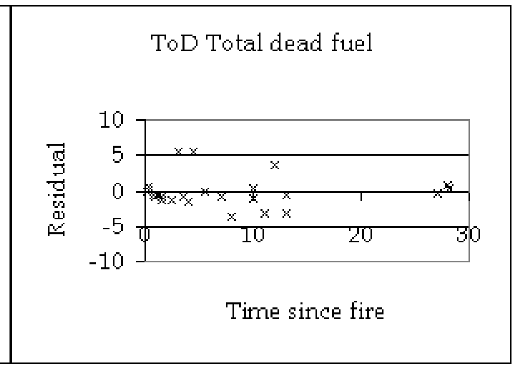


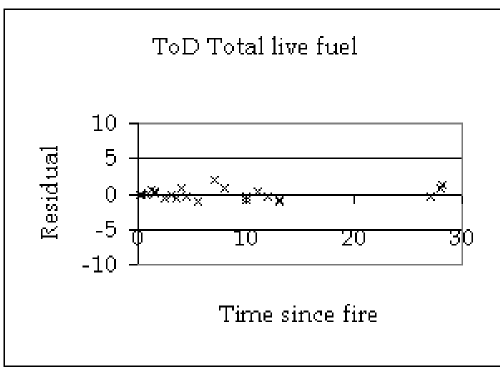


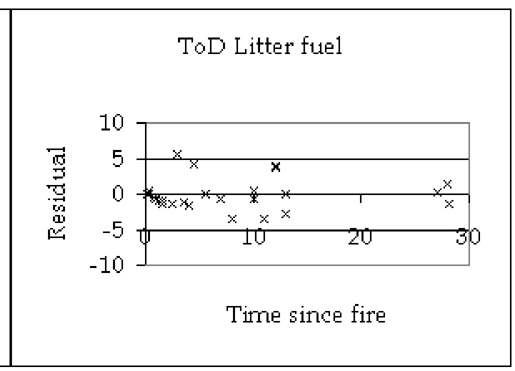


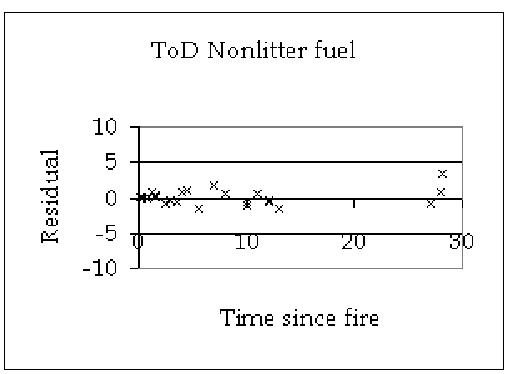
Total vegetation on dolerite





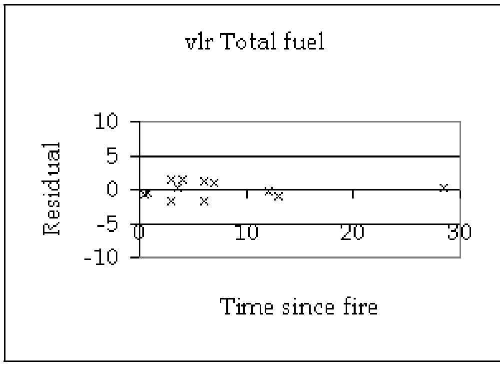


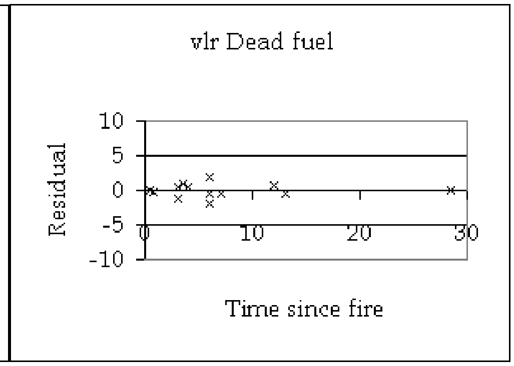


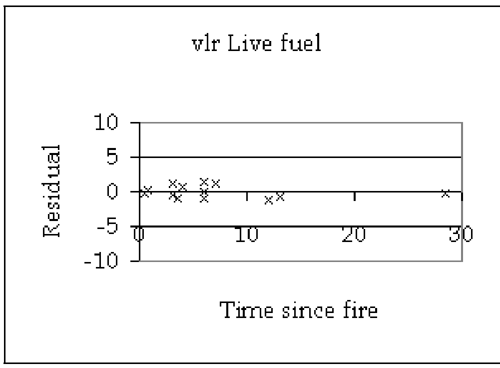


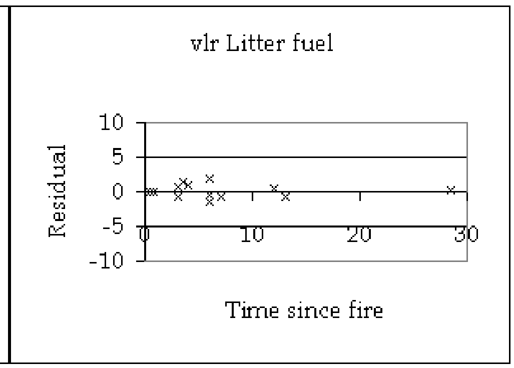
Rainfall ordering

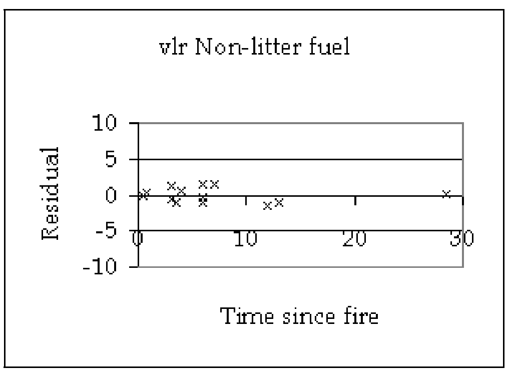
Very low rainfall



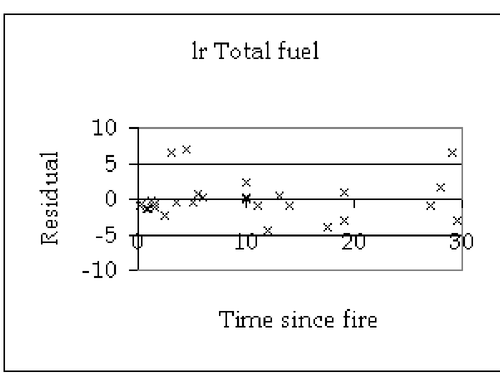


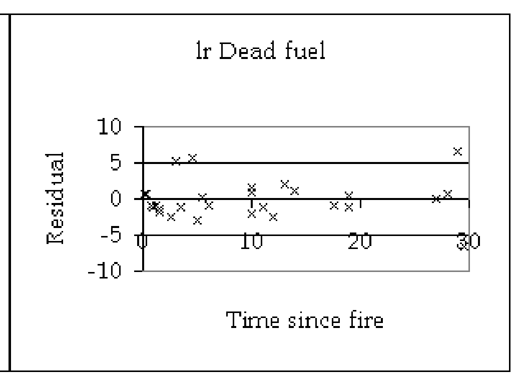


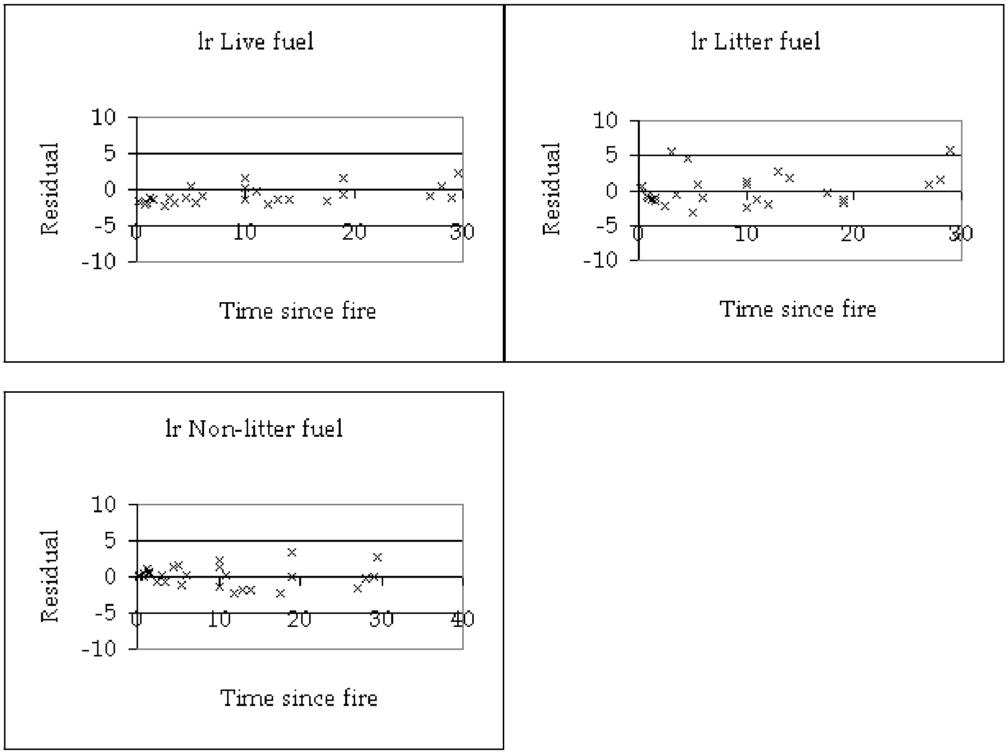




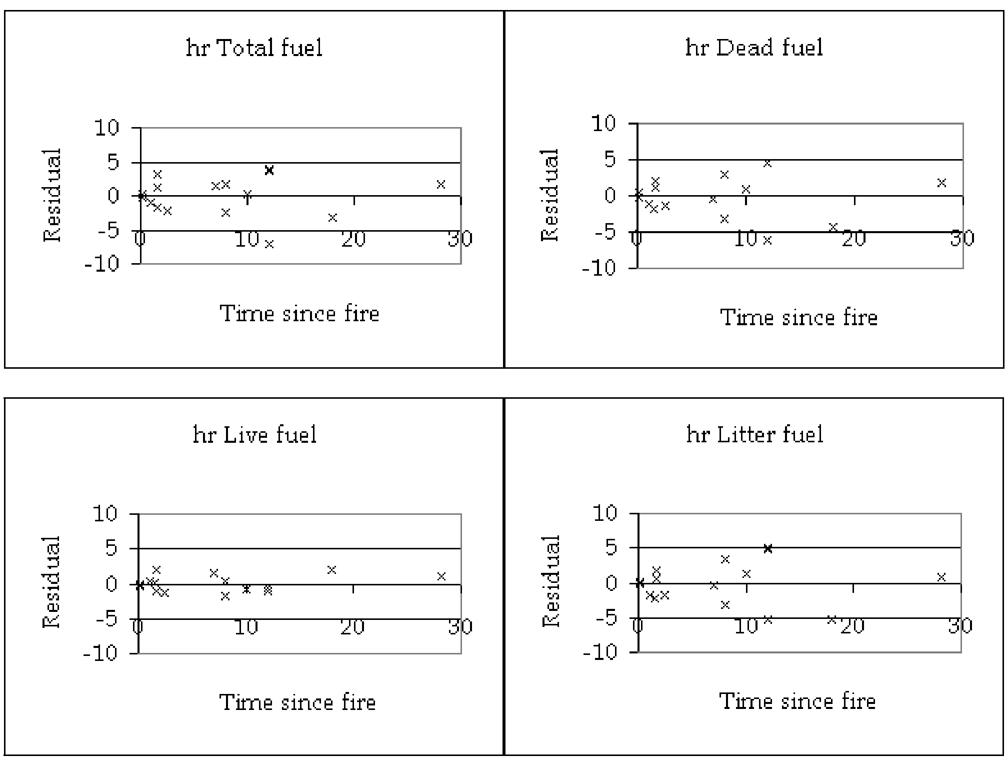
Low rainfall

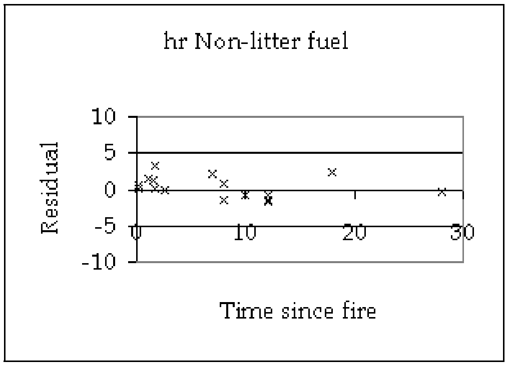






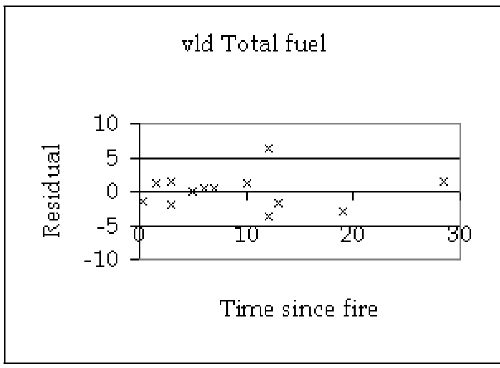
High rainfall

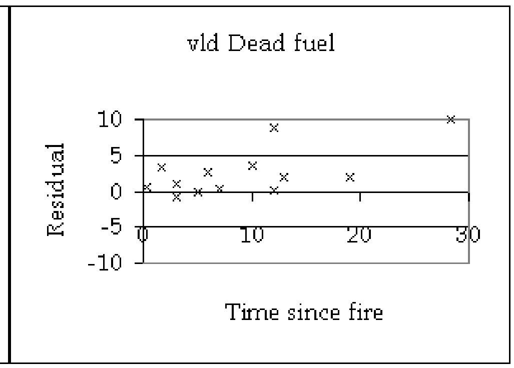


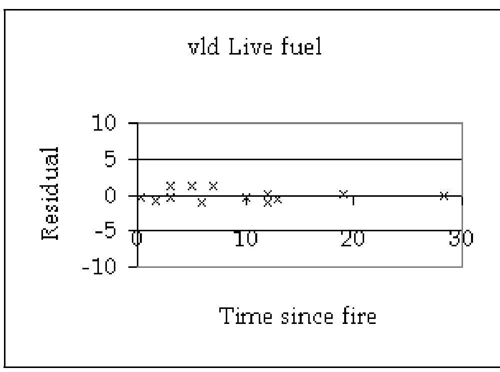


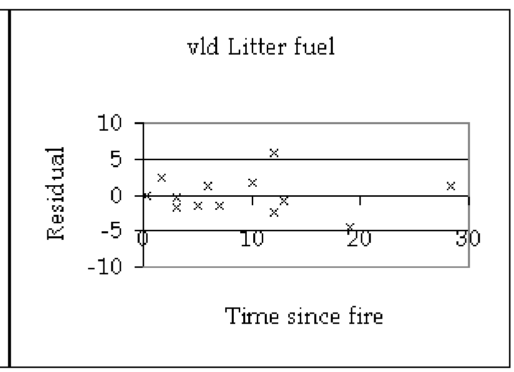
Tree density ordering

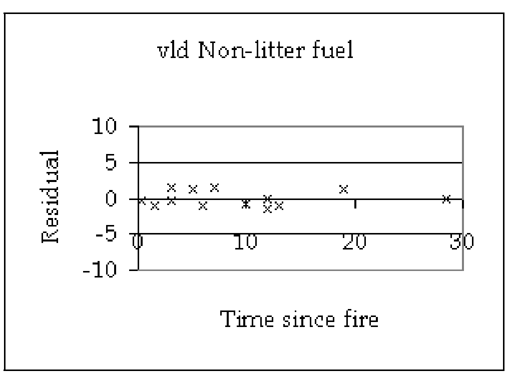
Very low density



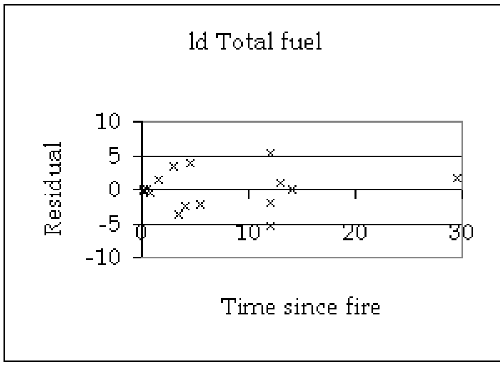


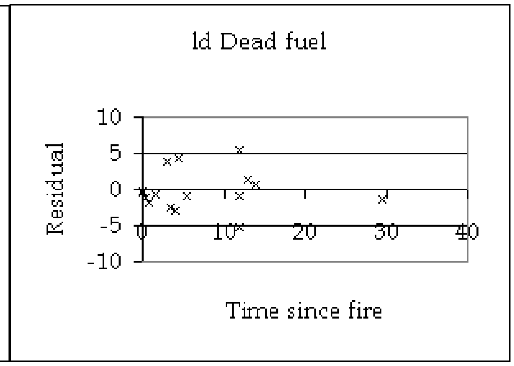


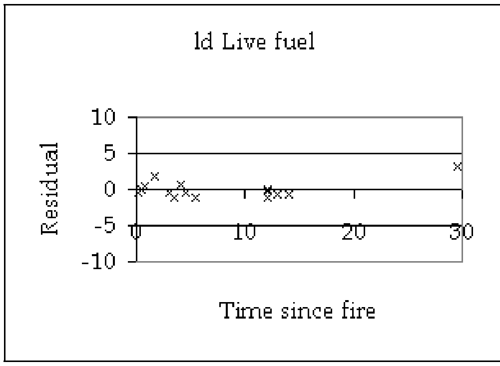


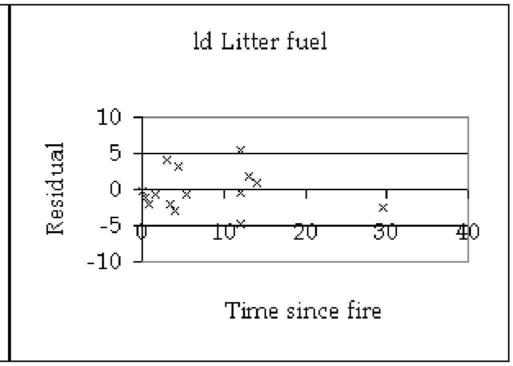


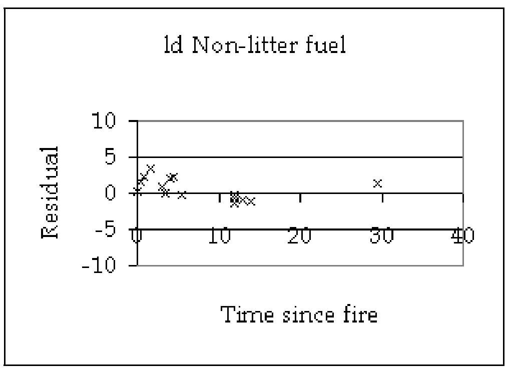
Low density



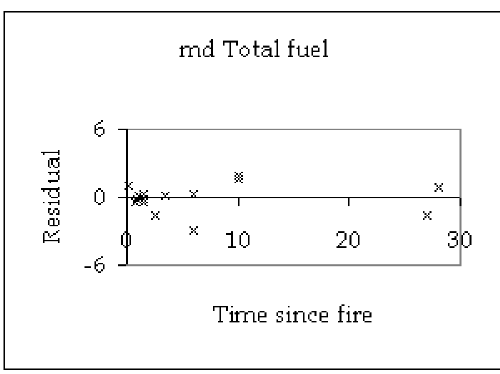


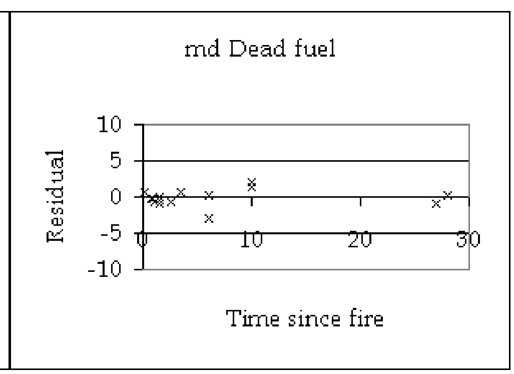


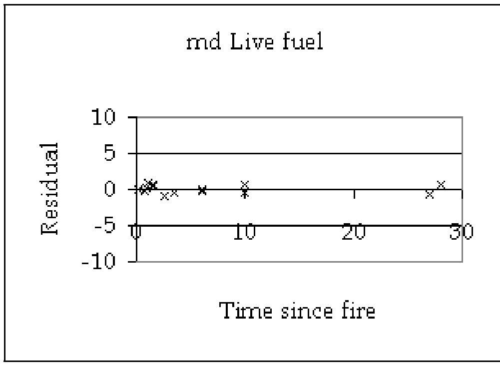


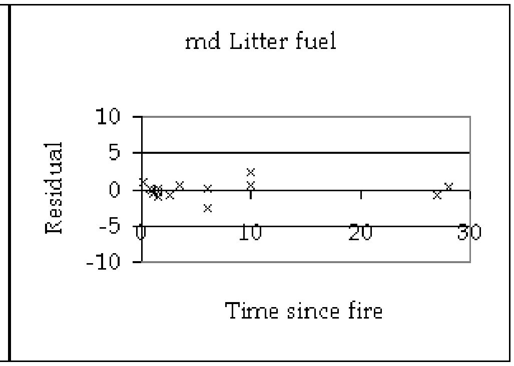


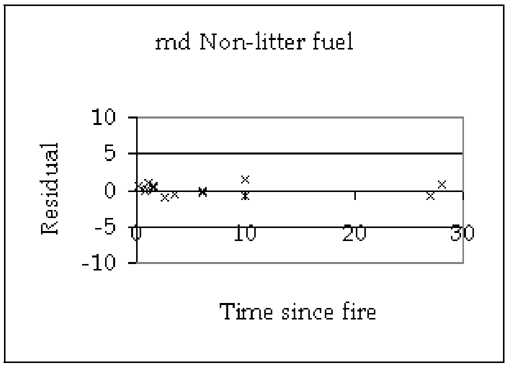
Medium density



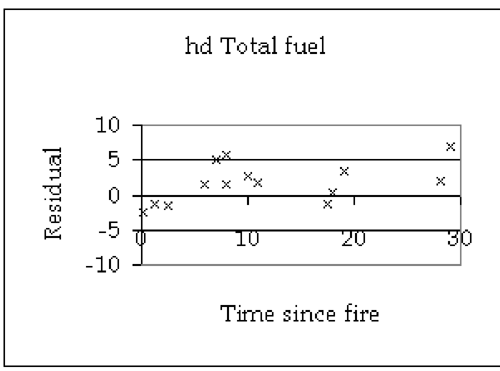


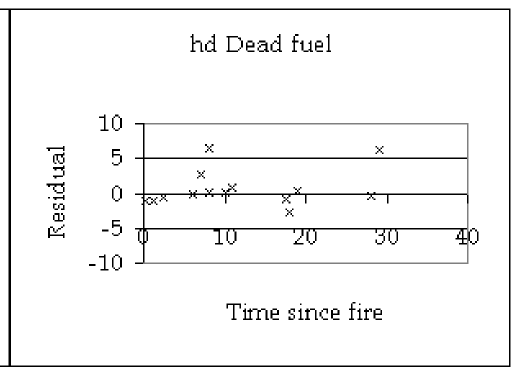


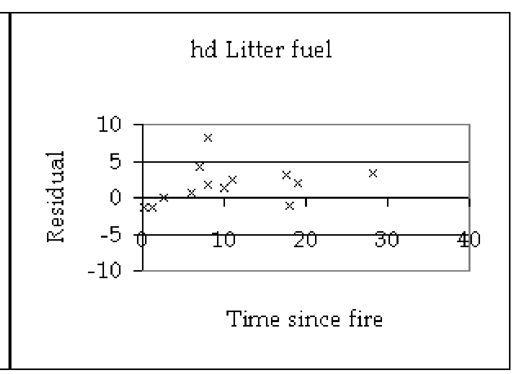


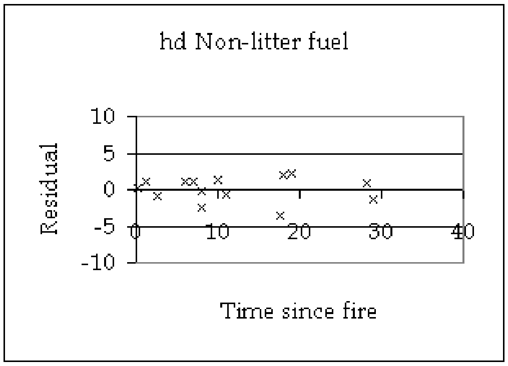


High density








hd Non-litter fuel
Residual
10
5
0
-5
-10
0
10
20
30
40
Time since fire

Appendix 4: TWINSPAN output

Order of samples

TW1	TW2	TW3	TW4	TW5
09 00	23 010	18 011	01 10	41 11
42 00	24 010	19 011	02 10	50 11
43 00	12 010	34 011	03 10	51 11
32 00	13 010	11 011	08 10	46 11
35 00	21 010	17 011	04 10	47 11
37 00	22 010	25 011	05 10	48 11
38 00	26 010	39 011	07 10	57 11
20 00	27 010	40 011	31 10	58 11
29 00	28 010	10 011	53 10	59 11
30 00	14 010	15 011	52 10	06 11
	33 010	16 011	54 10	49 11
	44 010	36 011	55 10	56 11
	45 010			

TWINSPAN output (simplified)

	0443333223	2211222221344	113112341110	000000335555	455444555045	
	9232578090	3423126784345	894175900566	123845713245	101678789696	
Acacia stricta	----------	-------------	--------111-	------------	------------	000000
Acacia verticillata	----------	-------------	--1---------	------------	------------	000000
Acrotriche serrulata	----------	-------------	----------1-	------------	------------	000000
Bulbine bulbosa	----------	--1----------	----------11	------------	------------	000000
Callistemon pallidus	----------	-------------	--------1---	------------	------------	000000
Coprosma hirtella	----------	-------------	--------1---	------------	------------	000000
Eriostemon verrucosus	----------	-------------	--------1---	------------	------------	000000
Exocarpos strictus	----------	---1---------	---------11-	------------	------------	000000
Geranium spp.	----------	1------------	------11---1	------------	------------	000000
Goodenia lanata	----------	-------------	---------1--	------------	------------	000000
Ozothamnus ferrugineus	----------	-------------	--------1---	------------	------------	000000
Hibbertia prostrata	----------	-------------	----------1-	------------	------------	000000
Lepidosperma inops	----------	-----1-------	--------1-1-	------------	------------	000000
Linum marginale	----------	-------1-----	---------11-	------------	------------	000000
Olearia argophylla	----------	-------------	--------1---	------------	------------	000000
Olearia erubescens	----------	-------------	--------1---	------------	------------	000000
Olea viscosa	----------	-------------	--------11--	------------	------------	000000
Pultenaea stricta	----------	-------------	--------1---	------------	------------	000000
Tetratheca pilosa	----------	-------------	----1---111-	------------	------------	000000
Viola hederacea	----------	-------------	--------1---	------------	------------	000000
Bedfordia salicina	----------	----11-------	--1-----1---	------------	------------	000001
Eucalyptus pulchela	-------111	1-1111---11--	111111111111	------------	------------	000001
Acacia myrtifolia	----------	-----1-------	--------1---	------------	------------	000010
Carex breviculmis	----------	1111-1----1--	--------1--1	------------	------------	000010
Clematis gentianoides	----------	--1--1-------	------------	------------	------------	000010
Convolvulus erubescens	----------	-------1-----	------------	------------	------------	000010
Cyathodes divaricata	----------	--11---------	------------	------------	------------	000010
Helichrysum scutellifolius	----------	--1----------	------------	------------	------------	000010
Hibbertia hirsuta	----------	--11-1-------	------------	------------	------------	000010
Lepidosperma gunnii	----------	--1--1-1-----	------------	------------	------------	000010
Lepidosperma laterale	----------	1111111------	---1----1-1-	------------	------------	000010

Olearia ericoides	----------	-----1-------	--------1---	------------	------------	000010
Olearia phlogopappa	----------	1------------	------------	------------	------------	000010
Opercularia varia	----------	--1----------	------------	------------	------------	000010
Podolepis jaceoides	----------	-------1-----	------------	------------	------------	000010
Agrostis spp.	1--1-1----	1111111111111	111--1111111	------------	------------	000011
Leptorhynchos squamatus	----------	--1-11-11-11-	---1-----111	------------	1-----------	000011
Plantago spp.	----------	111111----11-	---11---1111	------------	1-----------	000011
Ranunculus lappaceus	----------	11--------1--	------1----1	------------	------------	000011
Allocasuarina verticillata	--------11	111111111----	1-1-1111----	------------	--------1---	00010
Themeda triandra	--------11	111111111111-	----------11	----------1-	------------	00010
Chrysocephalum semipapposum	1---------	-------------	------------	------------	------------	00011
Elymus scaber	1-1-1-1---	1--1--111111-	-----------1	----------1-	------------	00011
Olearia ramulosa	---1-1--11	1111-1-11-1-1	----1-----1-	------1-----	------------	00011
Eucalyptus globulus	---1111-11	----------1--	1111--11-1-1	------------	1-----------	00100
Juncus spp.	-----11---	-------------	---1--------	------------	------------	00100
Scleranthus biflorus	-----1----	-------------	------------	------------	------------	00100
Ulex europaeus	--1-------	-------------	--1---------	------------	------------	00100
Dichondra repens	---1111---	-------------	------------	------------	--1---------	00101
Senecio spp.	111-----11	---111-----1-	111-1-111111	1--1--------	1-----11----	00101
Acacia melanoxylon	----------	1-1------11--	--11-11----1	1-------1---	------------	001100
Acaena echinata	-11-------	11----1111111	111-11---111	--------1-11	1-----------	001100
Bossiaea prostrata	--1-----1-	--11-111111-1	11-111111-11	----------11	--1111------	001100
Brachyscome spp.	----------	------11-----	---------111	---------1--	------------	001100
Acacia genistifolia	----------	--11---------	---------11-	-----1------	------------	001101
Acacia mearnsii	----------	-11111111--1-	------------	-------11---	------------	001101
Arthropodium milleflorum	----------	1111-1---1---	--------1--1	------------	------11----	001101
Oxalis perennans	-111111-1-	---1111111111	-----1------	----1--1----	1-----------	00111
Pimelia humilis	111111--11	-111---11--11	---111--111-	---1---111-1	1-----------	00111
Bursaria spinosa	---1-1-111	111111-111-11	111---11-11-	1--1---11-11	------------	010
Acacia dealbata	1111111111	---1----11111	111111--1111	1-1111111111	111---111-1-	011000
Austrodanthonia spp.	11111111--	--11111111-11	1-111111111-	-11-11111111	1-1---111111	011000
Asperula spp.	--------1-	----------1-1	-1---------1	----1-----11	------------	011001
Astroloma humifusum	1111----1-	1111111-11111	11-111--1111	11111111--1-	1-1111--1---	011001

Deyeuxia spp.	-11-1-1-11	1111111---111	111111111111	--1-1---11--	1--11111--1-	011001
Dichondra spp.	1111-1-11-	1111111111111	1111-1--1111	111-1111-1-1	111111---1--	011001
Dodonea viscosa	--------1-	--1111-11-1-1	--1-1-------	111-1-1-1-1-	------------	011001
Eucalyptus viminalis	--111111--	1--111---1111	11111-----11	11---1-1-11-	11----11----	011001
Exocarpos cupressiformis	11--1---11	1---1----11-1	111111---111	111111--1---	--1---1111--	011001
Gonocarpus tetragynus	1111------	--1111-111111	11-111111111	1--111111111	-11-----1111	011001
Helichrysum scorpioides	111-------	--1111--111-1	----1---1111	--1-1----11-	111111------	011001
Lomandra longifolia	-11111-111	1111111111111	111111111111	1111--111111	111111111--1	011001
Poa spp.	111-111111	1111111111111	111111111111	1111---111-1	11-11111--1-	011001
Austrostipa spp.	-111111111	1111111111111	111111111111	-11111111111	1-111111--11	011001
Wahlenbergia spp.	1---------	1--1-----11--	-----1--1111	----1-1--11-	-1-11-------	011001
Chrysocephalum apiculatum	-1--------	------1111--1	111-1-11--1-	1--1------1-	-1-11-1-----	011010
Hypericum gramineum	1---------	---------11-1	1-------1-11	------------	---11111----	011010
Schoenus apogon	--1-------	--1-11-----1-	11------111-	------------	1-111-------	011010
Allocasuarina monilifera	-------1--	---------1---	---1--------	------------	-----------1	011011
Diplarrena latifolia	-------111	---------111-	11---1111111	-1------1---	1-111---1---	011011
Lagenifera stipitata	----------	-------------	------1----1	------------	------1-----	011011
Pultenaea juniperina	1---------	-------------	----1-11111-	---1--------	1--------1--	011011
Crassula sieberiana	----111---	-------------	------------	-------1----	------------	0111
Ehrharta stipoides	111-111111	-------------	------11----	------11----	1--11-------	0111
Dianella revoluta	1--1----11	--11---1111-1	---111111111	11111111-111	-11-----11-1	100
Lissanthe strigosa	111-1-----	1-1111---1-1-	1---1----1--	1--111-11---	1-111-111---	100
Tetratheca labillardierei	1--11---1-	------------1	11----11----	-1111-------	--1---11111-	100
Epacris impressa	----------	---1-----1---	---11111111-	---1----11--	111-----1111	1010
Goodenia ovata	----------	-------------	--1-----1---	1--1--------	------------	1010
Leptospermum scoparium	----------	----------1--	---1-1111111	------------	111111---111	1010
Lomatia tinctoria	----------	-------------	--------11--	------------	1-1---------	1010
Daviesia ulicifolia	----------	----------1--	--------1111	-111---1----	---------11-	1011
Pimelia linifolia	----------	-------------	------11----	1--------1--	---------111	1011
Daviesia latifolia	1---------	-------------	------------	-1----1-----	------------	11000
Ozothamnus obcordatus	----------	-1-------1---	------------	111------11-	----------1-	11000
Cassytha pubescens	----------	---------1---	--1111--1---	-11--1--1111	-1-11----11-	11001
Gahnia radula	----------	-------------	--1---11----	-----1--11-1	11--------1-	11001

Pultenaea daphnoides	----------	--------1----	--1-1-------	11-1-1--1---	------------	11001
Acacia terminalis	----------	-------------	------1-----	------------	--1-----11--	11010
Dianella tasmanica	----------	-------------	--------1---	-----------1	-1----------	11010
Leucopogon virgatus	--1-------	-------------	----------1-	---------1--	11--------11	11010
Stylidium graminifolium	----------	-------------	--------111-	---------1--	111-------1-	11010
Banksia marginata	----------	---------1--1	------111---	1-------11-1	1111----111-	11011
Eucalyptus amygdalina	-11--1----	-----------11	----1-------	-----1111111	111111111111	11011
Gnaphalium collinum	-----1----	-------------	------------	------------	------11----	11011
Pteridium esculentum	----1-1---	-----------1-	----1----1--	---11----1-1	111---111-11	11011
Acacia suavolens	----------	-------------	------------	------------	-----------1	111000
Aotus ericoides	----------	-------------	------------	-1-------1--	---------11-	111000
Boronia pilosa	----------	-------------	------------	------------	----------1-	111000
Dillwynia glaberrima	----------	-------------	------------	------------	-----------1	111000
Hibbertia procumbens	----------	-------------	------------	------------	-----------1	111000
Hypolaena fastigiata	----------	-------------	------------	------------	-----------1	111000
Lepidosperma concavum	----------	-------------	------------	------------	-----------1	111000
Leptomeria drupacea	----------	-------------	------------	------------	---------1--	111000
Leptospermum glaucescens	----------	-------------	------------	------------	-----------1	111000
Leucopogon collinus	----------	-------------	--------1---	--------1---	-1-------111	111000
Pultenaea gunnii	----------	-------------	------------	------------	---------1--	111000
Amperea xiphoclada	----------	-------------	------------	---------1--	-1----11-111	111001
Cassytha glabella	----------	-------------	------------	------1-----	--1--------1	111001
Eucalyptus obliqua	----------	-------------	--------11--	---1------1-	--1111--11--	111001
Persoonia juniperina	----------	-------------	------------	------------	1---------1-	111001
Bossiaea cinerea	----------	-------------	------------	------------	-1----11---1	111010
Gompholobium huegelii	----------	-------------	------------	------------	------11----	111010
Carpobrotus rossii	----------	-------------	------------	------------	------1-----	111010
Pimelia nivea	----------	--1----------	------------	----------1-	-11---111---	111011
Bracteantha bicolor	----------	-------------	------------	------------	---11-------	111011
Allocasuarina littoralis	----------	------------1	------------	-11-11111111	-11---111-1-	111100
Drosera spp.	----------	-------------	------------	--11--------	------------	111101
Ehrharta distichophylla	----------	-----------1-	------------	-------11111	------------	111101
Leucopogon ericoides	----------	-------------	------------	-------11111	----------1-	111101

```
Ozothamnus purpurescens     ---------- ------------- ------------ -----1------ ------------ 111101
Pomaderris prolifera        ---------- ------------- ------------ -----1------ ------------ 111101
Pultenaea pedunculata       ---------- ------------- ------------ -11-111----- ------------ 111101
Stypandra caespitosa        ---------- ------------- ------------ ---------1-- ------------ 111101
Eucalyptus risdonii         -1-------- ------------- ------------ ----111----- ------------ 11111
Eucalyptus tenuiramis       1--------- ------------- ------------ 1111-------- ---------1-- 11111
Rhytidosperma procumbens    ---------- ------------- ---------1-- -----1---1-1 ---------1-- 11111
                            0000000000 0000000000000 000000000000 111111111111 111111111111
                            0000000000 1111111111111 111111111111 000000000000 111111111111
                                       0000000000000 111111111111
```