

The ecology of edges in Tasmanian wet forests managed
for wood production

By

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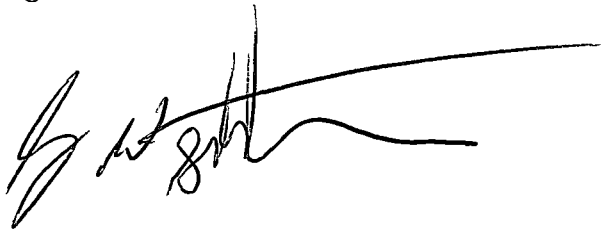
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Philosophy

University of Tasmania, November 2003.

Declaration

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A handwritten signature in black ink, appearing to read 'G Westphalen', with a long horizontal flourish extending to the right.

Grant Westphalen, 24th November 2003

Abstract

The study addresses microclimate and vegetation changes in the edges of logged coupes in southern Tasmanian wet forests and discusses general questions relating to forest edges.

Seasonal patterns of microclimate were investigated using a Before and After, Control and Impact (or "BACI") approach and a study of edges across a range of ages; less than 1 year, 2, 5, and 15 years old. There was a loss of canopy buffering of temperature and humidity in the understorey in warmer seasons, which extended up to 10 m distance into the undisturbed forest from the edge, regardless of its age. Otherwise gradients in microclimate within controls and at the BACI site prior to logging were analogous to those measured at forest coupe edges. Influences on the flora in the edge were thus considered likely to occur only during extreme climatic conditions (e.g. very hot dry windy days). Apart from seasonal differences, height above ground was also found to have a very important influence on the microclimate in the edges of forest coupes.

Vegetation changes were explored through surveys of the bryophyte and epiphytic vascular plants (otherwise described as "epiflora"), again employing a BACI design and edges of different ages. The epiflora was found to have very low survival rates on coupes and was therefore considered the most likely element of the flora to respond to microclimate changes, at least in the short term. Changes in the epiflora in forest edges were correlated with the microclimate response but also corresponded to the mechanical disturbance at both the canopy and ground level that resulted from the adjacent logging and firebreak construction. Epiflora composition did not alter with age of the edge but appeared to respond more to large-scale changes in the composition of the associated vascular flora and related substrates (dead logs and litter). Edge effects in southern Tasmanian wet forests in both microclimate and epiflora thus extended only a short distance into the intact forest (< 10 m) but were maintained for a prolonged period (at least 15 years).

There was no indication of increased seedling recruitment in the vascular flora within the edge, which may explain the lack of any apparent side canopy development that has been noted in other research. However, as with much of the Australian flora, successful recruitment for many species in southern Tasmanian wet forests requires

or is enhanced by destructive wildfires. A lack of woody plant recruitment within the firebreaks constructed at the edge of coupes may also play a role. It was considered that edge effects in tree and tall shrub components of the flora were expressed mostly in terms of mechanical damage that was partly due to adjacent logging but mostly a response to prolonged exposure to increased windthrow and may penetrate up to 50 m in from the forest edge.

Outcomes from this research highlight deficiencies in other published research of forest edges. These relate to a lack of information on 1) the nature of forest systems before edge establishment (*a priori* measurements), 2) appropriate levels of control (background variability) and 3) age related responses (succession). There is little comparable research on changes in microclimate with season in forest edges or on the relative importance of mechanical damage to forest edges on the changes in microclimate and flora. Future research should focus more on longer terms studies combining floristic, microclimatic and disturbance information with repeated measurements over several years or even decades.

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1 Introduction – Forest edges

1.1 The importance of edges

A matrix of differently aged coupes within patches of reserved forest will eventually dominate many of the worlds forested landscapes (Kimmins 1997, Lindenmeyer and Franklin 2000) and there is pressure on both governments and the timber industry to employ ecologically sustainable harvesting strategies (Ehrlich 1996, Kimmins 1997). Given the limited extent of legislated reserves for the preservation of forest biodiversity, species retention will largely be determined by the management strategies employed within production forests areas (Brown 1996, Lindenmeyer and Franklin 2000). This will largely be determined by:

- The size, viability and spatial dispersion of populations of forest organisms,
- The ability to facilitate or obstruct the movement of organisms and
- The buffering of sensitive areas and reserves (Lindenmeyer and Franklin 2000).

Conservation values within the matrix are best maintained through careful consideration of the spatial (Brown 1996) and temporal (Loyn 2000) arrangement of coupes to limit fragmentation and provide a diversity of regenerated landscapes that may promote diversity (Brown 1996, Loyn 2000).

Most important however, is the retention of significant areas of undisturbed vegetation within the framework of forestry operations (Kimmins 1997, Lindenmeyer and Franklin 2000). Apart from the provision of habitat for wildlife, these areas can protect sensitive areas along streams and rivers (Brosofske *et al.* 1997), unstable slopes and soils (Lindenmeyer and Franklin 2000) with isolation

restricted by the maintenance of unlogged corridors of vegetation (Kirkpatrick and Bowman 1982, Brown 1996, Lindenmeyer and Franklin 2000; Figure 1.1). These patches of vegetation are important for numerous reasons (Burgman and Ferguson 1995, Duncan and Johnson 1995, Lindenmeyer and Franklin 2000) including:

- Refugia for plant and animal species,
- A source of propagules for the regeneration of adjacent clearfelled forest (Williams-Linera *et al.* 1998, Ruben *et al.* 1999, Dettki *et al.* 2000, Oosterhoorn and Kappelle 2000),
- Help in the preservation of water catchments and streams (Brosfokske *et al.* 1997),
- Prevention of soil erosion and
- Recreation and/or tourism value or to provide visual relief from forestry operations.

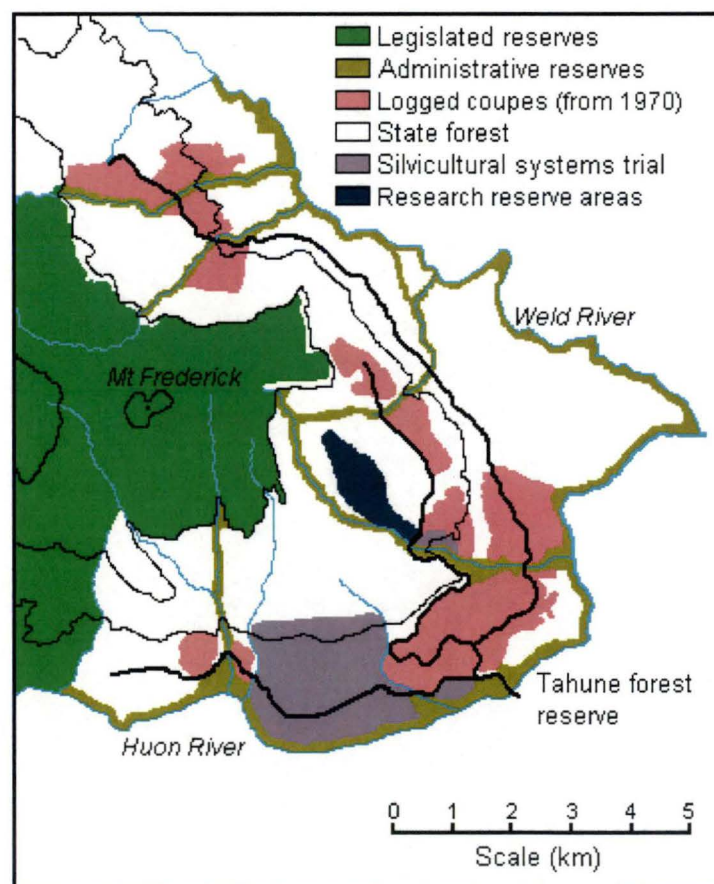


Figure 1.1 - An example of the mosaic of logged coupes and reserved patches including wildlife habitat strips and vegetation corridors in southern Tasmania (~ 60 km south of Hobart). Map courtesy Forestry Tasmania.

The implications of such an approach are landscapes comprised of a mosaic of reserved forest stands and a patchwork of logged coupes of varying ages (Kirkpatrick and Bowman 1982, Young and Mitchell 1994, Kimmins 1997, Williams-Linera *et al.* 1998, Esseen and Renhorn 1998). As information to guide conservation biologists and forest managers in production forests is lacking (Lindenmeyer and Franklin 2000), there is a need to increase our understanding of the dynamics of small remnant oldgrowth stands that are surrounded by regrowth forests (Murcia 1995, Ehrlich 1996, Brososke *et al.* 1997).

Clearfelling results in a sharp discontinuity between the logged and unlogged forest with an abrupt change in cover and a margin of altered microclimate (e.g. Wales 1972, Ranney *et al.* 1981, Lovejoy *et al.* 1986, Palik and Murphy 1990, Williams-Linera 1990, Camargo and Kapos 1995, Murcia 1995). The resultant “edge effects” may reduce the effective size of a fragment and can compromise its conservation values (Temple and Cary 1988, Murcia 1995). Studies of the influence of edge effects on reserves have been an integral part of the ongoing debate concerning the size, shape and number of conservation areas that are important for the maintenance of biodiversity in forest systems (Lovejoy *et al.* 1986, Cowling and Bond 1991, Burkey 1993, Zuidema *et al.* 1996, Kunin 1997, Hartley and Hunter 1998).

Little is known of the extent to which logged coupes in Tasmanian forests are subject to edge effects, but current production forests are afforded considerable areas of reserved forest patches and strips (about 30 % of log-able state forest; M. Brown, Forestry Tasmania, Pers. Com. 2000) that are adjacent to clearfelled patches (e.g. Figure 1.1; Duncan and Johnson 1995).

1.2 Forest edges and edge effects

Edge effects in the context of this study refer exclusively to anthropogenic disturbance. While sharp transitions between forest types and forest – savannah do exist, there is little if any comparable research conducted within these zones in spite of differences in the vegetation relative to the mature forest (Ashton 1981, Wardle 1981, Turton and Sexton 1996, Biddulph and Kellman 1998). Rather research on naturally occurring forest edges appears to focus on the mechanisms that maintain the edge: fires, floods, landslides, snowlines, etc (e.g. Ashton, Wardle 1981, Biddulph and Kellman 1998), movement/interactions of biota across the interface

(e.g. Canny 1981), the advance or retreat of the boundary over time (e.g. Wardle 1981, Turton and Sexton 1996, Biddulph and Kellman 1998) and the width of the boundary over time (Ashton 1981). Canny (1981) makes the point that all boundaries are arbitrary such that the perspective of the observer is the most important determining factor.

Creation of an edge can significantly alter growth, survival, reproduction and behaviour of both plant and animal communities (e.g. McDonnell and Stiles 1983, Kollman and Schneider 1997, Ostfeld *et al.* 1997, Restrepo and Gomez 1998, Gascon *et al.* 2000). Edge effects become more influential when forest fragments are small or irregular in shape (Forman and Godron 1986, Laurance 1991, Laurance and Yensen 1991, Restrepo and Vargas 1999), with forest species that are dependent on the conditions under a closed canopy restricted to the centre of an isolated patch or completely excluded from smaller stands (Levenson 1981, Lovejoy *et al.* 1986, Mills 1995). As a result, small patches, with a high perimeter/area ratio, may consist entirely of modified edge habitat (Kapos 1989, Santos and Tellería 1992, Mills 1995, Duncan and Johnson 1995) and can be very different from larger patches (Lovejoy *et al.* 1986, Wilcove *et al.* 1986, Laurance and Yensen 1991, Malcolm 1994).

Differences in the biota relative to the size of patches would be analogous with those described in island biogeography (*sensu* MacArthur and Wilson 1967), although Laurance and Yensen (1991) and Gascon and Lovejoy (1998) consider that this theory does not incorporate edge effects because it assumes that there is little variation in habitat over the total area of an isolate and ignores the effect of changes within the adjacent matrix.

1.2.1 Edge effects - fauna and fauna/flora interactions

Fragmentation of habitat and its associated edge effects are of major concern to wildlife conservation (Temple and Cary 1988), although research with respect to animal populations near edges has had an overwhelming focus on birds (e.g. Burgman and Ferguson 1995, Zuidema *et al.* 1996, Hartley and Hunter 1998). This is in spite of strong evidence of influences on other fauna types, including amphibians (Gascon 1993, Demaynadier and Hunter 1998), insects and other invertebrates (Bellinger *et al.* 1989, Bedford and Usher 1994, Lovejoy *et al.* 1984, Davies and Margules 1998) and mammals (e.g. Mills 1995, Laurance 1997). Fauna

responses to both fragmentation and edge effects are often highly variable and/or species specific, making generalisations difficult (Lindenmeyer *et al.* 1990, Gascon 1993, Burgman and Ferguson 1995, Donovan *et al.* 1997).

Changes in the abundance and behaviour of fauna in edges may be reflected in vegetational differences through the loss or gain of pollinators and seed dispersers and/or predators (McDonnell and Stiles 1983, Burkey 1993, Kollman and Schneider 1997, Ostfield *et al.* 1997, Restrepo and Gomez 1998, Restrepo and Vargas 1999). The flow-on effect of these changes to fauna on the vegetation are unknown (Burkey 1993) however, it may lead to prolific recruitment of some plant species (whose seed predators are absent) juxtaposed by very poor fruiting success in others (whose pollinators are removed). Many plants require their seed to pass through the gut of a dispersal vector before the seed will germinate (e.g. Barnea *et al.* 1991, Clergeau 1992, Traveset 1998, Yagahashi *et al.* 1998, Bell 1999). Even without this requirement, the loss of seed dispersal mechanisms has the potential to promote a dramatic shift in vegetation dynamics of the boundary zone. Creation of an edge may therefore have serious implications for the forest community at large spatial scales (Burkey 1993).

1.2.2 Edge effects - microclimate and floristics

The climate within a closed forest is very different from that of an open location (Kittredge 1948, Oke 1978, Franklin *et al.* 1991, Murcia 1995), as an established forest will ameliorate the prevailing local climatic conditions by shielding the ground and understorey (Oke 1978, Shuttleworth 1989, Franklin *et al.* 1991). Hence, when conditions outside a forest are warm and sunny, the understorey will be darker, cooler and more humid and have little or no air movement (Kittredge 1948, Oke 1978, Shuttleworth 1989, Luczaj and Sadowska 1997). This is because the location for the vast bulk of light absorption, the “thermodynamically active surface”, is incorporated within the canopy (Wales 1967, Oke 1978, Shuttleworth 1989).

Fragmentation of a closed forest either by clearing or natural processes creates an edge that allows a marginal zone of forest floor to become a thermodynamically active surface (Wales 1967) where sun, wind and rain can penetrate under the canopy (Wales 1967, Matlack 1993). The result is a gradient of microclimate changes between the forest edge and what is often described as “forest interior” (e.g. Malcolm

1994, Camargo and Kapos 1995, Murcia 1995, Turton and Freiburger 1997, Malcolm 1998). The development of a microclimate gradient leads to changes in both flora and fauna (e.g. Chen *et al.* 1992, Burkey 1993, Matlack 1993, 1994, Young and Mitchell 1994, Mills 1995, Malcolm 1998, Oosterhoorn and Kappelle 2000), which may give rise to communities that are characteristic of neither the closed forest nor the cleared area (Malcolm 1994).

Numerous studies (e.g. Kapos 1989, Burkey 1993, Matlack 1993, Malcolm 1994, Chen *et al.* 1995, Broszofske *et al.* 1997, Parry 1997) have established the nature of the microclimate gradient which occurs in the edge zone, including:

- Direct sun exposure,
- Increased soil and air temperature (average and diurnal/seasonal variation),
- Reduced average humidity, but increased variation,
- Greater wind penetration and turbulence and
- Increased exposure to direct rain and runoff.

The increase in light is considered to have a major role in the microclimate changes that occur along a forest edge, particularly those related to temperature and humidity (Kapos 1989, Matlack 1993, Chen *et al.* 1995). The effect of the boundary on the remnant vegetation alters as the boundary ages with the regenerating flora of the coupe changing concomitantly with the flora in the edge zone (e.g. Ranney *et al.* 1981, Matlack 1993, Mesquita *et al.* 1999). Hence, the extent of penetration of boundary effects into the interior of a stand varies considerably between forests and coupes of different ages (e.g. Ranney *et al.* 1981, Williams-Linera 1990, Matlack 1993, Malcolm 1994, Burgman and Ferguson 1995, Chen *et al.* 1995, Murcia 1995, Esseen and Renhorn 1998).

Changes in microclimate at a forest edge can have a wide range of effects on the associated vegetation (Wales 1967, Lovejoy *et al.* 1986, Kapos 1989, Laurance and Yensen 1991, Sizer and Tanner 1999, Gascon *et al.* 2000). These include:

- The proliferation of plant germination and growth.

Increased light in the edge releases established seedlings and saplings and promotes the germination of shade intolerant species, similar to the dynamics of forest gaps

(Wales 1972, Brokaw and Scheiner 1989, Veblen 1989, Whitmore 1989) resulting in increased stem density and basal area in the edge (Wales 1972, Ranney *et al.* 1981, Whitney and Runkle 1981, Williams-Linera 1990, Williams-Linera *et al.* 1998).

- Changes in plant growth form.

Another response to increased light availability, as well as the loss of competing neighbours, is the development of a wall of vegetation amongst trees at the edge, which eventually forms a “side canopy” (e.g. Lovejoy *et al.* 1986, Williams-Linera 1990, Brothers and Spingarn 1992, Matlack 1993, 1994, Camargo and Kapos 1995, Laurance *et al.* 1998, Sizer and Tanner 1999). Side canopy development may also be assisted by the increase in seed germination and growth.

- Effects on seedling germination and survival of shade tolerant species.

Some shade-adapted plants may be damaged by the increased light or overcome by competitors and thus restricted to the forest interior (e.g. Ranney *et al.* 1981, Whitney and Runkle 1981, Palik and Murphy 1990, Gehlhausen *et al.* 2000).

- Increased possibility of weed invasion.

Development of crops in the newly exposed area and the disturbances created by machinery near the edge may allow greater opportunities for weed species to infest an edge (Brothers and Spingarn 1992).

- Increased damage and mortality rates in mature trees.

This may be in response to microclimate stress (Lovejoy *et al.* 1986), increased windthrow (Laurance 1991, Laurance *et al.* 1998) and physical damage to neighbouring trees.

- Desiccation of the edge.

Drying out of the forest edge will affect mesic species (Ranney *et al.* 1981, Peacock 1994) and leaf litter that will in turn alter decay processes (Didham 1998). This may influence larger trees through the alteration of soil moisture (Kapos 1989), chemistry and mycorrhizal relationships (Lovejoy *et al.* 1986).

1.2.3 Previous research on edges

Previous research into vegetation edges has focussed on the distance to which altered microclimate and/or floristic changes may penetrate the otherwise undisturbed forest (e.g. Ranney *et al.* 1981, Palik and Murphy 1990, Williams-Linera 1990, Chen *et al.* 1992, Fraver 1994, Camargo and Kapos 1995, Jose *et al.* 1996, Parry 1997, Turton and Freiburger 1997, Laurance *et al.* 1998, Oosterhoorn and Kappelle 2000). When the penetration distance of the edge effect and patch size information are combined, the amount of unaffected or “interior forest” can be determined (Lovejoy *et al.* 1986, Laurance 1991, Laurance and Yensen 1991, Palik and Murphy 1990, Malcolm 1994, Young and Mitchell 1994). This is considered essential in the establishment of the conservation value of forest fragments (Lovejoy *et al.* 1986, Chen *et al.* 1992, Young and Mitchell 1994).

While useful insights are obtained from fragmented systems (and indeed are often the only ones available) the degree of the edge effect may itself be influenced by the size of the fragment (Murcia 1995). To effectively examine edge effects in isolation there needs to be research focussed on edges abutting continuous forest.

Microclimatic measurements obtained from forest edges have commonly included light (often photosynthetically active radiation – PAR), temperature and humidity (often vapour pressure deficit – VPD; Chen *et al.* 1995, Matlack 1993, Young and Mitchell 1994, Camargo and Kapos 1995, Parry 1997, Turton and Freiburger 1997). Soil characters such as temperature, pH, moisture content, nitrogen and phosphorus levels have also been considered (Jose *et al.* 1996, Turton and Sexton 1996).

Vegetation surveys have included (amongst others) composition (Palik and Murphy 1990, Jose *et al.* 1996), percentage cover (Fraver 1994), basal area, tree mortality, stem density (Lovejoy *et al.* 1986, Chen *et al.* 1992, Laurance *et al.* 1998) and epiphyte growth (Renhorn *et al.* 1997, Esseen and Renhorn 1998).

Typical examples of the approach to research in edges are provided in studies by Matlack (1993, 1994) conducted at 14 different sites in Pennsylvania and Delaware, USA. Microclimate was surveyed at 0, 5, 10, 20, 30, 40 and 50 m from each edge in a grid comprising ten parallel transects 5 m apart (Matlack 1993). Microclimate data, (Matlack 1993) comprising temperature, light, rainfall and VPD, were collected at 30 cm above ground level near the middle of the day from summer to early

autumn. Canopy openness and litter moisture were also measured. The light regime indicated that the edge effect extended 10 and 35 m into the forest at younger edges and influenced temperature, VPD and litter moisture content over this distance.

Unlike other vegetation studies that tend to focus on large woody vegetation (e.g. Williams-Linera 1990, Fraver 1994, Laurance *et al.* 1998), Matlack (1994) was concerned with the effect of the edge on herbs and seedlings. Vegetation was surveyed using grids similar to that employed for microclimate (Matlack 1993). At each point on the grid, the number of stems for all species < 2 m tall was assessed in 1 × 1 m quadrats. Soil depth, pH, litter depth, and the percentage cover of exposed rock and wood were also estimated. Fifteen species that were adapted to forest gap environments tended to accumulate close to the edge, mostly within 5 m, which correlated with the microclimate gradient at recent edges (Matlack 1994).

Although Matlack (1993, 1994) might be considered typical in terms the approach to edge research, there is little common ground between studies (Murcia 1995). The penetration distance that edge effects may extend into a forest varies considerably (Laurance and Yensen 1991), ranging from as little as 5 m (Palik and Murphy 1990) up to 137 m (Chen *et al.* 1992) using vegetation characteristics and from 10 m (Matlack 1993) to 240 m (Chen *et al.* 1995) using microclimate.

Some of this variation is due to the aspect of edge. In the northern hemisphere, south facing forest edges receive more direct light exposure and hence have larger edge effects than other directions (Laurance and Yensen 1991, Matlack 1993, Fraver 1994). The opposite occurs in the southern hemisphere (Young and Mitchell 1994, Parry 1997, Turton and Freiburger 1997). Apart from aspect, the edge effect is said to vary according to forest type, architecture, age of the edge (Matlack 1993, 1994), the type and nature of the abutting matrix (Mesquita *et al.* 1999, Gascon *et al.* 2000), the time of day and the time of year (Ranney *et al.* 1981, Williams-Linera 1990, Malcolm 1994, Burgman and Ferguson 1995, Chen *et al.* 1995, Murcia 1995, Turton and Freiburger 1997, Esseen and Renhorn 1998).

Murcia (1995) found that there were numerous problems in the current research on edge effects including a lack of appropriate replication, poorly defined starting points for measurement (“zero” points) and a widespread oversimplification in the design. Young and Mitchell (1994) made the assumption that forest microclimate and

composition prior to fragmentation was uniform across the entire system, and that all fragments were created at the same time. Other researchers avoided sources of variability such as streams, steep slopes, soil boundaries (Fraver 1994), forest structural differences (Parry 1997) and canopy gaps (Chen *et al.* 1992, Matlack, 1993, 1994, Renhorn *et al.* 1997, Sizer and Tanner 1999, Oosterhoorn and Kappelle 2000). Even within research where no such criteria are specified, there appears to be an implicit assumption that the “forest interior” is uniform in terms of structure, composition and microclimatic properties. Research conclusions are thus very site-specific and there is little development of general theories with respect to edges (Murcia 1995).

Current research methods on edges tend to assess the pattern of microclimate and/or vegetation over numerous distances perpendicular to the edge (e.g. Palik and Murphy 1990, Chen *et al.* 1992, Matlack 1993, Fraver 1994, Young and Mitchell 1994, Camargo and Kapos 1995, Jose *et al.* 1996, Parry 1997, Renhorn *et al.* 1997, Turton and Freiburger 1997, Saunders *et al.* 1999). With such an approach, the presence and strength of gradients of change in the edge can be established. However, the detection of gradients in microclimate or vegetation within a forest boundary may not necessarily be related to the presence of an edge.

Slope and aspect are influential on undisturbed forest microclimates (Kittredge 1948, Geiger 1965, Oke 1987) and natural forest gaps are a source of variability, allowing relatively high amounts of light to reach the forest floor (Fletcher *et al.* 1985, Ashton 1992, Brown 1993). Smaller canopy gaps may also be important, particularly for light regimes (Ashton 1992). Light, temperature and humidity are considered relatively stable compared to the climate outside the forest (Kittredge 1948, Oke 1978, Shuttleworth 1989, Franklin *et al.* 1991), but variability in the structure of the forest has concomitant effects on the microclimate. For a study to establish the existence of gradients related to an edge, it must consider the potential for other gradients that might relate to slope, soil, moisture, etc.

Most edge research compares data collected at a succession of distances with a deeper point, generally described as “forest interior” (e.g. Laurence and Yensen 1991, Matlack 1993, Young and Mitchell 1994, Camargo and Kapos 1995, Murcia 1995, Renhorn *et al.* 1997). Many climate studies also juxtapose their measurements with those in an adjacent exposed area to determine the extremes of microclimate

change from which gradients within the oldgrowth are related (e.g. Matlack 1993, Young and Mitchell 1994). Only Camargo and Kapos (1995) and Parry (1997) considered the need for microclimate control transects in undisturbed forest.

Edge effects have nearly always been studied on established borders. Lovejoy *et al.* (1986) reported that there were visible effects on vegetation observable within a few days of fragmentation but there are no studies of the direct impact of edge creation on an established forest both before and after the event. Research on existing edges does not account for gradients that might prevail in the undisturbed forest (Margules *et al.* 1998). Monitoring of the existing forest dynamics prior to edge creation is necessary to give a context to the edge effect (Margules *et al.* 1998). Such research must be undertaken at the site of the proposed clearance as well as at appropriate undisturbed controls (*sensu* Green 1979, Stewart-Oaten *et al.* 1986, Underwood 1991, Smith *et al.* 1993, Underwood 1994).

Vertical gradients in microclimate are commonly observed from the forest floor to the top of the canopy (e.g. Oke 1978, Eliás *et al.* 1989, Shuttleworth 1989). Despite this, the heights for data collection for edge studies vary from 30 cm (Matlack 1993) up to 3 m (Parry 1997) with little if any justification. Such differences in method are likely to explain some of the variability observed between studies. Camargo and Kapos (1995) considered the vapour pressure deficit at different heights above ground in 12-year-old tropical edges, but this study is an exception.

1.3 Tasmanian wet forests, forestry and edges

1.3.1 Tasmanian forests

The forests employed in this study are described as either “wet sclerophyll” or “mixed forest” (Gilbert 1959, Jackson 1968, Mount 1979). Both types comprise an emergent very open canopy of tall eucalypts (~ 60 - 70 m), in this case *Eucalyptus obliqua* over a dense, even closed, sub-canopy of sclerophyllous shrubs and trees (for wet sclerophyll) or a closed sub-canopy of rainforest species (~ 30 – 50 m in both cases; Figure 1.2). In terms of composition, either of the closed canopies may vary substantially, depending on a number of environmental factors (see below). The forest structure in this study may thus be similar to other edge research in rainforest scenarios, in that the edge abuts a closed canopy, but different in that the Tasmanian forests in this study have the emergent tall over-canopy. The latter may have

important implications for disturbance at the edge in light of greater exposure to windthrow (Laurance 1991, Laurance *et al.* 1998).



Figure 1.2 - Edge of a recently logged coupe in southern Tasmania showing the emergent canopy of eucalypts and the closed sub-canopy of rainforest species.

In terms of evolution, the oldest vegetation type on the Tasmanian landscape is temperate rainforest, which remains similar to the extensive forests that once grew on the Gondwana super continent (Nelson 1981, Hill *et al.* 1999) from which Australia separated 55 MA (Duigan 1965). Close relatives of the Tasmanian rainforest flora, in particular the genera *Nothofagus*, *Eucryphia*, *Lagarostrobos*, *Phyllocladus*, *Aristotelia*, *Coprosma* and *Uncinia*, can be found in other Gondwanan fragments, especially New Zealand, New Caledonia and South America (Nelson 1981, Jarman and Brown 1983, Read 1999).

The maximum distribution of temperate rainforest is ultimately determined by rainfall and temperature (Jackson 1968). In southern Australia, this equates to wetter portions of Tasmania, Victoria and small patches in New South Wales (Read 1999). While rainforest is the climax vegetation within these areas (Gilbert 1959, Jackson 1968), a number of preceding successional phases add considerably to the biodiversity and structural complexity of these zones (Jackson 1968). At any one site the major determinant to the successional status of the system is the frequency of fires (Gilbert 1959, Jackson 1968, Read 1999).

Fires at very high frequency (< 25 years average interval) drive the system toward a treeless sedgeland, grassland or shrubland (Gilbert 1959, Jackson 1968). Gilbert (1959) suggested that such frequent burning was possibly the result of Aboriginal

land management practices, as such burns promoted game and allowed for easier passage than through dense forest. While there is no doubt that Tasmanian Aboriginal people used fire, there is continuing debate about the suggestion that they were a driving influence in large-scale structuring of the vegetation.

When the fire interval increases to 25 – 100 years, the vegetation becomes a “wet sclerophyll forest” which consists of tall eucalypts over a variable understorey containing some of *Acacia* (*A. dealbata*, *A. verticillata*, *A. melanoxylon*, *A. mucronata*), *Aristotelia peduncularis*, *Bauera rubioides*, *Bedfordia salicina*, *Cassinia aculeata*, *Coprosma quadrifida*, *Cyathodes glauca*, *Olearia* (*O. argophylla*, *O. lirata*, *O. stellulata*), *Leptospermum* (*L. lanigerum*, *L. nitidum*, *L. glaucescens*), *Melaleuca squarrosa*, *Monotoca glauca*, *Pimelea* (*P. cinerea*, *P. drupacea*), *Pomaderris apetala*, *Nematolepis squamea*, *Pittosporum bicolor*, *Richea pandanifolia* and *Zieria arborescens* (Duncan 1985, Jackson 1999, Wells and Hickey 1999). The ground layer is often rich in ferns, including *Dicksonia antarctica*, *Blechnum wattsi*, *B. nudum*, *Histiopteris incisa*, *Hymenophyllum*, *Hypolepis rugosula* and *Polystichum proliferum* (Duncan 1985, Wells and Hickey 1999), herbs (*Hydrocotyle*, *Senecio*) and monocots such as *Dianella*, *Tasmannia*, *Drimophyla cyanocarpa*, *Gahnia grandis*, *Lepidosperma elatius*, and orchids (Duncan 1985, Wells and Hickey 1999).

At long fire intervals (100 - 350 years), the understorey becomes dominated by rainforest taxa such as *Nothofagus cunninghamii*, *Eucryphia lucida*, *Phyllocladus aspleniifolius*, *Atherosperma moschatum* and *Anodopetalum biglandulosum* and the system is termed “mixed forest” (Gilbert 1959, Jackson 1968, Mount 1979). Other tree genera found in mixed forest (and pure rainforest) include *Athrotaxis*, *Lagarostrobos*, or *Diselma* (Jarman and Brown 1983) with the understorey consisting of a selection from *Olearia*, *Anodopetalum*, *Aristotelia*, *Archeria*, *Cyathodes*, *Monotoca*, *Prionotes*, *Richea*, *Trochocarpa*, *Anopterus*, *Pittosporum*, *Agastachys*, *Cenarrhenes*, *Orites*, *Telopea*, *Coprosma*, *Acradenia*, *Pimelea* and/or *Tasmannia* (Jarman and Brown 1983, Read 1999). The major fern genera are usually *Dicksonia*, *Polystichum* and *Blechnum* (Jarman *et al.* 1987). Mixed forest, the precursor to pure rainforest, has its greatest extent and diversity in Tasmania and is important both environmentally and commercially (Hickey 1993). The wet sclerophyll and mixed forest types have been described together as “wet eucalypt

forest” (Kirkpatrick *et al.* 1988). In both systems, the dominant overtopping eucalypts are often *Eucalyptus obliqua*, *E. regnans* or *E. delegatensis* (Wells and Hickey 1999).

At a fire interval greater than 350 – 450 years, the eucalypts die without replacement and the system becomes a pure rainforest (Gilbert 1959, Jackson 1968, Mount 1979, Hickey 1993). In the absence of fire, a rainforest will persist indefinitely because the community dominants are not dependant upon broad-scale disturbance for their regeneration.

Jackson (1968) and Mount (1979) infer that all the eucalypts within a single stand of mixed forest are likely to be all the same age. However, Hickey *et al.* (1999) found that almost half of the extant tall eucalypt forests in the Warra region in southern Tasmania (see below) had survived at least one fire and that less than half of the forest burnt since 1850 was replaced by single aged stands. Hence, while the role of fires in driving the structure of Tasmanian wet forests is not disputed, the complex mosaic of forest patches indicate that the above model is overly simplified and only applies to severe wildfires. Fires of reduced intensity (cooler fires in the Warra area occur at night and in the early mornings in summer) will have less impact on the system, such that there is higher survivorship within the extant vegetation. Mueck *et al.* (1996) concluded that understorey plants in Victorian wet forests are capable of persisting for long periods, even in the presence of regular fires. Fires thus range in effect from those that do little other than remove litter and some ground level plants, to those that destroy everything.

1.3.2 Tasmania forestry and edges

Harvesting practices in Tasmanian wet eucalypt forest follow a pattern of clearfelling, slash burning and resowing with eucalypt seed, in rotations of 80 -100 years (Gilbert and Cunningham 1972, Felton 1976, Kirkpatrick and Bowman 1982, Hickey and Wilkinson 1999). Current average coupe sizes are about 50 ha but occasionally exceed 100 ha (Hickey 1993). The process of coupe assessment prior to logging requires that any rare species or forest types be protected in patches from which logging is precluded (Duncan and Johnson 1995). Other unlogged areas include borders of vegetation along streams and patches left for slope stabilisation with corridors left to link these fragments with each other and with larger

conservation areas (Duncan and Johnson 1995). The assumption is that these patches of comparatively undisturbed forest act as refugia for the flora and fauna of the area and may act as a propagule source for recolonisation of the coupe (Duncan and Johnson 1995). It is hoped that such an approach will maintain the biodiversity of the system at the landscape level (Taylor 1991, Duncan and Johnson 1995, Brown 1996). However, the extent to which these retained areas are unaffected by logging will depend on the extent of boundary (or edge) influences.

Regeneration of a clearfelled coupe relies on one or more of the following (Felton 1976, Duncan 1985, Hickey 1993):

- Germination from seed sown deliberately (commercial species).
- Resprouting from coppice and germination and growth from seed and seedlings that have survived the slash burn.
- Germination from seed distributed into the coupe by other means (i.e. wind, water animal or unintentionally by people).

Distribution of seed/spores as part of the regeneration of a coupe has been demonstrated (Hickey 1993), but it has been noted from studies of longer-term changes (20 to 30 years post-logging or fire) that there is a lack of regeneration in epiphytic fern taxa (Hickey 1994). While the reduction of substrate, in particular manferns (*Dicksonia antarctica*; Beever 1984, Ough and Murphy 1997) could be part of this problem, a lack of propagule sources may also be important. Epiphytic recruitment in a coupe must derive either from taxa that have survived the regeneration burn and/or from external sources.

Peacock (1994) described some quantitative changes that occurred in adjacent remnant streamside vegetation following cable logging and burning in Tasmanian mixed forest and noted a decline in health of many of the understorey taxa, probably as a consequence of increased light exposure resulting in lower humidity and higher desiccation rates. Neyland and Brown (1994) noted similar changes at the edges of remnant rainforest patched in eastern Tasmania, along with the growth of opportunistic shrubs on the more disturbed sites. There was also an increase in windthrown damage to neighbouring trees with the loss of branches or even entire crowns of canopy species. Peacock (1994) concluded that there were significant detrimental edge effects in exposed streamside stands, particularly when it was

disturbed by the action of fuel reduction or regeneration burns and recommended that further research on the issue of edge effects and the effects of forest fragmentation.

1.4 Bryophytes in Tasmania and in edge research

The cryptogamic flora (including bryophytes and lichens) of Tasmania is both rich and varied (Dalton *et al.* 1999), with 643 recognised bryophyte species comprised of 282 hepatics (mostly liverworts) and 361 mosses (Ratkowsky 1987, Dalton *et al.* 1991, Jarman and Fuhrer 1995). In spite of this large number, the degree of endemism is relatively low (~ 9 % for mosses, while hepatics are unknown in this respect; Dalton *et al.* 1991). Approximately 75 % of all moss species in Tasmania also occur in New Zealand, which, along with the southern Australian mainland, has the closest affinity to the Tasmanian bryophyte flora (Beever *et al.* 1992).

Bryophytes are considered an important pioneer group in disturbed habitats, capable of occupying a diverse array of substrates - from bare rock and soil through to both living and dead logs and stems (Duncan and Dalton 1982, Jarman and Fuhrer 1995). In such a role, they often facilitate the establishment of other species (Jarman and Fuhrer 1995). Bryophytes also influence the water holding capacity of the substrate, stabilise soil, assist in nutrient cycling, may influence decomposition and provide food and habitat to a diverse assemblage of invertebrates (Jarman and Fuhrer 1995).

In most wet vegetation types, the bryophyte diversity and numbers of individuals is much higher than that of the vascular flora (Kantvilas and Jarman 1991, Jarman and Fuhrer 1995, Jarman *et al.* 1999), although their contribution to biomass is relatively low (Jarman *et al.* 1999). Between vegetation types, the bryophyte flora is considered markedly different (e.g. Kantvilas and Jarman 1993, Jarman and Fuhrer 1995) with rainforest offering one of the richest bryophyte floras with some 220 species (Jarman and Fuhrer 1995). However, few of the bryophytes found in rainforest are restricted to this forest type (Jarman and Fuhrer 1995). The bryophyte flora thus adds significantly to forest biodiversity (Kantvilas and Jarman 1993) and small patches of distinctive forest may have substantially more conservation importance than that implied by their vascular plant composition, particularly when the invertebrate fauna that is associated with mosses and liverworts is included.

While the bryophyte composition of regenerating coupes has been considered (see Duncan and Dalton 1982), the effect of logging on mosses and liverworts at the

forest edge has not been investigated in spite of the widespread opinion that bryophytes are highly responsive to disturbances (Edwards 1986), including differences in microclimate (e.g. Kenkel and Bradfield 1986, Piippo 1982, Frahm and Gradstein 1991, Kantvilas and Jarman 1993).

Kantvilas and Jarman (1993) suggested that microclimate changes in an isolated patch of rainforest in eastern Tasmania were likely to be the major cause for differences between small patches and larger areas of contiguous rainforest, but offered no evidence. There appears to be little information on the role of bryophytes as indicators of environmental change let alone any research on bryophytes in edges. The limited available research from elsewhere (Europe) suggests that bryophytes will increase in abundance in edges owing to the removal of smothering leaf litter (Gonschorrek 1977 in Luczaj and Sadowska 1997, Balcerkiewicz and Kasproicz 1989 in Luczaj and Sadowska 1997). However, Ranney *et al.* (1981) and Peacock (1994) suggest that bryophytes will be adversely affected in dryer edge zones. Clearly, there is scope for a closer examination of the behaviour of mesic species in terms of edge effects. Luczaj and Sadowska (1997) consider it “astonishing” that there has not been more research on the nature of bryophytes in forest edges.

1.5 Aims of this study

The aim of this study is to determine the extent of forest edges in Tasmanian wet eucalypt production forests using microclimate, bryophyte and epiphytic fern communities (otherwise collectively defined as “epiflora”) as well as vascular plant composition. This will provide useful insights into the conservation status of forest reserves aimed at preserving biodiversity at the landscape scale as part of current logging codes of practice. The identification of species indicative of edge effects will also be explored as well as some general questions relating to the nature of research on edges and edge effects. The key issues addressed in each chapter are summarised below.

Chapter 2 – Mechanical disturbance at the edge of coupes

This chapter examines the mechanical disturbance at coupe edges that results from logging and firebreak construction. A number of specific questions were examined:

1. Does the slope of the coupe adjacent to the edge influence the extent of disturbance into the undisturbed forest?

2. Is there a relationship between the amount of disturbance within a forest edge and the age of the edge?
3. Is there any relationship between the aspect of a forest edge and the distance to which disturbance penetrates?
4. Is there a profound increase in the area of a logged coupe if the mechanical disturbance at the edge is included?

Chapter 3 – Microclimate and vegetation in undisturbed forests over small spatial scales

This chapter quantifies gradients in microclimate within the first 2 m above ground level and correlate these with epiflora (bryophytes and epiphytic ferns). More specifically, this study will determine:

1. Do gradients in microclimate exist in the zone 0 - 2 m above ground level and if so is it likely to be a confounding factor in comparing studies that measure the degree of disturbance and/or change in microclimates at different heights above ground?
2. Does epiflora composition change with increasing height in the 0 – 2 m range above ground?
3. To what degree does substrate type influence epiflora composition?

Chapter 4 – Gradients in microclimate in a forest edge using a before and after, control and impact (BACI) approach

The objective of this chapter is to determine to what degree microclimatic gradients present within an undisturbed patch of forest remain influential after the creation of an edge. There were three specific questions:

1. Is the BACI approach appropriate to the estimation of an edge effect?
2. What changes in microclimate are observed between impact and control transects as a result of edge creation?
3. What seasonal changes in microclimate occur within a young edge?

Chapter 5 – Gradients in vegetation in a forest edge using a BACI approach

This chapter examines natural levels of variability in epiflora and shrub and tree component within an undisturbed forest relative to the same site after creation of the edge. The specific questions under test were:

1. Is the BACI approach appropriate for the study of edge effects in terms of both the epiflora and vascular vegetation and to what degree does an *a priori* understanding of the system influence the determination of an edge effect?
2. What are the short-term edge effects on the epiflora and vascular plant composition in terms of both the amount of change and distance these penetrate into the undisturbed forest?
3. What epiflora taxa epiflora are the best indicators of the edge effect?

Chapter 6 – Gradients in microclimate in forest edges of different ages

In this chapter, seasonal changes in the microclimate will be considered at the edges of four regenerating Tasmanian wet forest coupes that vary in age from less than 6 months to 15 years. The specific questions are:

1. What are the seasonal patterns in microclimate in edges of different ages?
2. Is there a moderation in the fluctuation of microclimate in forest edges as adjacent coupe regenerates?

Chapter 7 – Gradients in vegetation in forest edges of different ages

This chapter examines successional changes in epiflora and vascular flora in edges. The aims were:

1. To determine the width of the forest edge effect as measured by the cover of vascular plants and whether this corresponds to PAR gradients. Does the width of the edge effect decline with age?
2. To determine the width of the forest edge as measured by changes in epiflora, to see if this was affected by age of the edge, and whether this agreed with microclimate measurements (particularly maximum temperature and VPD.
3. To see if a distinctive “edge flora” develops within forest edges in southern Tasmania.

4. To establish if the three temporal phases of edge dynamics described by Matlack (1994) can be applied to Tasmanian forest edges.

Chapter 8 – General discussion

This chapter comprises a synthesis of findings and management implications of edge effects in Tasmanian wet forests managed for wood production.

1.6 Site descriptions

1.6.1 The Warra LTER region

The research undertaken in this project was conducted within the Warra Long Term Ecological Research (LTER) region approximately 60 km southwest of Hobart (Figure 1.3). This is one of a network of LTER locations around the world that are aimed at advancing our understanding of a range of environments and their responses to different management systems over long temporal scales (Long Term Ecological Research 1998: <http://lternet/edu/>). A notable example is the H.J. Andrews LTER site in Oregon, USA, which has been a site for coniferous forest research since 1948 (H.J. Andrews Experimental Forest 2000: <http://www.fsl.orst.edu/lter/homepage>).

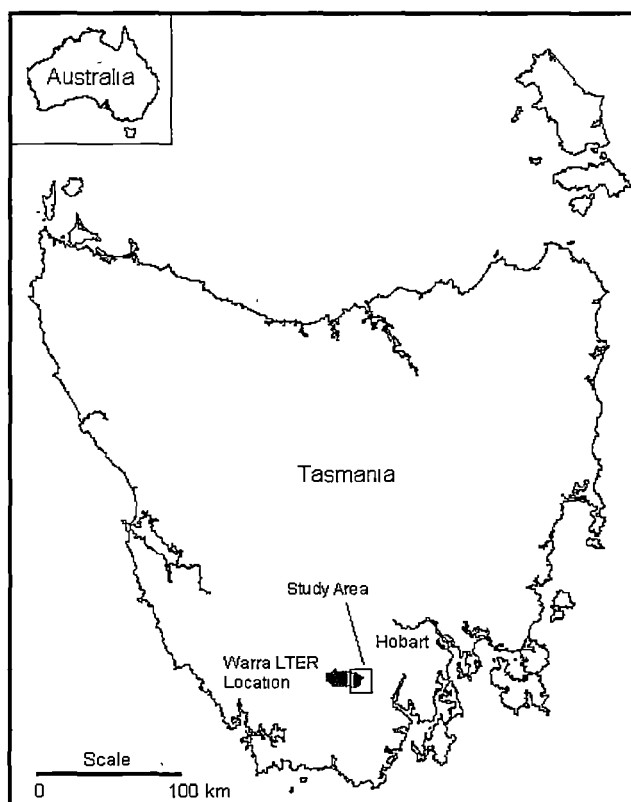


Figure 1.3 - The location of the Warra Long Term Ecological Research (LTER) region in Tasmania, ~ 60 km southwest of the state capital, Hobart. Map courtesy of Forestry Tasmania copied with permission.

The Warra LTER region is itself contained within a larger zone, Nature Conservation Region 10B (NCR10B), as defined by Orchard (1988). Five different basic forest types are recognised from within the region, comprising 19 rainforest, 7 swamp forest, 26 mixed forest, 20 wet sclerophyll and 21 dry sclerophyll forest communities (Duncan and Johnson 1995).

Commercial logging in the Warra area started in the early seventies, with about 840 ha harvested during the period from 1972 – 1993 (Hickey *et al.* 1999). In 1995 an area of 15,900 ha, including both State Forest and World Heritage Area, was designated as an LTER region and is expected to become a focus for research on a range of issues concerning the management of both commercially logged forests and conservation areas (Forestry Tasmania 1999: <http://www.warra.com/>). A 200 ha Silvicultural Systems Trial to investigate alternative techniques to clearfell, burn and sow began in 1998 (Figure 1.4; Hickey *et al.* 1999). The network of established coupes and the trial areas provided the framework for the research undertaken in this project. Restricting the study to the Warra area had logistic advantages, but also allowed the possibility that some of the sites in this research could form the basis for longer term monitoring.

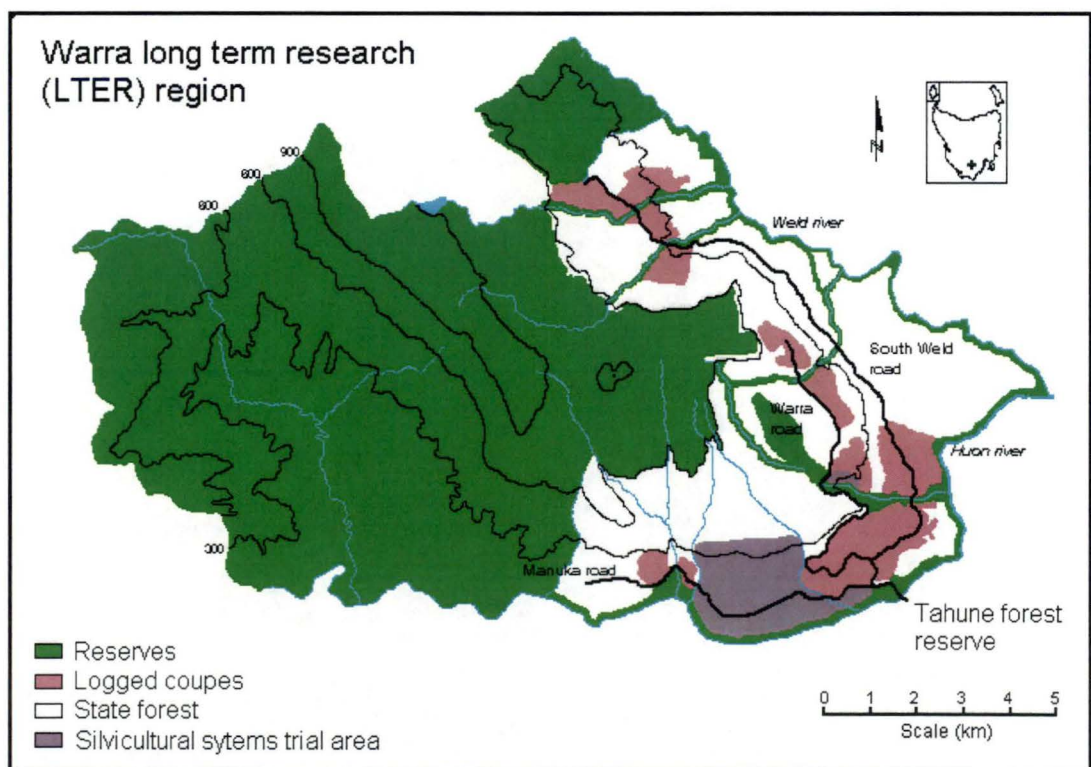


Figure 1.4 - The Warra LTER region about 60 km southwest of Hobart showing the matrix of logged coupes within State Forest, the Silvicultural Systems Trial area and legislated reserves. Map courtesy of Forestry Tasmania copies with permission.

Several large wildfires have occurred within recorded history of the area in 1898, 1906, 1914 and 1934 (Hickey *et al.* 1999). The 1898 and 1934 fires are notable for both their intensity and extent, and have had a profound influence on the vegetation in the southern forests. All of the sites employed in this study have a known fire history.

1.7 Study locations

There were ten locations employed across the various aspects of this study (Figure 1.5). Five were used in the study of disturbance to bryophytes in edges and on the coupe itself (Table 1.1; Yellow and Blue but not the Glover site; Chapter 2), four were employed in the vertical study of microclimate and epiflora composition in undisturbed forest (Table 1.1; Red; Chapter 3) and four were employed in edge studies, with one site (Small) in the BACI study (Table 1.1; Blue; Chapters 4 & 5), which was also used in the consideration of coupes of different ages (Table 1.1; Blue; Chapters 6 & 7).

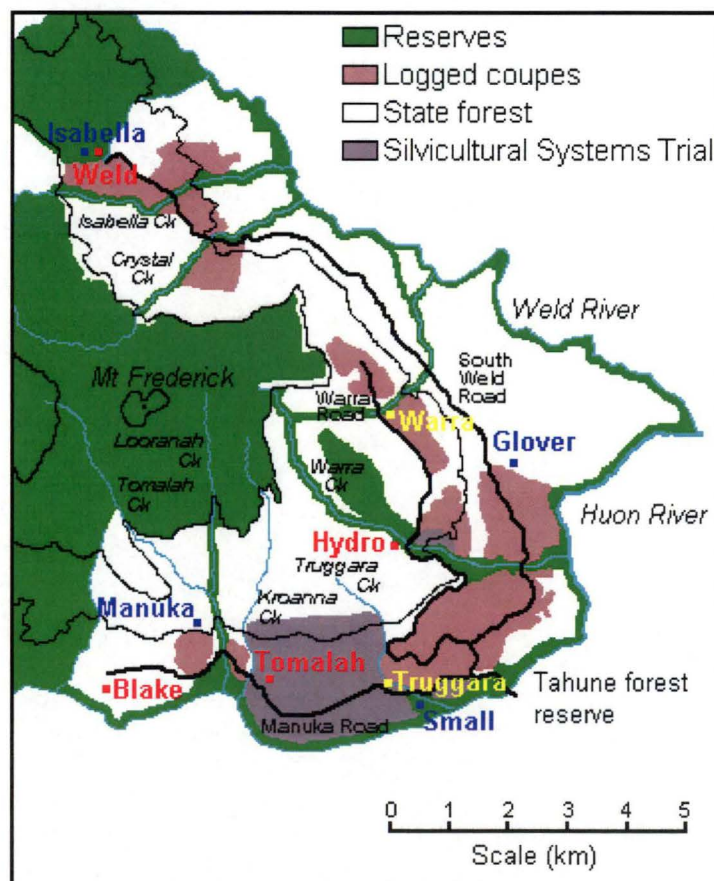


Figure 1.5 - Eastern half of the Warra LTER showing the sites employed in this study. Yellow and blue (but not Glover) labeled sites were used in the bryophyte disturbance study (Chapter 2), red labels show the vertical scale research sites (Chapter 3) while blue alone indicates where edge surveys were undertaken (Chapters 4 to 7).

Forest types were based on Jarman *et al.* (1994) for rainforest communities and Kirkpatrick *et al.* (1988) for wet eucalypt forest. These were generally based on TASFORHAB surveys (Peters 1984) undertaken at each site. All sites employed in the vertical and edge studies required relatively easy access from a nearby road, as well as a nearby open patch of ground for the collection of exposed climate data.

Table 1.1 - The ten locations employed through this study (data courtesy Forestry Tasmania). All coupes were within the Warra LTER region. The secondary names (such as One-year) are the labels used for sites in the study of edges of different ages (Chapters 6 & 7). Fire history refers to the number of years since the last fire; major fire events and where surviving trees (veterans) are present (see Alcorn *et al.* 2001). Yellow shading indicates sites used only in the disturbance survey (Chapter 2), red for sites employed in the vertical survey (Chapter 3) and blue for edge related study sites (Chapters 4 to 7).

Location name(s)	Lat/Long	Coupe burn	Geology	Elevation (m)	Age since last fire and fire history (yrs)
Truggara	43°05.74' S 146°41.937' E	-	Jurassic dolerite fine talus	130 - 160	65 Fire mosaic (1914 + 1934 + 1898+ veterans)
Warra	43°04.39' S 146°42.019' E	April 1998	Jurassic dolerite fine talus	340 - 500	300
Hydro	43°04.445' S 146°42.238' E	-	Jurassic dolerite fine talus	350 - 360	300 - 400
Blake	43°05.787' S 146°39.209' E	-	Alluvial sand gravel and clay	90 - 110	101 (1898 + veterans)
Tomalah	43°05.629' S 146°40.537' E	-	Jurassic dolerite fine talus	180 - 200	65 (1914 + veterans)
Weld	43°00.868' S 146°38.574' E	-	Jurassic dolerite fine talus	400 - 440	300 - 400
Small (One-year)	43°05.849' S 146°41.936' E	March 1998	Jurassic dolerite fine talus	80 - 120	65 Fire mosaic (1934 + 1914 + 1898 + veterans)
Manuka (Two-year)	43°05.194' S 146°39.728' E	March 1996	Jurassic dolerite boulder talus	300 - 400	65 Fire mosaic (1934 + 1898 + veterans)
Isabella (Five-year)	43°00.922' S 146°38.5' E	April 1992	Jurassic dolerite fine talus	480 - 520	300 - 400
Glover (15-year)	43°03.745' S 146°43.494' E	March 1982	Jurassic dolerite boulder talus	60 - 100	65 (1934 + veterans)

1.7.1 Chapter 2 – Mechanical disturbance at coupes edges

Truggara

This site was employed only in the edge disturbance survey. The site was based at the edge of a recently logged, but, at that time, unburnt coupe (~ 18 ha; Warra 8B; Figure 1.5). Vascular composition of the edge comprised OB1110 (*Eucalyptus obliqua*, *Anopterus glandulosus*, *Acacia verticillata* mixed forest) and OB101 (*E. obliqua*, *Nothofagus cunninghamii*, *Monotoca glauca* mixed forest), a widespread community type that has a dense non-rainforest component (Kirkpatrick *et al.* 1988).

This site was intended as a study of the effect of the regeneration burn on the border vegetation with respect to radiant heat and smoke. Unfortunately, the appropriate weather conditions for burning did not eventuate for this site in that year and the survey had to be abandoned.

Three of the four sites employed in the edge effect investigations were also used in surveys of mechanical disturbance at the edge; Small, Manuka and Isabella.

Warra

This large coupe (160 ha) on the Warra Road (Figure 1.5) was used in both edge disturbance measurements and to determine what bryophytes were capable of surviving the regeneration burn. There was no opportunity to collect vegetation data prior to logging, but a botanical survey done as part of the timber harvesting plan suggested that the coupe was oldgrowth mixed forest dominated by *E. delegatensis*, *Phyllocladus aspleniifolius*, *Atherosperma moschatum*, *Eucryphia lucida* and *Nothofagus cunninghamii* in a tall open forest with an understorey that included *Dicksonia antarctica* (Williams 1986). The age of the forest is difficult to ascertain, but it has been estimated at roughly 300 years (Table 1.1).

1.7.2 Chapter 3 – Vertical microclimate and vegetation surveys

Hydro

This site was within a large patch of 300 - 400 yr old mixed forest (130 ha) on the Warra road (Figure 1.5; Table 1.1) of the type OB1100. This is described as an *E. obliqua*, *Atherosperma moschatum*, and *Cenarrhenes nitida* mixed forest that tends to grow on poorer sites largely in western Tasmania (Kirkpatrick *et al.* 1988). A nearby exposed apiary area (< 100 m distant) was used to obtain exposed microclimate data.

Blake

These sites were based on an unlogged 45 ha coupe (Blakes 1A) at the end of Manuka Road on a flat patch of boggy ground adjacent to the Huon River (Figure 1.5). This patch was probably burnt in the 1898 wildfire (Table 1.1). The forest classification was OB1100 at site D (see Hydro) and the other sites (E and F) were OB1001. The latter was an *E. obliqua*, *N. cunninghamii*, *A. glandulosus* and *Hymenophyllum flabellatum* mixed forest that is widespread in southern forests

(Kirkpatrick *et al.* 1988, Duncan and Johnson 1995), with a thamnic rainforest understorey, a few non-rainforest elements and a rich fern flora (Kirkpatrick *et al.* 1988). The exposed site was fixed at the terminus of the Manuka road (Figure 1.5). This was not as open as at other locations, with large trees within 20 m of the site, but was the only space available.

Tomalah

This was on the edge of Manuka Road at a 10 ha unlogged Silvicultural Systems Trial coupe (Warra 8C; Figure 1.5). This site was last burnt in 1934 but there is also evidence of older fires (1898 and 1914), and some surviving oldgrowth veterans (Alcorn *et al.* 2001, Forestry Tasmania 1999; Table 1.1. Forest classification for all three points within the location was OB0111, a wet sclerophyll forest comprised of *E. obliqua*, *Melaleuca squarrosa* and *Monotoca glauca* considered typical of poorly drained sites (Kirkpatrick *et al.* 1988, Duncan and Johnson 1995). Exposed microclimate data were collected from the roadside verge.

Weld

This stand comprised old mixed forest and rainforest (300 – 400 yrs; Table 1.1). It was somewhat remote from the other sites in the vertical study, at the end of the South Weld Road (Figure 1.5). The coupe (34 ha) abutting the forest was burnt in 1992 (Table 1.1). The Weld sites were all classified as OB1100, as found at the Hydro site. Exposed microclimate data were collected on the coupe.

1.7.3 Chapters 4 to 7 – BACI and site for age studies

All sites used in edge studies were in continuous forest, such that there was ample space for control transects. The BACI study (Chapters 4 & 5) required an unlogged, but designated, boundary. This was chosen at the edge of one of the Silvicultural Systems Trial coupes on the Manuka road (Figure 1.5). This site was also used in the site for the age study (Chapters 6 & 7), such that it was the youngest of the four edges based on the time since the regeneration burn: Small (< 0 - 1 year) Manuka (~ 2 years), Isabella (~ 5 years) and Glover (~ 15 years; Table 1.1)

Forest classifications for each site were based on TASFORHAB surveys (Peters 1984) undertaken at roughly 50 m intervals on control and impact transects across each site. Most edges in the survey had southerly aspects (i.e. the exposure of the

edge faced southwards) except at Small, where the surveyed edge faced the west-northwest.

Small (One-year)

This 16 ha coupe was the location for the before and after, control and impact (BACI) study and was the youngest site in the investigation of edges of different ages ($< 0 - 1$ year; Table 1.1). It has a complex fire history with a mosaic of four age classes from 1934, 1914 and 1898 fires as well as some veteran trees of considerable age (~ 300 years; Hickey *et al.* 1999, Alcorn *et al.* 2001; Table 1.1). This was reflected in the number of different forest communities across the site, the most common of which were OB1110 (see Truggara) and OB1001 (see Blake) communities, followed by the OB1100 (see Hydro) and OB101 types (see Truggara; Table 1.2). The exposed point was rather remote from this edge, 2 - 3 km distant on a regenerating coupe.

Table 1.2 - Details of forest classifications at the Small location. Forest classification was based on Kirkpatrick *et al.* (1988). Shading indicates control transect distances.

Transect pair or transect	Distance (m)	Forest Classification
13+14	10	OB1110
13+14	50	OB1100
13+14	100	OB1100
15	100	OB1001
15	150	OB101
16	10	OB1001
16	50	OB1001
17+18	100	OB1001
17+18	150	OB1110
17+18	200	OB1100

Manuka (Two-year)

The surveyed edge abutted a 45 ha coupe on the Manuka road (Figure 1.5), burnt in 1996 (Table 1.1) making the site ~ 2 years old at the time of the study. The age of the uncut adjacent forest was quite variable, but the youngest elements appeared to date from the 1934 fire. Other trees are slightly older and likely to result from the 1898 fire, while there are also some veteran trees of greater age. The forest classifications for the site comprised a mixture of mostly OB1100 and OB1110 (see Hydro and Truggara respectively; Table 1.3). The exposed point was on the coupe ~ 100 m downhill from the edge.

Table 1.3 - Details of forest classifications at the Manuka location. Forest classification was based on Kirkpatrick *et al.* (1988). Shading indicates control transect distances.

Transect pair or transect	Distance (m)	Forest Classification
7+8	10	OB1110
7+8	50	OB1100
7+8	100	OB1100
9	110	OB1100
9	150	OB1100
10	10	OB1100
10	50	OB1110
11+12	110	OB1110
11+12	150	OB1100
11+12	200	OB1100

Isabella (Five-year)

This site was located just uphill of the Weld site used in the vertical survey (Figure 1.5), and is within the same 300 – 400 year old mixed forest and rainforest adjacent to a coupe (34 ha) that was burnt in 1992. It was thus from ~ 5 years old at the time of the study (Table 1.1). Forest types were similar to the Weld sites further downhill (i.e. OB1100) and included OB1110 (see Truggara) with a Thamnic 1.1 rainforest (*sensu* Jarman *et al.* 1994; Table 1.4). Thamnic 1.1 is a pure rainforest type dominated by *Nothofagus cunninghamii* with strong representation from *Eucryphia lucida*, and *Atherosperma moschatum* or *Phyllocladus aspleniifolius* (Jarman *et al.* 1994). This rainforest type is widespread and considered to be well developed at the nearby Isabella Creek in the South Weld Forest Reserve (Duncan and Johnson 1995).

Table 1.4 - Details of forest classifications at the Isabella location. Forest classification is based on Kirkpatrick *et al.* (1988) for wet eucalypt forest and Jarman *et al.* (1994) for rainforest. Shading indicates control transect distances.

Transect pair or transect	Distance (m)	Forest Classification
1+2	10	THAMNIC 1.1
1+2	50	OB1100
1+2	100	OB1100
3	110	OB1110
3	150	OB1100
4	10	OB1100
4	50	OB1100
5+6	110	OB1100
5+6	150	OB1100
5+6	200	OB1110

Glover (15-year)

The Glover site (near Glover's Bluff on the South Weld Road; Figure 1.5) had the oldest edge in the survey at ~ 15 years, with the adjacent coupe (Warra 3C; 93 ha) burnt in 1982 (Table 1.1). It has, conversely, the most consistently young forest, with a mixture of 1934 regrowth and some surviving veterans. The forest types are

almost all OB1100 (see Hydro), but with one example of the OB11010 type (Table 1.5). This type, an *E. obliqua*, *Orites diversifolia*, *Cyathodes glauca* mixed forest, is most commonly found in the nearby Picton River Valley (Kirkpatrick *et al.* 1988).

Table 1.5 - Details of the forest classifications at the Glover site. Forest classification was based on Kirkpatrick *et al.* (1988). Shading indicates control transect distances.

Transect pair or transect	Distance (m)	Forest Classification
19+20	10	OB1100
19+20	50	OB1100
19+20	100	OB1100
21	110	OB1100
21	150	OB1100
22	10	OB1100
22	50	OB1100
23+24	110	OB11010
23+24	150	OB1100
23+24	200	OB1100

2 Mechanical disturbance at coupe edges

2.1 Introduction

Research on vegetational changes in edges has tended to attribute differences to the altered microclimate regime (e.g. Chen *et al.* 1992, Matlack 1993, 1994, Young and Mitchell 1994, Malcolm 1998, Gehlhausen *et al.* 2000). Other forms of disturbance in the edge are often ignored, although damage due to increased windthrow is widely acknowledged (e.g. Lovejoy *et al.* 1986, Laurance 1991, Chen *et al.* 1992, Fraver 1994, Laurance 1997, Laurance *et al.* 1998) and there may be further losses of foliage due to increased light levels on shade-adapted foliage (Bazzaz 1991).

The most immediate disturbance at the forest edge due to logging is the physical disruption to soil and vegetation caused by the tree felling and removal process. This results in varying degrees of damage to the crowns of trees at an edge. The felling of trees over a coupe boundary into unlogged vegetation may result in widespread disruption. Current Tasmanian forestry practices aim to keep this to a minimum and it is generally done only for safety reasons. There is also the disturbance associated with construction of firebreaks around the perimeter of most Tasmanian coupes prior to regeneration burning (Peacock 1994, Duncan and Johnson 1995).

The coupe firebreak is a strip of mineral soil devoid of all flammable organic matter that protects the surrounding unlogged vegetation against the possibility of an outbreak during the regeneration burn. Most logging slash is pushed inwards, away from the edge, in line with current forest practices (J. Hickey, Forestry Tasmania, Pers. Com. 1999; Figure 2.1) although some debris is inevitably pushed into the unlogged edge zone. The recommended width of the strip varies, but 3 - 6 m is considered the minimum (R. Chuter, Forestry Tasmania, Pers. Com. 1999) and

personal observations put this width at from 10 - 15 m (Figure 2.1). The edge of a coupe is thus often fringed with compacted bare earth and unburnt logging debris left as a result of either tree felling and/or firebreak construction. This may have important implications for the microclimate and vegetation in this zone.

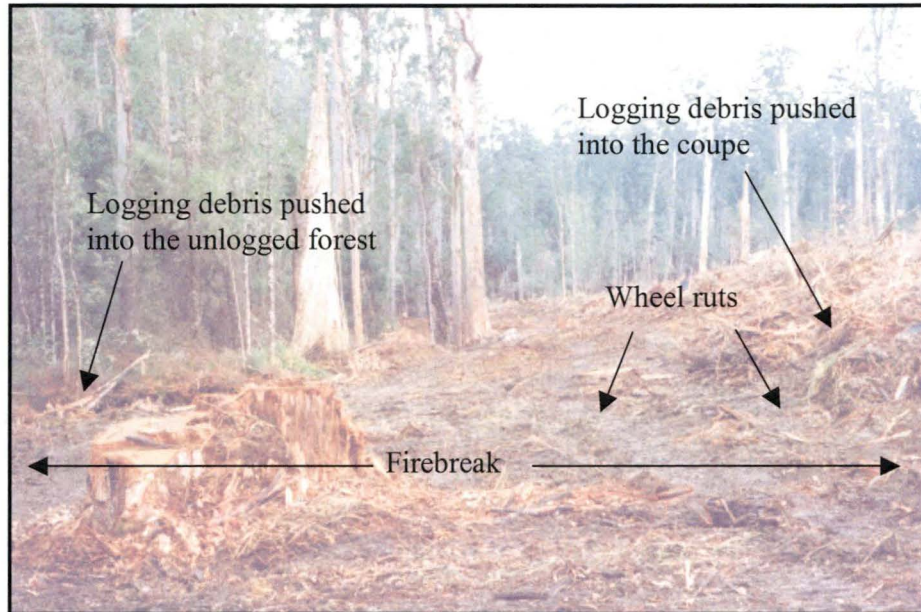


Figure 2.1 - The firebreak at the edge of coupe prior to the regeneration burn. Debris from its construction can be seen on either side of the break. Machinery ruts are just visible at the centre right.

In this chapter, the nature of the disturbance at the edge of coupes is considered to determine the extent to which vegetation changes in this zone may be subject to mechanical damage chiefly from the processes of logging and firebreak construction. The level of disturbance at each edge can be correlated with microclimate and floristic changes, which will permit a clearer understanding of their relative importance to the overall dynamics of these zones. A number of specific questions were examined:

1. Does the slope of the coupe adjacent to the edge influence the extent of disturbance into the undisturbed forest?
2. Is there a relationship between the amount of disturbance within a forest edge and the age of the edge?
3. Is there any relationship between the aspect of a forest edge and the distance to which disturbance penetrates?
4. Is there a profound increase in the area of a logged coupe if the mechanical disturbance at the edge is included?

2.2 Methods

In January 1999, one unburnt coupe (denoted Truggara) and four burnt coupes (denoted Warra, Small, Isabella and Manuka respectively; Table 2.1) were assessed in terms of the penetration of woody debris from the outer edge of their firebreaks into the adjacent undisturbed forests. Forest structure and composition at all sites was broadly similar (See Chapter 1), although the coupes varied in age, size and the edge aspect considered (Table 2.1). The latter being a proxy for prevailing wind exposure. The position of the edge relative to the local topography also differed between sites with “Uphill” indicating where the edge runs perpendicular to the slope and that an observer would be looking uphill when facing the edge (i.e. away from the centre of the coupe), “Downhill” is the reverse, while “Parallel” indicates where the edge ran along the slope. Three of the coupes were also employed in edge effect studies (Small, Manuka and Isabella; Chapters 4 to 7).

Table 2.1 - Coupes employed in the edge disturbance study. Age refers to the time since the regeneration burn, slope indicates the position of the edge relative to the local topography, edge of the coupe considered generally correlates with microclimate and vegetation studies.

Coupe	Size (ha)	Age (years)	Edge relative to slope	Aspect considered
Warra	160	< 1	Downhill	South
Small	16	< 1	Downhill	West
Isabella	34	< 5	Parallel	North
Manuka – NE	45	< 2	Uphill	Southwest
Manuka – NW	45	< 2	Downhill	Southeast
Truggara	18	Not Burnt	Parallel	West

The outermost wheel rut (i.e. closest to the forest edge) left by the passage of machinery during the construction of the firebreak was chosen as the base point for all measurements (Figure 2.2). This provided an unambiguous datum to which other distances could be related. The distance that woody debris (dead timber, boughs, whole stems or foliage) extended into the edge below a height of 1.3 m (breast height) was assessed within 2 m wide transects that ran out of each coupe into the undisturbed forest in a direction roughly perpendicular to the rut (Figure 2.2). In addition, the distance to the first upright (living) stem of greater than 10 cm diameter at breast height was noted (Figure 2.2). The position of the edge of the canopy along each transect was determined using a modified single lens reflex camera attached to a vertical monopod (determined using a spirit level; Figure 2.3). This device enabled a vertical view of the canopy edge on a line perpendicular to each transect (Figure 2.2). Distances were measured to the nearest 0.1 m.

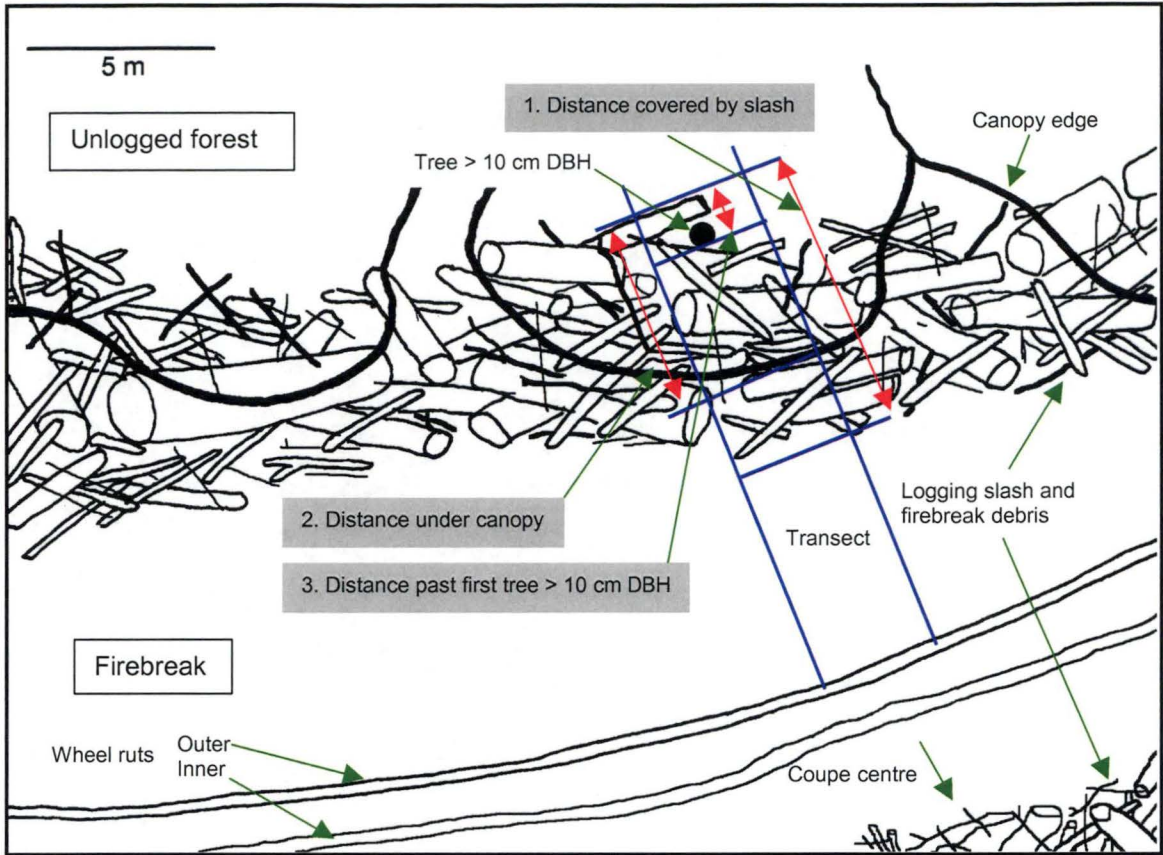


Figure 2.2 - The survey method for determining the penetration of mechanical disturbance in coupe edges. Three measurements were considered (grey shaded): 1. Total distance along transects with logging slash present (Slash distance), 2. Distance for the presence of slash under any overhead canopy (Canopy penetration) and 3. Distance for the presence of slash past the first living tree (●) with DBH > 10 cm (Forest penetration). Measurements were taken at ~ 20 m intervals with twenty samples obtained at each site.

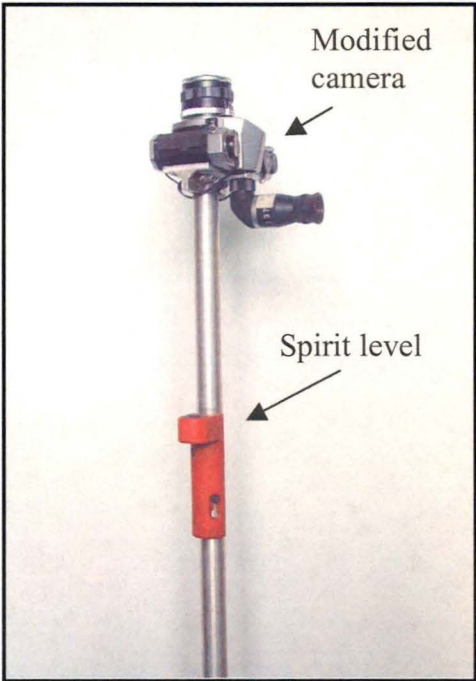


Figure 2.3 - Modified single lens reflex camera and monopod device used to determine the position of the canopy edge from ground level.

Transects were measured at roughly 20 m intervals along the selected edge with twenty replicate measurements obtained at each site. Slope and aspect were also measured at each point. At Manuka, two sides were examined: the northeastern edge (sloping uphill as one looks out of the coupe) and the northwestern edge (sloping downhill; Table 2.1). This was prompted by personal observations suggesting that there may be differences in the quantity of slash relative to the slope of the edge. All other sites ran either Downhill (Small, Warra) or Parallel to the slope (Truggara, Isabella; Table 2.1).

Three different disturbance distances were considered (Figure 2.2):

1. The total transect distance with logging debris present (Slash distance).
2. The distance logging debris penetrated past the canopy edge (Canopy penetration).
3. The distance logging debris penetrated past the first upright tree (Forest penetration).

All univariate statistics were calculated using the JMP Software (Version 3.1.2, Sas Institute Inc. © 1989 - 1995). A Bartlett test (Bartlett 1937 in Zar 1984) indicated that all of the distances considered had unequal variances (Slash distance $P = 0.0001$; Canopy penetration $P = 0.0397$; Forest penetration $P = 0.0371$). For this reason, Analyses of Variance (ANOVA) of all distances between each site/edge were performed using the Welch ANOVA, a modified form of standard analysis with the sample means weighted using the reciprocal of the variance of the group means (Welch 1951 in Zar 1984). Significant differences were established using a non-parametric form of the Tukey-Kramer Honestly Significant Difference (HSD) test (Kramer 1956 in Zar 1984) as described in Zar (1984).

2.3 Results

Average Slash distance varied between sites substantially more than either canopy or Forest penetration (Figure 2.4). Slash distance at the edge was significantly larger at Warra (9.7 m), Small (8.4 m) and Isabella (7.7 m) than at Truggara (3.6 m) (Table 2.2; Table 2.3). There was a significant difference for Forest penetration on the uphill vs. downhill sites however the larger distance occurred at the uphill site (Uphill - Manuka – NE: 2.0 m vs. Downhill - Manuka – NW: 0.1 m) in contrast to

what would appear logical. However, the limited number of sites and power (see below) considered makes this result problematic (Table 2.4), which was supported by the comparison of the average distance against slope with regression values of less than 0.219 for all three distance measures (Table 2.3).

Additional regression analyses indicated that there was no relationship between any distance and the aspect of the edge (Table 2.2). This suggests that there was unlikely to be any relationship to wind exposure. Neither was there any correlation with the age of the edge (Table 2.2).

Table 2.2 - Welch ANOVA for Slash, Canopy penetration and Forest penetration distances across the six coupe edges. * = highly significant differences (P < 0.001), NS = not significant. Power refers to the likelihood of detecting a 15 % change in the mean. Least significant number (LSN) refers to the minimum number of samples required to determine significant changes. Regressions indicate the r squares for each distance measure relative to slope or aspect.**

Distance measure	N	Power	Least Sign. Number	ANOVA (Welch)	Sign.	Regression Slope	Regression Aspect	Regression Age
Slash distance	20	0.68	131	0.0001	***	0.219	0.256	0.019
Canopy penetration	20	0.17	554	0.3441	NS	0.038	0.23	0.215
Forest penetration	20	0.07	2662	0.0877	NS	0.05	0.17	0.374

Table 2.3 – Modified Tukey-Kramer Honestly Significant Difference (HSD) test for Slash distances measured at six coupe edges. “+” = significant differences, NS = not significant.

Locations	Warra	Small	Isabella	Manuka - NW	Manuka - NE	Truggara
Warra	NS					
Small	NS	NS				
Isabella	NS	NS	NS			
Manuka - NW	NS	NS	NS	NS		
Manuka - NE	NS	NS	NS	NS	NS	
Truggara	+	+	+	NS	NS	NS

Table 2.4 - Welch ANOVA for Slash, Canopy penetration and Forest penetration distances across edges, comparing slope differences between Uphill (Manuka-NW) and Downhill (Manuka-NE). ** = significant differences (P < 0.01), NS = not significant.

Distance measure	N	ANOVA (Welch)	Sign.
Slash distance	20	0.045	NS
Canopy penetration	20	0.2184	NS
Forest penetration	20	0.0077	**

Neither Canopy penetration or Forest penetration were significantly different across all sites, however the power of the sampling for all three measures was low (Table 2.2). A very large number of samples (Least Significant Numbers (LSN) of 554 and 2662 for Canopy penetration and Forest penetration respectively) would be required to detect changes with confidence (20 % difference from the mean detected with

85 % probability - allowing a 15 % chance of a Type II error). Such a level of sampling was considered impracticable. Even for the Slash distance, the power of the test was 0.68 (LSN = 131 compared to 120 samples collected; Table 2.2).

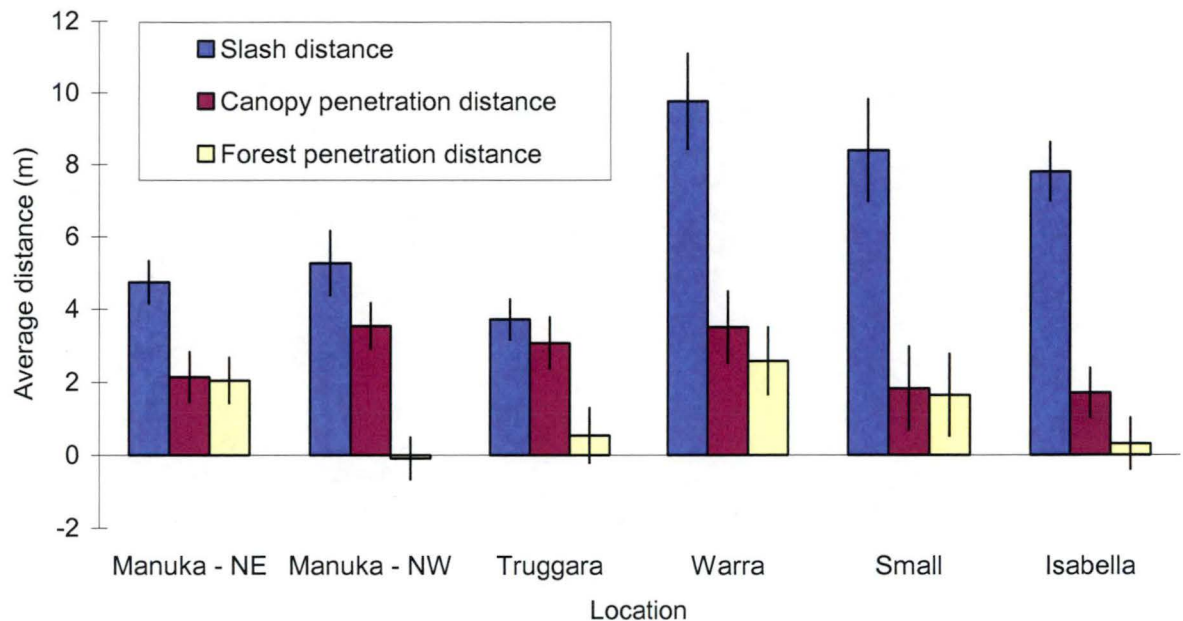


Figure 2.4 - The average of Slash distance (blue), Canopy penetration (magenta) and Forest penetration (yellow) at the six coupe edges. Bars are standard error.

Average Canopy penetration ranged from 1.7 m at Isabella to 3.5 m at Manuka - NW and Warra, while the average Forest penetration was slightly more variable, ranging from -0.1 m at Manuka - NW to 2.6 m at Warra (Figure 2.4). Variation between sites within both parameters was less than the Slash distance (3.7 – 9.7 m). Thus, while the amount of debris on an edge may be large, the actual penetration of this material remains similar (on average) regardless of the site. For example, the Warra coupe had an average Slash distance of 9.7 m while Truggara had only 3.7 m, but both sites had similar average Canopy penetration (3.1 – 3.5 m) and Forest penetration distances (0.5 – 2.5 m; Figure 2.4).

Both Canopy and Forest penetration distances can be used to estimate the increased area of influence a coupe might have on the surrounding system. Based on an average square coupe with perimeter length of ~ 3 km (J. Hickey, Forestry Tasmania, Pers. Com. 1999) and using the mean and standard error of (2.63 ± 1.93 m for Canopy penetration, 1.17 ± 1.92 m for Forest penetration), the increase in the functional area of the coupe ranged from 0.21 – 1.37 ha in terms of Canopy penetration and from 0 – 0.93 ha using Forest penetration. The former is probably

closer to reality as coupe edges are delineated on maps from aerial photographs that depict the canopy edge.

2.4 Discussion

The margins of Tasmanian coupes are fringed with a mixture of bare soil and woody debris that is pushed under the canopy into the undisturbed forest to an average distance of less than 3 m. This distance was similar across all sites regardless of the total Slash distance. It may be that the trees in an edge act as a buffer, allowing roughly similar quantities of logging slash to filter into the undisturbed forest. Peacock (1994) observed the partial burial of manferns (*Dicksonia antarctica*) at the edge of recently logged coupes in southern Tasmania as a result of debris from firebreak construction, but gave no indication as to the distance this disturbance penetrated (although microclimate changes were estimated to penetrate ~ 20 m). Neyland and Brown (1994) in a study of anthropogenic disturbances on Tasmanian rainforest estimated that a 40 m buffer was required to protect a patch of forest from the effects of road construction and logging. Other studies of mechanical disturbance at edges have been primarily concerned with the effect and extent of windthrow (e.g. Laurance 1991, 1997) rather than responses to ground level factors.

The reasons for differences between sites in terms of Slash distance, Canopy penetration and Forest penetration are likely to be complex. Logging contractors use different equipment (either bulldozers or excavators) to construct firebreaks and there are also differences between individual machine operators. Terrain and substrate factors (slope, soil composition, presence of boulders, etc) will affect the clearing process as will any remaining vegetation. The extent of canopy damage from tree felling is also likely to vary between forest types due to differences in canopy density and architecture. Large-scale forest composition of the edges was broadly similar and yet still encompassed four different *Eucalyptus obliqua* community types (*sensu* Kirkpatrick *et al.* 1988) and one rainforest community type (*sensu* Jarman *et al.* 1994).

Although it would seem logical that a downhill slope out of a coupe was more likely to accumulate woody debris (Harmon *et al.* 1986) and soil disturbance (possibly due to water runoff), the slope of the downhill edge actually had less forest penetration distance. However, this result was based on observations from only a single coupe

and there are a number of other factors that might explain this difference (see above). The lack of any relationship with age of the edge may also be explained by these factors.

Coarse woody debris is an important component of forest ecosystems (Attiwill 1994, McCarthy and Bailey 1994) as it provides:

- Substrate for plants (especially cryptogams - ferns, mosses, liverworts, lichens and fungi; Harmon *et al.* 1986),
- Shelter for birds and mammals (e.g. Harmon *et al.* 1986, Buchanan *et al.* 1995, Loeb 1999, Menzel *et al.* 1999),
- Substrate for nutrient cycling (Harmon *et al.* 1986),
- Habitat for terrestrial invertebrates (Harmon *et al.* 1986) and
- Habitat for fish and aquatic invertebrates in streams and rivers (e.g. Phillips 1995, Humphries *et al.* 1996, Beechie and Sibley 1997).

Lesica *et al.* (1991), McCarthy and Bailey (1994) stress the importance of fallen timber as a forest structural component. In many forest types, there is a strong correlation between species diversity and the amount of fallen timber (Franklin *et al.* 1986, Lesica *et al.* 1991). The woody debris pushed into the edge of a coupe may thus act as refuges for wildlife and play an important role in stabilising soil in a zone that is often highly disturbed.

Coarse woody debris in the form of slash on coupes is often considered from a fire hazard perspective (Bradshaw 1992, O'Connell and McCaw 1997, Kalabokidis and Omi 1998) and the effect that controlled burning has on the system. This includes the movement of nutrients (e.g. nitrogen, phosphorus, potassium, calcium, magnesium and carbon) in soil and debris (e.g. Harwood and Jackson 1975, Macadam 1987, Romanya *et al.* 1994, Attiwill 1994), and the physical and hydrological changes that occur in soil in response to burning intensity (Rab 1996). A few studies (e.g. Harmon *et al.* 1986, McInnis and Roberts 1995, Rumble *et al.* 1996) have centred on seedling growth and stand regeneration in the presence of logging slash that can afford shelter from climate extremes.

Lesica *et al.* (1991) found significant differences between the amounts of woody debris on 70-year-old secondary regrowth and 300-year-old oldgrowth. Harmon *et*

al. (1986), in a comprehensive review of the role of woody debris, concluded that forests used for wood production were very different from natural systems, owing to dissimilar input rates, species composition in the debris and mechanisms/pathways for decomposition. Söderström (1988) found considerable differences in the availability of logs at intermediate decay stages between 50 – 60 year-old regeneration and oldgrowth forest. It was suggested that this had an important role in determining concomitant differences in the bryophyte and lichen epiflora between sites.

Didham (1998) considered leaf litter decomposition rates at forest edges in different sized tropical forest fragments and found highly variable decay rates within edges, with turnover times 3 - 4 times higher than that of undisturbed forest. These occurred within 50 m of the edge of some forest fragments contrasted by no change in the border of continuous forest. Differences between sites were attributed to the highly patchy distribution of litter feeding termites, as there was no correlation with other factors including microclimate, biomass quantity and moisture content or overall invertebrate densities. The effect of fragmentation was thus considered to create more variable decomposition rates within tropical forest edges with concurrent changes in litter structure and nutrient cycling (Didham 1998).

If the Didham (1998) result translates to southern Tasmanian forests, the logging debris at the edge of a logged coupe is unique, as it is comprised of material not typical of undisturbed forest (at least in terms of input rates and microclimate), but is not burnt and hence it is also different from the debris on the exposed coupe. The biota supported by the border zone and rates and pathways for decay are unknown, but may comprise a combination of taxa and processes similar to undisturbed forest that are mediated by the altered microclimate of the edge (e.g. Chen *et al.* 1992, Matlack 1993, 1994, Young and Mitchell 1994, Malcolm 1998, Gehlhausen *et al.* 2000) and may be ecologically similar to that of woody debris in forest gaps.

Regardless of the parameter, the increase in area is minor compared to the overall size of a coupe (~ 56 ha based on a 3 km square), but high variability in this form of disturbance suggests that some sections of an edge will have little or no debris in contrast to others where the Slash distance is extensive. Moreover, this is an underestimate, as coupe borders tend to follow features (streams, slopes and forest types) that never run in straight lines. A more convoluted coupe border, with a

higher perimeter to area ratio, will have a substantially larger additional area affected by mechanical disturbance.

2.5 Conclusions

Mechanical damage at the edge of coupes showed no response to age, slope and wind exposure (aspect). Rather, it would appear that site-specific factors such as the forest type, machinery used in firebreak construction and possibly even the vagaries of their operators are more responsible. Lack of power in the sampling regime makes generalisations difficult.

Modelling the additional area imbued by logging slash did not add significantly to its overall size. However, unburnt slash at coupe edges may perform an ecological role very different to the debris either on the coupe or within the undisturbed forest and may be most analogous to woody debris in forest gaps.

Regardless of the distance covered by debris at the fringes of a coupe, the penetration of this material under the canopy appears to be similar. The presence of woody debris under the canopy where microclimate changes have been based averaged less than 3 m and the overlap with climate gradients is thus considered to occur only at points closest to the edge (0 m points).

3 Microclimate and vegetation in undisturbed forests over small spatial scales

3.1 Introduction

It has been established that the major elements of the change in microclimate in a forest edge are a consequence of the increased light exposure at or near ground level (e.g. Burkey 1993, Matlack 1993, Malcolm 1994, Chen *et al.* 1995). The ground thus becomes a “thermodynamically active surface” (Wales 1967) and results in a zone of higher, more variable temperatures and lower, more variable humidity which is gradually replaced by a stable interior forest climate as one moves further into undisturbed forest (e.g. Kapos 1989, Matlack 1993, Chen *et al.* 1995). These changes in microclimate influence the community structure of the edge zone through effects on seedling development and mortality, survival of under-canopy plants and invasion of the edge by shade intolerant species (Chen *et al.* 1992, Burkey 1993, Matlack 1993, Malcolm 1994, Brosfokske *et al.* 1997, Sizer and Tanner 1999).

A similar series of microclimate changes is likely to be encountered with increasing height above ground. However, few studies of microclimate in forest edges give any consideration or justification for the height utilized in data collection. Measurement heights vary substantially starting at 0 m (Saunders *et al.* 1999, Gehlhausen *et al.* 2000), 0.3 m (Brothers and Spingarn 1992, Matlack 1993, Cadenasso *et al.* 1997), 1 m (Young and Mitchell 1994), 1.5 m (Williams-Linera 1990, Didham 1998, Williams-Linera *et al.* 1998, Sizer and Tanner 1999), 2 m (Chen *et al.* 1992, Brosfokske *et al.* 1997) and even 3 m above ground level (Parry 1997, Renhorn *et al.* 1997). Occasionally there is no indication of the data collection height (e.g. Palik and Murphy 1990, Jose *et al.* 1996).

Matlack (1993) considered it important to measure close to the herb and seedling layer (~ 0.3 m above ground), as these were likely to be at risk from edge effects (Restrepo and Vargas 1999). Renhorn *et al.* (1997) also had good reasons for evaluating microclimate at 3 m above ground, as this was where their transplanted lichen samples were located. Both Matlack (1993) and Renhorn *et al.* (1997) were exceptional in that they justified their choice of microclimate measurement height. Camargo and Kapos (1995) considered vapour pressure deficit (VPD) at a range of heights (1.5, 3, 5, 7.5 and 10 m) at different distances from the edge (0, 5, 10, 20, 40, 60, 80, 100, 150 and 200 m) and found significant increases between heights within distances that correlated with foliage density, but no relationship to distance from the edge. The likelihood of changes in microclimate with height may make little difference within a specific study, however comparisons between studies are more difficult when different measurement heights have been employed.

Most research concerned with vertical forest microclimates focuses within the canopy or measures from ground level to the top of the canopy at scales of at least 0.5 - 1 m intervals (e.g. Hutchison and Matt 1977, Eliás *et al.* 1989, Barker 1996, Berry *et al.* 1997). Hutchison and Matt (1977) deemed it important to sample within the herb layer, but this study, like others, lacked any ability to resolve small-scale differences near ground level, where edge-related measurements are obtained.

If changes in microclimate have any effect on established trees, it would seem logical that the major influence will be at either or both of the two largest interfaces a tree has with its environment - the canopy and/or the roots. The canopy has an established series of mechanisms that must absorb a degree of climatic variability and will hence accommodate extremes of climate resulting in more stable conditions for the soil and therefore the roots (Kittredge 1948, Oke 1978, Shuttleworth 1989). It has been suggested that changes in microclimate can alter mycorrhizal relationships that could be a major influence on the growth and survival of tropical trees near edges (Lovejoy *et al.* 1986). The influence of microclimate changes on established trees may be best investigated with measurements at or below ground level. If the interest of the study is the microclimatic effect of edges on established trees it would be illogical to consider changes above ground level that, at best, give an indirect indication of changes in soil temperature and moisture. Large vascular trees are probably most vulnerable to edge effects at the seedling stage (Restrepo and Vargas

1999) and microclimate measurements are probably most appropriate at this level (*sensu* Matlack 1993, Renhorn *et al.* 1997). The biological relevance for measurement at levels above ground (> 0.3 m) is lacking in most edge studies.

Gradients in forest microclimate from ground level to the top of the canopy have received little attention compared with the amount of research focussed on the horizontal plane (Parker 1995, Barker 1996). However, vertical changes in microclimatic patterns have been considered important in relation to the distribution of species (Terbough 1985), biomass (Ardhana *et al.* 1988, Maguire and Bennett 1996) and/or the physiological properties of vegetation (Smith *et al.* 1985, Bazzaz 1991, Liu and Muller 1993, Gallego *et al.* 1994, Mantovani 1999). A great deal of this research has centred on the ecophysiology of the canopy components of large trees (e.g. Oberbauer and Strain 1986, Parker 1995, Benzing 1995) or the entire vertical column has been considered (e.g. Hutchison and Matt 1977, Eliás *et al.* 1989, Barker 1996, Berry *et al.* 1997). However, there has been no investigation of vertical microclimate in the region near ground level, where horizontal gradients are the focus of edge research.

Piippo (1982) and Frahm and Gradstein (1991) suggest that bryophytes are useful indicators of climate change. Kantvilas and Jarman (1993) suggest that cryptogamic differences between oldgrowth forest and 20-year-old regeneration in southeast Tasmania were driven by changes in microclimate (although substrate differences should also be noted). Terbough (1985) considered that vertical changes in microclimate were important factors in the distribution of plant species in tropical forest, including the bryophytes, lichens and epiphytic ferns. Finally, Kenkel and Bradfield (1986) proposed that the zonation of bryophytes on the lower 5 m of *Acer macrophyllum* stems was strongly influenced by microclimate.

In this chapter, the vertical gradients in microclimate within 2 m of ground level in undisturbed southern Tasmanian wet forests will be investigated and related to surveys of vascular vegetation and epiflora (bryophytes and epiphytic ferns). Vertical climatic data will indicate if there are implications for microclimate measurement height in edge effect surveys and whether these can be correlated with the epiflora to verify that the latter can be indicators of environmental change over small spatial scales. These sources of information will then be used in the development of methodologies for edges effect studies (Chapters 4 to 7), in

particular the optimal height for microclimate and epiflora surveys. More specifically the study will determine:

1. Do gradients in microclimate exist in the zone 0 - 2 m above ground level and if so is it likely to be a confounding factor in comparing studies that measure the degree of disturbance and/or change in microclimates at different heights above ground?
2. Does epiflora composition change with increasing height in the 0 – 2 m range above ground?
3. To what degree does substrate type influence epiflora composition?

3.2 Methods

3.2.1 Temperature, vapour pressure deficit and photosynthetically active radiation

Temperature, vapour pressure deficit (VPD) and photosynthetically active radiation (PAR) were measured at three sites within each of four locations – Hydro (Sites A, B, C), Blakes (D, E, F), Tomalah (G, H, I) and Weld (J, K, L; Figure 3.1; see Chapter 1 for site descriptions). Each site comprised two trees that were at least 50 m from the nearest non-natural (anthropogenic) boundary and from other sites.

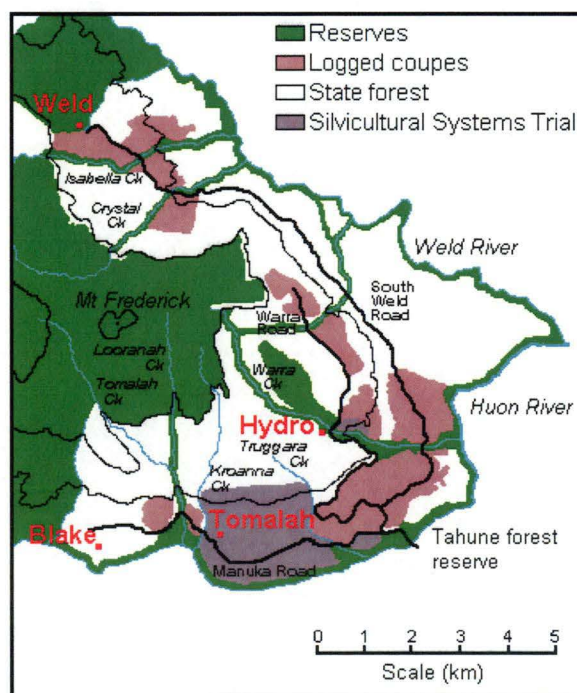


Figure 3.1 - The location of sites used in the vertical microclimate and vegetation study in undisturbed forest: Hydro, Blake, Tomalah and Weld (see Chapter 1 for more information). Map courtesy Forestry Tasmania.

PAR was measured using a series of eight Delta-T quantum sensors (Delta-T Devices, Cambridge UK) attached to a Campbell 21X multi-channel data logger (Campbell Scientific, Logan, Utah USA.). Temperature and humidity (measured as vapour pressure deficit - VPD) were measured using thirty Tinytag temperature data loggers (Gemini Data Loggers (UK) Ltd., Chichester, UK) configured according to the guidelines set out in Appendix A. This formed a series of fifteen unventilated wet/dry bulb humidity measurement devices shielded inside sections of PVC pipe.

A stability analysis of all temperature probes was undertaken and found differences of 1 °C for less than 3.5 % of measurements (Appendix B). PAR probes were already calibrated as part of non-related research and were within a few percent.

Probes were attached to spikes that were hammered into each tree on the side that received the most exposure to direct sunlight (Figure 3.2). The spikes prevented any direct contact between the trunk and the sensors so that the data obtained would relate to the environment immediately surrounding the epiflora that occupied these zones (*sensu* Barker 1996), but not be influenced by the tree itself. Temperature loggers were placed at 5 points on each tree, starting at the ground (0 cm) and then at 20, 60, 120 and 220 cm above this level. Quantum sensors were mounted at 0, 120 and 220 cm only. Microclimate data were collected from deployments over 3 to 5 days at each site from 15th February to the 31st March 1997, with all sensor reading at 5 min intervals.

At each site, a second set of data loggers was placed at the same heights on a freestanding pole located in a nearby cleared area (< 100 m from the site; Figure 3.3). The minimum distance from the pole to the nearest tree varied from 5 m (roadside verge - Tomalah) to 30 m (on a recently logged and burnt coupe - Weld).

Quantum sensors were fixed vertically on the most exposed face of the pole at two heights (0 and 220 cm) to give an indication of localised shading as exposed points often maintained a low cover of shrubs and/or young trees. A level of redundancy in Quantum sensors was also advisable as they incurred high levels of disruption due to herbivores (probably possums) chewing on the wiring. PAR data were thus often incomplete and, consequently, a running average across 12 samples (1 hour) was taken across all data to smooth extremes and indicate the more general light regime.

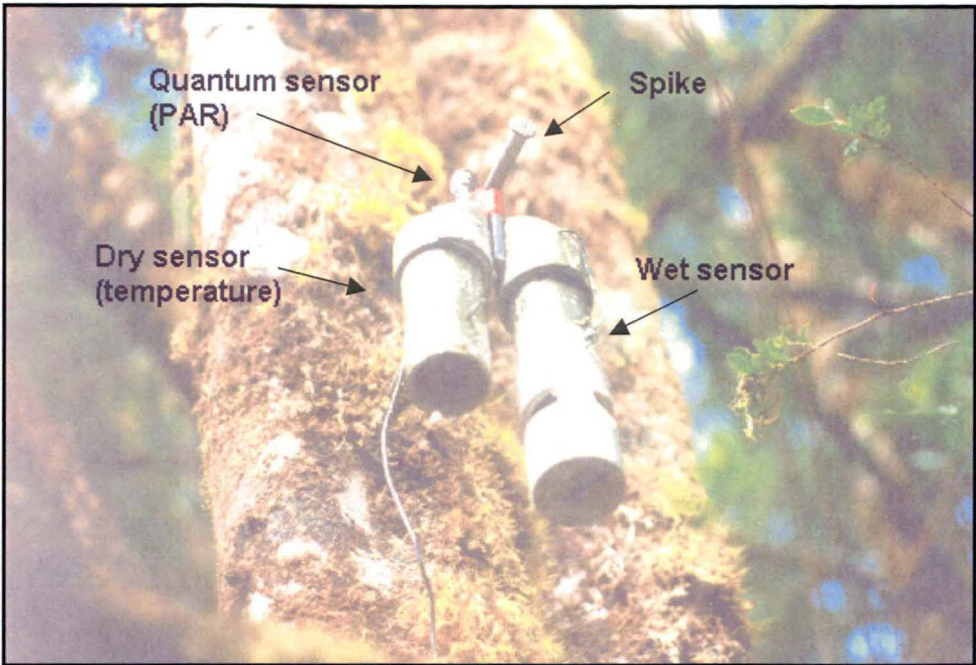


Figure 3.2 - A group of climate sensors, including wet and dry temperature dataloggers (see Appendix A) and a PAR probe attached via a spike to a tree 220 cm above the ground.

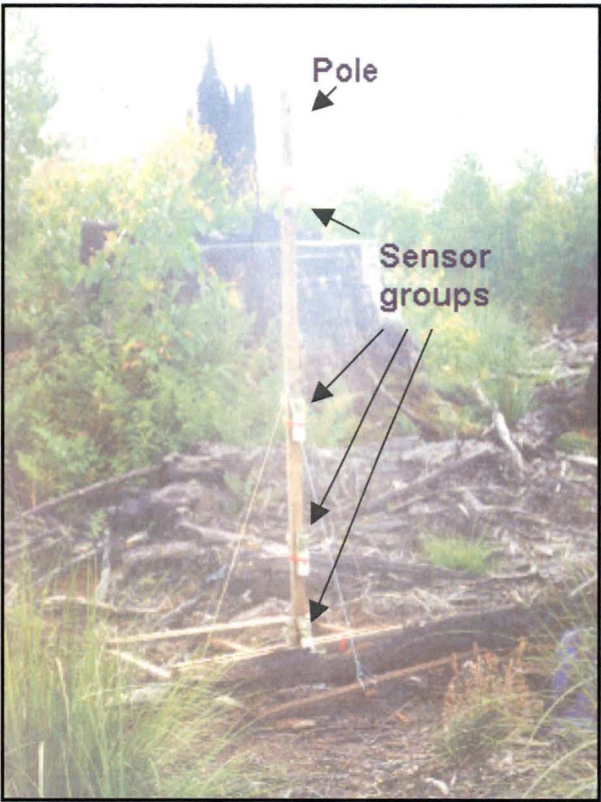


Figure 3.3 - A series of sensor groups (see Figure 3.2), attached to a freestanding pole in an exposed position, in this case a recently logged coupe. These were run concurrently with measurements over the same vertical range obtained in nearby undisturbed forest.

3.2.2 Vegetation surveys

The vegetation at each site was broadly characterised using the TASFORHAB vegetation profile (Peters 1984). The TASFORHAB protocol produces a description of forest structure within an estimated 30 m diameter circular plot (which roughly

equates to 0.1 ha). A 20×2 m quadrat was surveyed parallel to the non-natural edge and centred as closely as possible on the pair of trees from which climate data were collected (Figure 3.4). The quadrat was surveyed in 10 contiguous 2×2 m subplots. The projected cover of vascular plant taxa within or overhanging the subplot was classified on a modified Braun-Blanquet scale (Mueller-Dombois and Ellenberg 1974). The number of all stems rooted in the subplot and the diameter at breast height (DBH) of all stems larger than 1 cm was also noted.

Within each of the 2×2 m subplots a sheet of A4 sized overhead transparency (297×210 mm) was used to trace the non-vascular and epiphytic colonies (otherwise referred to as epiflora) on each substrate; ground, logs, rocks, tree trunks - low and high and manferns (*Dicksonia antarctica*) - low and high. The position for each map was selected subjectively such that it was central within the subplot (where possible) and covered only one substrate type. The high point on tree trunks was at 220 cm (in line with climate measurement), while the high point on manferns was either 220 cm or just under the crown if the fern was shorter. Manferns less than 50 cm high were only sampled at their base while the high point tracing was considered as missing data. Tracings were made of all mosses, liverworts, filmy ferns and other epiphytic plants, as well as areas of bare substrate and patches of leaf litter and small woody debris (Figure 3.5). Boundaries between different colonies of epiphytes are often diffuse and demarcations were located where the balance of dominance between taxa was roughly even.

To increase the number of maps obtained from each substrate type (and consequently the power of the survey) a series of extra samples was collected using a modified Point-Centred Quarter method (Mueller-Dombois and Ellenberg 1974). A random distance and bearing was taken to three points within a notional area of 50×50 m that was centred on the 20×2 m quadrat. At each point, the distance was measured to the closest tree and manfern within each quarter defined by the bearing and an imaginary perpendicular line (Figure 3.4). If no manfern or tree occurred within 20 m of the point centre, it was recorded as missing data. Tracings of the epiflora were made on each of these trees and manferns (low and high as before).

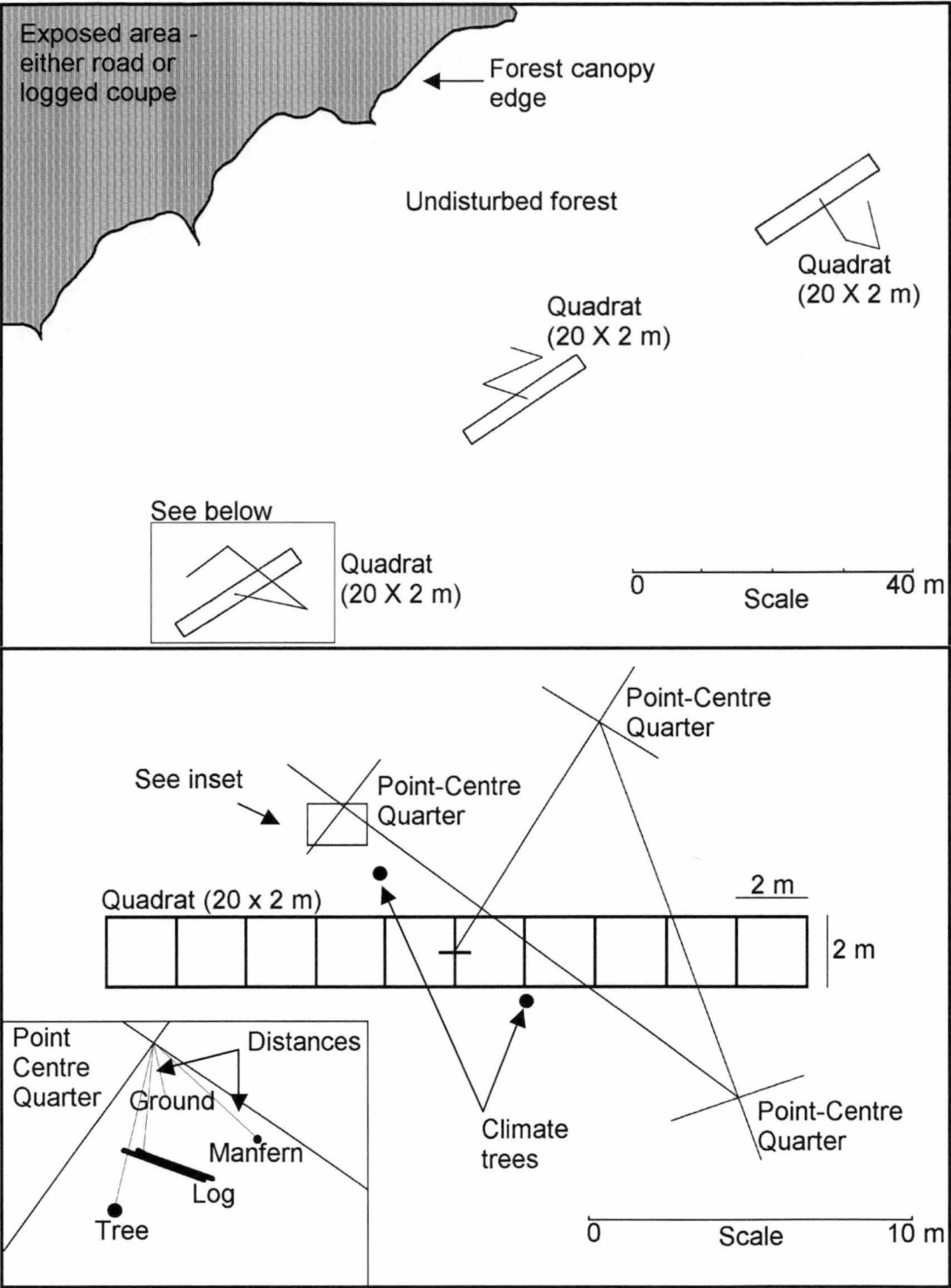


Figure 3.4 - A schematic diagram of the arrangement of quadrats and point-centre quarter surveys used to sample the vegetation at each Location. Each quadrat with its overlaying TASFORHAB and point-centre quarter survey constituted a site.

Ground substrate maps were placed at 2 m distance and 45° to the point in each quarter (unless it was occupied by another substrate, in which case the nearest available space was used; Figure 3.4). The remaining substrates (rocks and logs) had tracings made on their first occurrence within each quarter (measured from the point centre) within a maximum distance of 20 m from the point. Ten “quarters” were

considered in this manner, doubling the number of maps taken at each site, broadening the scale of the non-vascular and epiphytic fern survey to incorporate a much larger area and encompassing a greater number of substrate tree species.

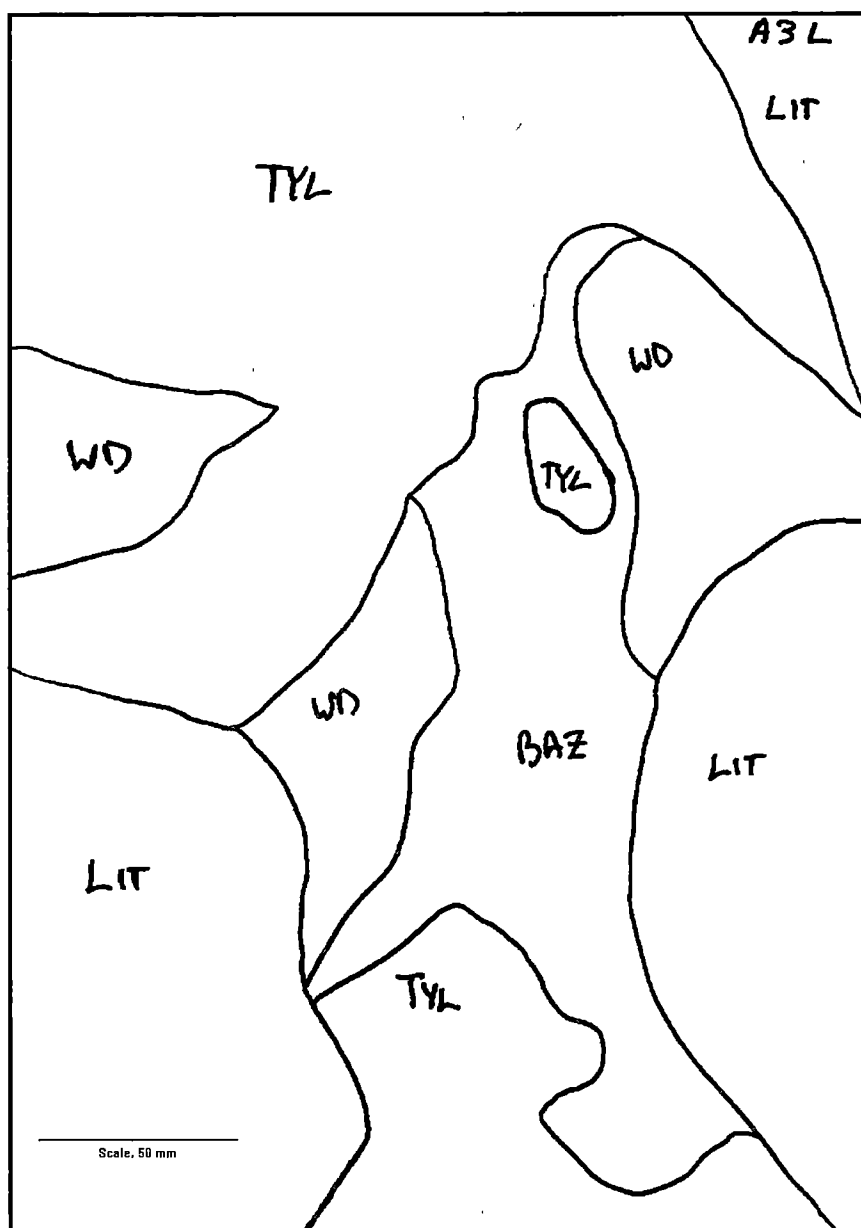


Figure 3.5 - An example of a typical epiflora tracing. There are only four different types represented on this plot: WD = Wood, TYL = *Tylimanthus*, BAZ = *Bazzania*, LIT = Litter. Note that each map normally covered an A4 sized sheet (297 × 210 mm). These maps were obtained from up to five substrates in each subplot and point-centre quarter: Logs, Stems, Rocks, Ground and Manferns.

Identification of bryophytes often requires a high level of experience and/or microscopic characteristics. Within the broad spatial scale used in this study, the methods of identifying different moss and liverwort taxa were restricted to those species that could be readily identified in the field. Many taxa were thus assigned to a higher taxonomic group (either genus or family) or to a “functional group” (*sensu*

Clement and Shaw 1999). Functional groups are considered as a complex of often quite divergent species that have adopted highly similar growth forms. Texts used to assist in identifications were Scott *et al.* (1976), Scott (1985) and Jarman and Fuhrer (1995). All lichens in the survey were combined as a single group.

Analyses of ecological data at taxonomic levels other than species may result in little or no loss of information (Warwick 1988a, 1988b, Ferraro and Cole 1995) and has the advantage of requiring a far less exhaustive understanding of the taxonomy of the system (Agard *et al.* 1993). It is, however, important to remain wary of making comparisons with other research, which may use a different level of taxonomic rigour. In this study, the best possible resolution for each taxon has been employed, so that analyses are comprised of mixed taxonomic levels.

Maps were photocopied to produce a permanent record (the plastic sheets were then cleaned and re-used). A Numonics Electronic Planimeter (Model 1210-2, Numonics Corporation, Pennsylvania USA.) was used to estimate the area of each colony.

3.3 Data analyses

All univariate statistics were calculated using the JMP software (Version 3.1.2, Sas Institute Inc. © 1989-1995); Shannon-Weaver diversity was calculated using an in-house Microsoft ACCESS database (9.0.2720, Microsoft Corporation © 1992-1999). Multivariate data analyses were undertaken using the PC-ORD for Windows analysis package (PC-ORD Version 4.0, MjM Software Design © 1995-1999; McCune and Mefford 1999). Microclimate data were compared for within each site and its exposed point. Comparisons of climate data between sites were deemed inappropriate because the vagaries of weather on/at any particular site/day are unlikely to produce meaningful insights when compared to another site/day. Vapour pressure deficit was calculated using the formula in Appendix A.

There was some overlap in the taxa employed in the vascular and epiflora analyses with the ferns Hymenophyllaceae (6 species), *Grammitis* spp., *Blechnum* spp., *Histiopteris incisa*, *Rumohra adiantiformis*, *Tmesipteris* spp. and some flowering plants, *Gahnia grandis*, *Prionotes cerinthoides*, *Drimophyla cyanocarpa*, *Galium australis* and the Orchidaceae repeated in both datasets (Table 3.1; Table 3.2). These groups occurred on substrate maps and hence were included as components of the epiflora, but they may also be influential at the larger scale. To decide which species

should be in either analysis makes an *a priori* choice as to which taxa may be important at either scale that seemed both arbitrary and unnecessary, as analyses of both components were undertaken independently.

Table 3.1 - List of the taxa employed in the epiflora analyses. Shaded species were also included in the vascular analyses.

Analysis_ID	Family	Genus or Species
Acrobolbaceae	Acrobolbaceae	<i>Acrobolbus cincinnus</i>
Acrobolbaceae	Acrobolbaceae	<i>Marsupidium surculosum</i>
Acrobolbaceae	Acrobolbaceae	<i>Tylimanthus</i> spp.
LeptGaud	Aulacomniaceae	<i>Leptotheca gaudichaudii</i>
Blechnum	Blechnaceae	<i>Blechnum wattsi</i>
Bryum	Bryaceae	<i>Bryum</i> spp.
Gahnia	Cyperaceae	<i>Gahnia grandis</i>
Histiopteris	Dennstaedtiaceae	<i>Histiopteris incisa</i>
Dicranaceae	Dicranaceae	<i>Bartramia</i> spp.
Dicranaceae	Dicranaceae	<i>Dicranoloma</i> spp.
Rumohra	Dryopteridaceae	<i>Rumohra adiantiformis</i>
Prionotes	Epacridaceae	<i>Prionotes cerinthoides</i>
Frullania	Frullaniaceae	<i>Frullania</i> spp.
Sticherus	Gleicheniaceae	<i>Sticherus lobatus</i>
Grammitis	Grammitidaceae	<i>Grammitis</i> spp.
Hookeriaceae	Hookeriaceae	<i>Acrophyllum dentatum</i>
Hookeriaceae	Hookeriaceae	<i>Distichophyllum</i> spp.
HymenAust	Hymenophyllaceae	<i>Hymenophyllum australe</i>
HymenCupr	Hymenophyllaceae	<i>Hymenophyllum cupressiforme</i>
HymenFlab	Hymenophyllaceae	<i>Hymenophyllum flabellatum</i>
HymenMarg	Hymenophyllaceae	<i>Hymenophyllum marginatum</i>
HymenPelt	Hymenophyllaceae	<i>Hymenophyllum peltatum</i>
HymenRaru	Hymenophyllaceae	<i>Hymenophyllum rarum</i>
PolyVeno	Hymenophyllaceae	<i>Polyphlebium venosum</i>
Hypnum	Hypnaceae	<i>Hypnum</i> spp.
HypnComo	Hypnodendraceae	<i>Hypnodendron comosum</i>
CyatBulb	Hypopterygiaceae	<i>Cyathophorum bulbosum</i>
HypoRotu	Hypopterygiaceae	<i>Hypopterigium rotulatum</i>
Lopidium	Hypopterygiaceae	<i>Lopidium concinnum</i>
GackWein	Lepidolaenaceae	<i>Gackstroemia weindorferi</i>
Bazzania	Lepidoziaceae	<i>Bazzania</i> spp.
Lepidoziaceae	Lepidoziaceae	<i>Acromastigum</i> spp.
Lepidoziaceae	Lepidoziaceae	<i>Lepidozia</i> spp.
Lepidoziaceae	Lepidoziaceae	<i>Telaranea</i> spp.
LeucCand	Leucobryaceae	<i>Leucobrium candidum</i>
Drimophyla	Liliaceae	<i>Drimophyla cyanocarpa</i>
Weymouthia	Meteoriaceae	<i>Weymouthia</i> spp.
Orchidaceae	Orchidaceae	<i>Townsonia viridis</i>
Orthotrichaceae	Orthotrichaceae	<i>Macromitrium microstomum</i>
Zygodon	Orthotrichaceae	<i>Zygodon</i> spp.
Acrochila	Plagiochilaceae	<i>Acrochila biserialis</i>
Plagiochila	Plagiochilaceae	<i>Plagiochila</i> spp.
Tmesipteris	Psilotaceae	<i>Tmesipteris</i> spp.
GlypSior	Ptychomniaceae	<i>Glyphothecium sioroidea</i>
PtycAcic	Ptychomniaceae	<i>Ptychomnium aciculare</i>
RhizNova	Rhizogoniaceae	<i>Rhizogonium novae hollandiae</i>
Galium	Rubiaceae	<i>Galium australe</i>
ParaTulo	Schistochilaceae	<i>Paraschitochila tuloides</i>
Schistochila	Schistochilaceae	<i>Schistochila lehmanniana</i>
Sematophyllaceae	Sematophyllaceae	<i>Wijkia extenuata</i>
Trichocoleaceae	Trichocoleaceae	<i>Trichocolea mollissima</i>
Dirt	Not Applicable	Not Applicable
UND (Undefinable taxa)	"	"
Lichen	"	"
Litter	"	"
Rock	"	"
Seedling	"	"
MF (Manfern trunk)	"	"
ThalLiv	"	"
Wood (trees and logs)	"	"

Epiflora taxa also incorporated a number of artificial groups (Table 3.1). The Dicran group included species of the Dicranaceae, mostly *Dicranoloma* and *Bartramia*, but also members of other families such as the Ditrichaceae. The Lepidozids belonged to the Lepidoziaceae, a large group in Tasmania, of which many members can only be distinguished with microscopic features (Jarman and Fuhrer 1995). All lichens were considered as a single group, as were all thallose liverworts, most of which were likely to be members of the Aneuraceae and Metzgeriaceae.

Table 3.2 - List of vascular plant species. Shaded species were included in the epiflora analyses.

ANALYSIS_ID	Family	Species
Blech	Blechnaceae	<i>Blechnum wattsii</i>
BlecNudu	Blechnaceae	<i>Blechnum nudum</i>
OleaArgo	Compositae	<i>Olearia argophylla</i>
AnodBigl	Cunoniaceae	<i>Anodopetalum biglandulosum</i>
BaurRubi	Cunoniaceae	<i>Bauera rubioides</i>
GahnGran	Cyperaceae	<i>Gahnia grandis</i>
Lepidosperma	Cyperaceae	<i>Lepidosperma</i> spp.
HistInci	Dennstaedtiaceae	<i>Histiopteris incisa</i>
Hypolepis	Dennstaedtiaceae	<i>Hypolepis rugosula</i>
DickAnta	Dicksoniaceae	<i>Dicksonia antarctica</i>
PolyProl	Dryopteridaceae	<i>Polystichum proliferum</i>
Rumohra	Dryopteridaceae	<i>Rumohra adiantiformis</i>
ArisPedu	Elaeocarpaceae	<i>Aristotelia pedunculata</i>
CyatGlau	Epacridaceae	<i>Cyathodes glauca</i>
PrioCeri	Epacridaceae	<i>Prionotes cerinthoides</i>
TrocCunn	Epacridaceae	<i>Trochocarpa cunninghamii</i>
AnopGlan	Escalloniaceae	<i>Anopterus glandulosus</i>
EucrLuci	Eucryphiaceae	<i>Eucryphia lucida</i>
NothCunn	Fagaceae	<i>Nothofagus cunninghamii</i>
Grammitis	Grammitidaceae	<i>Grammitis</i> spp.
HymenAust	Hymenophyllaceae	<i>Hymenophyllum australe</i>
HymenCupr	Hymenophyllaceae	<i>Hymenophyllum cupressiforme</i>
HymenFlab	Hymenophyllaceae	<i>Hymenophyllum flabellatum</i>
HymenPelt	Hymenophyllaceae	<i>Hymenophyllum peltatum</i>
HymenRaru	Hymenophyllaceae	<i>Hymenophyllum rarum</i>
PolyVeno	Hymenophyllaceae	<i>Polyphlebium venosum</i>
AcacDeal	Leguminosae	<i>Acacia dealbata</i>
AcacMel	Leguminosae	<i>Acacia melanoxylon</i>
AcacVert	Leguminosae	<i>Acacia verticillata</i>
Drimophyla	Liliaceae	<i>Drimophyla cyanocarpa</i>
AtheMosc	Monimiaceae	<i>Atherosperma moschatum</i>
CallPall	Myrtaceae	<i>Callistemon pallidus</i>
EucaObli	Myrtaceae	<i>Eucalyptus obliqua</i>
LeptLani	Myrtaceae	<i>Leptospermum lanigerum</i>
MelaSqua	Myrtaceae	<i>Melaleuca squarrosa</i>
Pterostylis	Orchidaceae	<i>Pterostylis</i> spp.
TownViri	Orchidaceae	<i>Townsonia viridis</i>
PittBico	Pittosporaceae	<i>Pittosporum bicolor</i>
PhylAspl	Podocarpaceae	<i>Phyllocladus aspleniifolius</i>
Tmesipteris	Psilotaceae	<i>Tmesipteris</i> spp.
PomaApet	Rhamnaceae	<i>Pomaderris apetala</i>
CoprQuad	Rubiaceae	<i>Coprosma quadrifida</i>
Galium	Rubiaceae	<i>Galium australe</i>
CorrLaur	Rutaceae	<i>Correa lauranciana</i>
PhebSqua	Rutaceae	<i>Nematolepis squamea</i>
PimeDrup	Thymelaeaceae	<i>Pimelea drupacea</i>

Another common epiflora group was dubbed UND (undefinable taxa) and used where taxa were too entangled to be deciphered. In terms of composition, this group is certain to have members of the Lepidoziaceae (very fine filamentous forms), as well as fungal hyphae and even filamentous algae. Because of uncertainty in

identification, it was decided to incorporate all of the Acrobolbaceae members (*Tylimanthus*, *Acrobolbus* and *Marsupidium*), members of the Sematophyllaceae (*Sematophyllum* and *Wikia*) and members of the Hookeriaceae (*Acrophyllum* and *Distichophyllum*) as single groups in the analyses (Table 3.1).

The only vascular plant included in the epiflora analysis that was not apparent in the vascular surveys was *Sticherus lobatus*. In addition, the epiflora analysis included the substrates - Litter, Dirt, Wood (exposed tree trunk or log), Rock, and Manfern (exposed manfern trunk - *Dicksonia antarctica*) and “Seedlings” of larger trees that were all included in the data as “pseudotaxa” (Table 3.1).

Data were interpreted using the multivariate ordination technique Non-metric Multi-Dimensional Scaling (MDS). This approach enables plots (in n dimensions) to be created from a multi-dimensional data set. An ordination in two or three dimensions enables easier visualisation of gradients in the data but the faithfulness of the MDS analysis, in terms of its ability to truly represent relationships between samples is a function of the associated stress value (Clarke 1993). Within the PC-ORD package the stress of the data at different levels of dimensionality is statistically compared to that of a randomised dataset generated within the program. The best combination of stress level and dimensionality is then selected (PC-ORD Version 4.0, MjM Software Design © 1995 –1999; McCune and Mefford 1999).

For the epiflora data, a modified form of the Importance Value, as described by Mueller-Dombois and Ellenberg (1974), was calculated for all taxa within each map:

$$\text{Importance Value} = \text{Relative Frequency} + \text{Relative Cover Abundance}$$

Generally, importance values are a combination of three factors: Relative Frequency, Relative Dominance and Relative Density (Mueller-Dombois and Ellenberg 1974). In this case, a Cover-Abundance measure had to be employed in place of Relative Dominance and Relative Density, as there is no sensible way to obtain density data from colonial life forms. Relative Frequency was based on the frequency of colonies.

To determine the relative value of each substrate to small-scale biodiversity, the Shannon-Weaver diversity index (Shannon 1948, Bowmen *et al.* 1971) was calculated using the relative area of epiflora taxa on each substrate within each site.

The use of relative area as an indicator of abundance assumes that the contribution of each individual to the area covered is approximately the same. While this is not the case, this approach still reflects taxa abundances, in that rare taxa should maintain relatively less area.

3.4 Results - Microclimate

3.4.1 Photosynthetically active radiation

Photosynthetically active radiation (PAR) was substantially reduced in the enclosed forest (Figure 3.6; Figure 3.7) with Site A (Hydro) having the highest average level of light penetration (22 % of maximum PAR at the exposed point) at the high point (220 cm), but amongst the lowest for the middle (120 cm) and low (0 cm) points (< 2.5 % and < 1 % respectively; Figure 3.7). Sites D, E and F (all Blake) had a similar pattern of attenuation (10 % down to 7 %, 17 % to 7 % and 21 % to 10 % respectively; Figure 3.7).

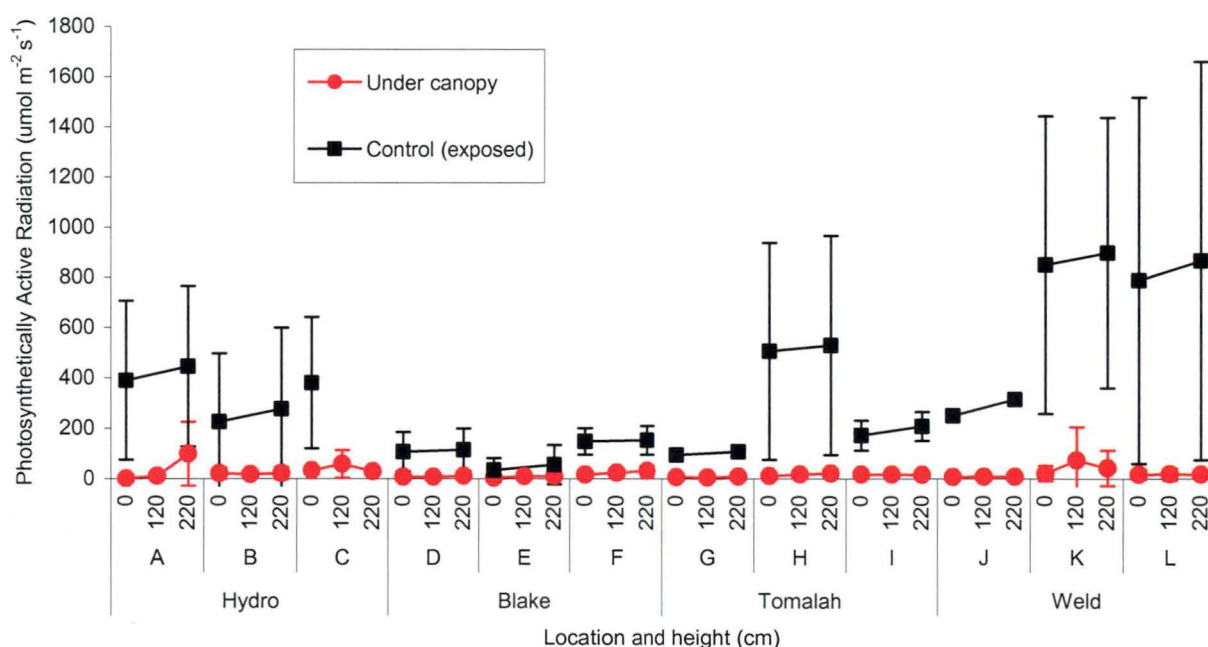


Figure 3.6 - Average hourly maximum PAR at each site within each location (red) relative to the exposed point (black). Bars are standard error. Lack of PAR data at site C from 220 cm is due to probe failure.

Other sites were more evenly distributed, with Site B (Hydro) at 6 - 8 %, Sites H and I (both Tomalah) at 2 - 4 % and 8 - 9 % respectively, and Sites J and L (both Weld) each with 2 - 3 % of the maximum PAR at their respective exposed positions (Figure 3.7). Differences between locations are likely to reflect the degree of structural

complexity of the understorey vegetation within each site. The range of PAR recordings across exposed points ($34 \mu\text{mol m}^{-2} \text{s}^{-1}$ at E to $897 \mu\text{mol m}^{-2} \text{s}^{-1}$ at K; Figure 3.6) indicated large day-to-day variability.

While average hourly maximum PAR was always less under the canopy than at the exposed position (Figure 3.6; Figure 3.7), height gradients were uncommon. Sites A, B, C (Hydro), H (Tomalah) and K, L (Weld) all had high exposed levels of PAR, but the corresponding enclosed points showed little difference relative to other sites (D, E, F and G) where the exposed PAR was lower (Figure 3.6). Under the canopy, average PAR was thus remarkably stable between sites (deployments) compared to the respective exposed points.

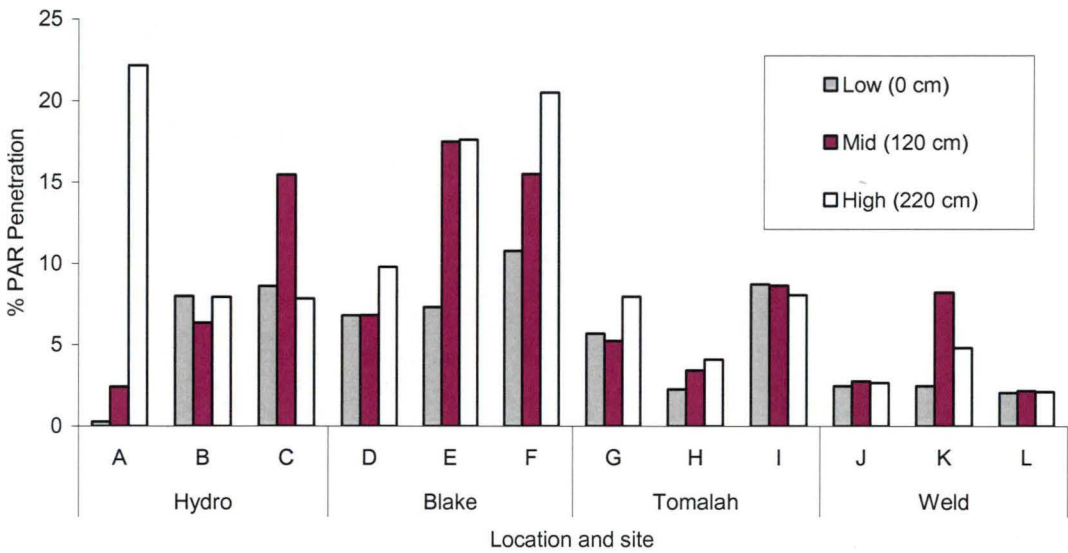


Figure 3.7 - Penetration of PAR maxima at each site in the undisturbed forest as a percentage of the maximum light interception at the exposed point.

The curious anomaly of lower measurement points indicating higher average levels of light penetration was particularly prevalent at site C (Hydro), but also occurred at B (also Hydro), G and I (Tomalah) and J, K, L (Weld) (Figure 3.6). This has been reported elsewhere (Hutchison and Matt 1977) and thought to be the effect of light backscattering from the ground and surrounding vegetation. If such is the case, the light climate near ground level cannot be expressed in terms of a simple attenuation model. A pattern of decreasing PAR attenuation with increased height was only observed at five sites - A (Hydro), D, E, F (Blake) and H (Tomalah; Figure 3.7).

3.4.2 Temperature

The average temperature at each height at the hottest time of the day (maximum temperature at 220 cm at the exposed point) was usually lower under the canopy (Figure 3.8). This probably indicates the buffering effect of the forest canopy on the local climate, although, in spite of the shielding on the temperature loggers, some direct absorption of incident radiation in the open could be expected, owing to the somewhat dark colour on the probe housings. Exposed temperatures may be actually slightly cooler than indicated. Temperature buffering was however, apparent at all sites with the under-canopy microclimates on average ~ 0.5 - 7 °C cooler than the exposed position (Figure 3.8). This difference was substantially larger during warmer exposed conditions, although a high level of variability was apparent at all sites. The biggest difference occurred at Site A (Hydro) which was, on average, 7.8 °C cooler between the 0 cm levels and 11.6 °C cooler than the average maximum temperature recorded at the exposed point at the same time (Figure 3.8).

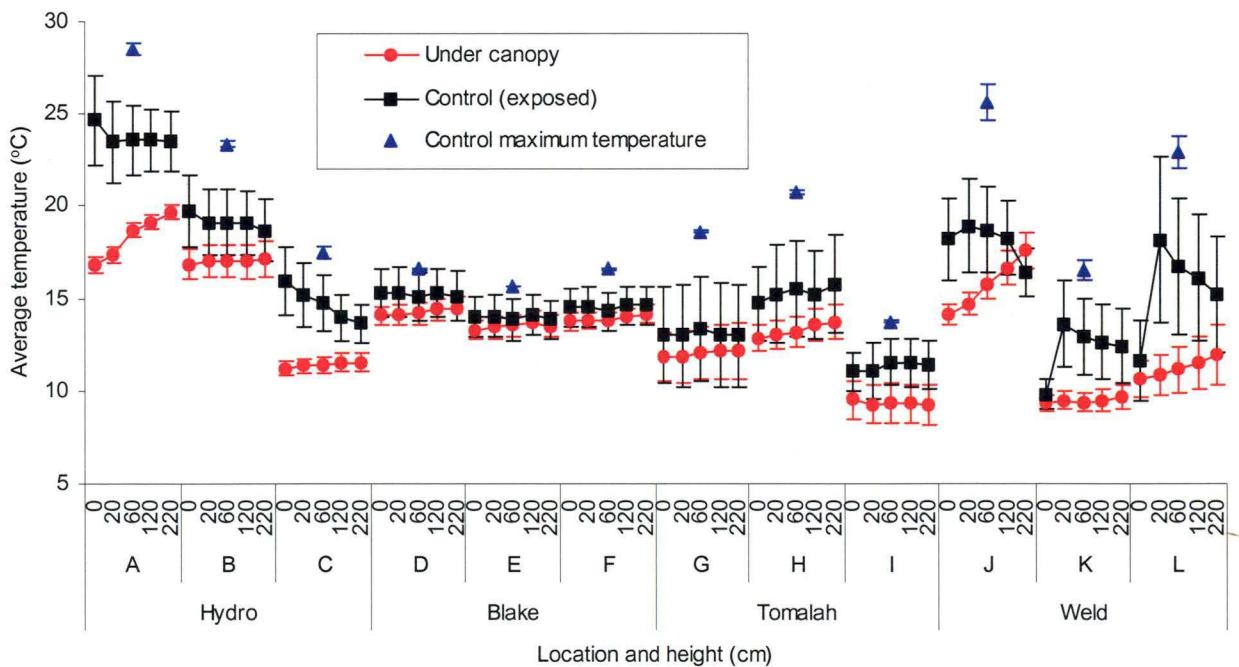


Figure 3.8 - The average temperature at each height within each site at the warmest time of day (measured at the exposed points). Bars are standard error.

At all sites from the Weld location (J, K and L), the temperature at the exposed point increased (sharply at sites K and L) from 0 - 20 cm and then declined (Figure 3.8). This pattern of colder air at lower levels was not observed at any other site, however the Weld was somewhat remote from the other locations (Figure 3.1), it was more

exposed and had the highest elevation (see Chapter 1), conditions that might have promoted the development of frosts and hence very cold air at ground level. There was no evidence of below freezing temperatures at this site, although colder air may have derived from the slopes above which comprises the north-facing slopes of the Mt Weld range that rises to more than 1,200 m above sea level. The upper levels of this ridge are largely un-vegetated and thus more likely to experience snow and frost.

Gradients of increasing average temperature with height were common under the canopy, although very shallow at most sites (Figure 3.9), such that they approach the level of accuracy that could be achieved with these temperature probes (Appendix B). Sites A (Hydro), H (Tomalah), J and L (both Weld) were the most apparent examples of temperature gradients under canopy, but all sites except Site I (Tomalah) had at least a slightly positive slope with height (Figure 3.8; Figure 3.9). At those sites for which patterns of this type are difficult to substantiate, Sites B and C (Hydro), D (Blake), G and H (Tomalah) and K (Weld), there was at least a small portion of each day spent in a gradient (Figure 3.10). These times varied from less than 2 hours (Sites B, C - Hydro and K - Weld) to more than 18 hours (Site J - Weld).

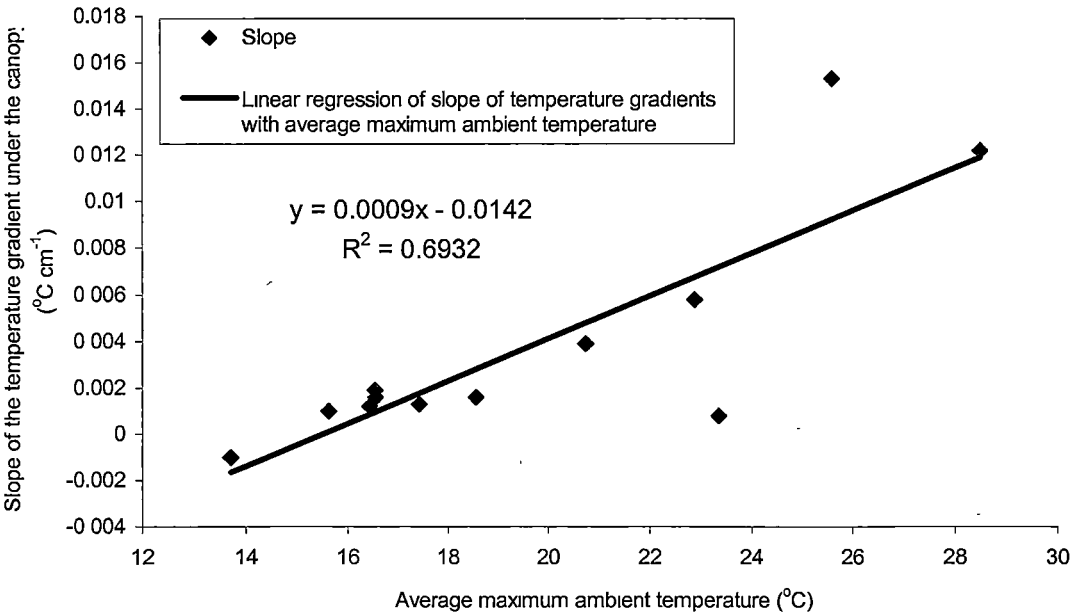


Figure 3.9 - The slope of temperature gradients under the canopy plotted against the average maximum temperature at the exposed point. Regression was highly significant ($P < 0.001$).

The slope of the gradient was positively correlated with exposed maximum temperatures (Figure 3.9), implying that warmer weather promotes steeper temperature differences beneath a forest canopy near ground level. The degree of air stability will also be important over such a small distance range. Those sites for

which no gradient time was registered, E and F (Blake) and I (Tomalah; Figure 3.10) also had the lowest average maximum temperature (Figure 3.8). While it is not suggested that shallow gradients of short duration were directly influential to the distribution of the epiflora, it suggests a potential for larger, more prolonged gradients (such as that observed at J) when exposed conditions are warmer. The effect of extreme exposed conditions (*sensu* Gaines and Denny 1993) may become significant.

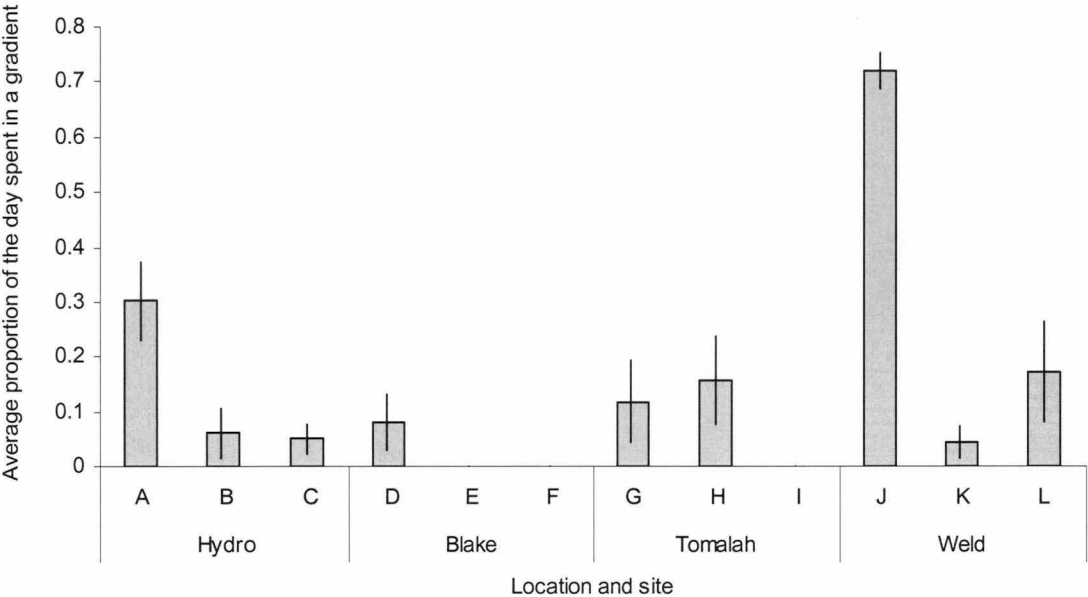


Figure 3.10 - The average proportion of each day in which a temperature gradient of cooler to warmer with increasing height was observed. Bars are standard error.

While the average temperature may increase with height under canopy, the corresponding temperatures at the exposed position often declined (Figure 3.8). The best examples of this trend occurred at Sites A, B, C (Hydro), J, K and L (Weld) and indicate that the difference between the enclosed forest and exposed temperatures often decreased with height, although at a few sites the average temperature increased at both points (Sites H and I - Tomalah). At J (Weld), the highest point (220 cm) was actually 1.2 °C warmer at the enclosed position at the warmest time of the day (Figure 3.8), which may be due to the retention of warmer air under the canopy from prior warm weather.

3.4.3 Vapour pressure deficit

At six sites (D, E, F - Blake and G, H, I - Tomalah) there is often little difference in average vapour pressure deficit (VPD) between the enclosed forest and the exposed points, although the latter was often slightly higher, indicating drier conditions and/or

larger air currents in the open (Figure 3.11). At other sites (A, B, C - Hydro and J, K, L - Weld), the difference was up to 0.6 kPa (at 0 cm from Site A). The observed changes in VPD were often based on temperature differences that were within the accuracy range of the probes (Appendix B).

Gradients indicative of drier, more turbulent conditions with increasing height were observed at most locations - Sites A, B (Hydro), D, E (Blake), H (Tomalah) and J, K, L (Weld; Figure 3.11). These appear to correlate with maximum exposed temperatures. Forest VPD was also relatively stable within heights regardless of exposed changes, with standard errors ranging from 0 to 0.03 kPa, compared to 0 to 0.22 kPa at the exposed points (Figure 3.11).

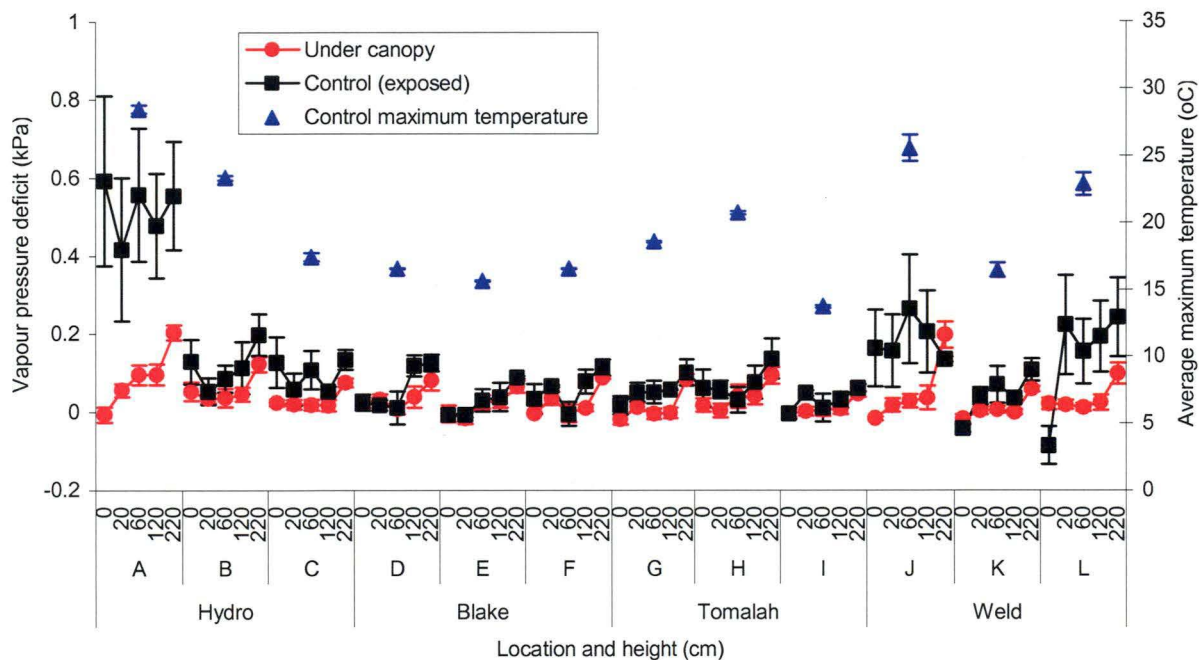


Figure 3.11 -The average vapour pressure deficit (VPD) for each height within each site at the warmest time of the day at the exposed points. Bars are standard error.

Exposed point VPD tended to be slightly drier, but otherwise tracked with enclosed forest values at most sites and hence also correlated with maximum temperatures (Figure 3.11). Exceptions to this occurred at Sites A, C (Hydro), J and L (Weld) where the average VPD at the exposed point was highly variable both within and between heights. Site A was the best example, ranging from 0.42 - 0.59 kPa at the exposed, compared to 0 - 0.2 kPa under the canopy (Figure 3.11).

The average difference in VPD between the exposed point and enclosed forest values was positively correlated with the average maximum temperature (Figure 3.12, $R^2 =$

0.63), implying that warmer days favour larger VPD differences and stronger gradients in moisture or air movement. Site A (Hydro) had the largest difference, averaging 0.43 kPa, while Site E was the smallest, averaging 0.01 kPa (Figure 3.12).

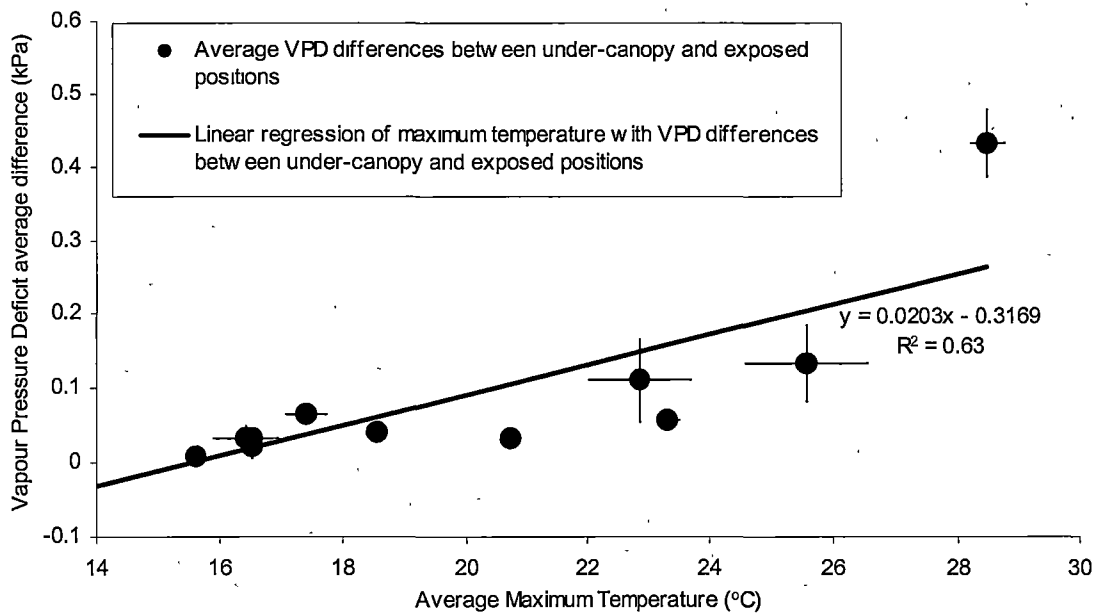


Figure 3.12 - Regression of the average across heights of the difference between the under-canopy and exposed positions across with the average maximum temperature. Bars are standard error. Regression was highly significant ($P < 0.001$).

3.5 Results - Vegetation

There were no qualitative differences between maps obtained from subplots (labelled with upper case; G, L, R, TH, TL, MFH and MFL) and those surveyed using the point centre method (lower case; g, l, r, th, tl, mfh and mfl; Figure 3.13). The information from both sources was thus considered jointly within each substrate at each site. Substrates were broadly distinct, although ground (g and G) and rock (r and R) maps were interspersed. Rock-based maps were, however, rare within the survey as this substrate was poorly represented. There was considerable similarity within log-based (l and L) maps while the tree and manfern groups (both low and high within each; th, TH, tl, TL, mfl, MFL, mfh and MFH) were more diverse, but nonetheless distinct in terms of epiflora composition (Figure 3.13). These substrate groups are ordered along what appear to be two different height gradients. From right to left, there were ground and rock (g, G, r and R) followed by log (l and L), tree low (tl and TL), and then tree high (th and TH), although the latter two are relatively more interspersed. On a second gradient, almost perpendicular to the first, manfern low (mfl and MFL) and manfern high (mfh and MFH) are aligned, but there is even more overlap than on trees, possibly because not all Manfern high points

were at 220 cm (see Methods; Figure 3.13). Tree low is similar to log substrate.

However, logs both in the ordination and quite literally, are the substrate transition from trees to ground.

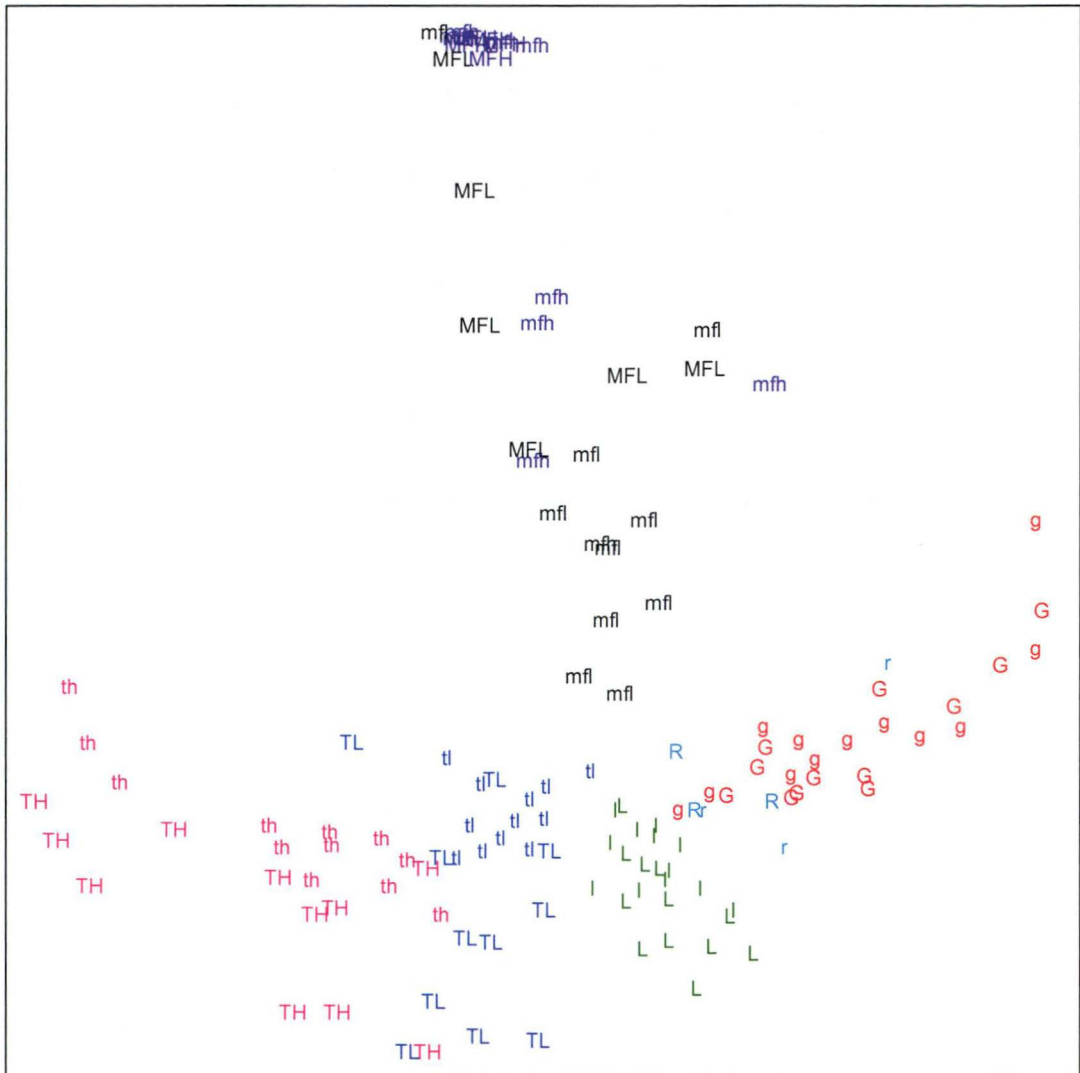


Figure 3.13 - MDS ordination in two dimensions of epiflora importance values from maps within subplots (UPPER case) and those from point centre quarters (lower case). G and g = ground, R and r = rock, L and l = log, TL and tl = tree low, TH and th = tree high, MFL and mfl = manfern low and MFH and mfh = manfern high.

The inclusion of bare patches of wood on trees and logs and exposed areas of manfern trunk in the analyses of epiflora taxa (Table 3.1) must assist in the formation of distinct clusters based on substrate (Figure 3.13). Removal of these pseudotaxa might result in less resolved clusters. However, patches of bare substrate could be present for any number of reasons, not the least of which is the microclimate gradient and it was thus thought relevant to include them in analyses.

Consideration of the same analysis with sites indicated that substrates within each location did not form distinctive groupings (Figure 3.14). While some small clusters

of the same location occurred, the overall impression is one of randomness, suggesting that, at this scale, substrate is more influential on epiflora composition than site.

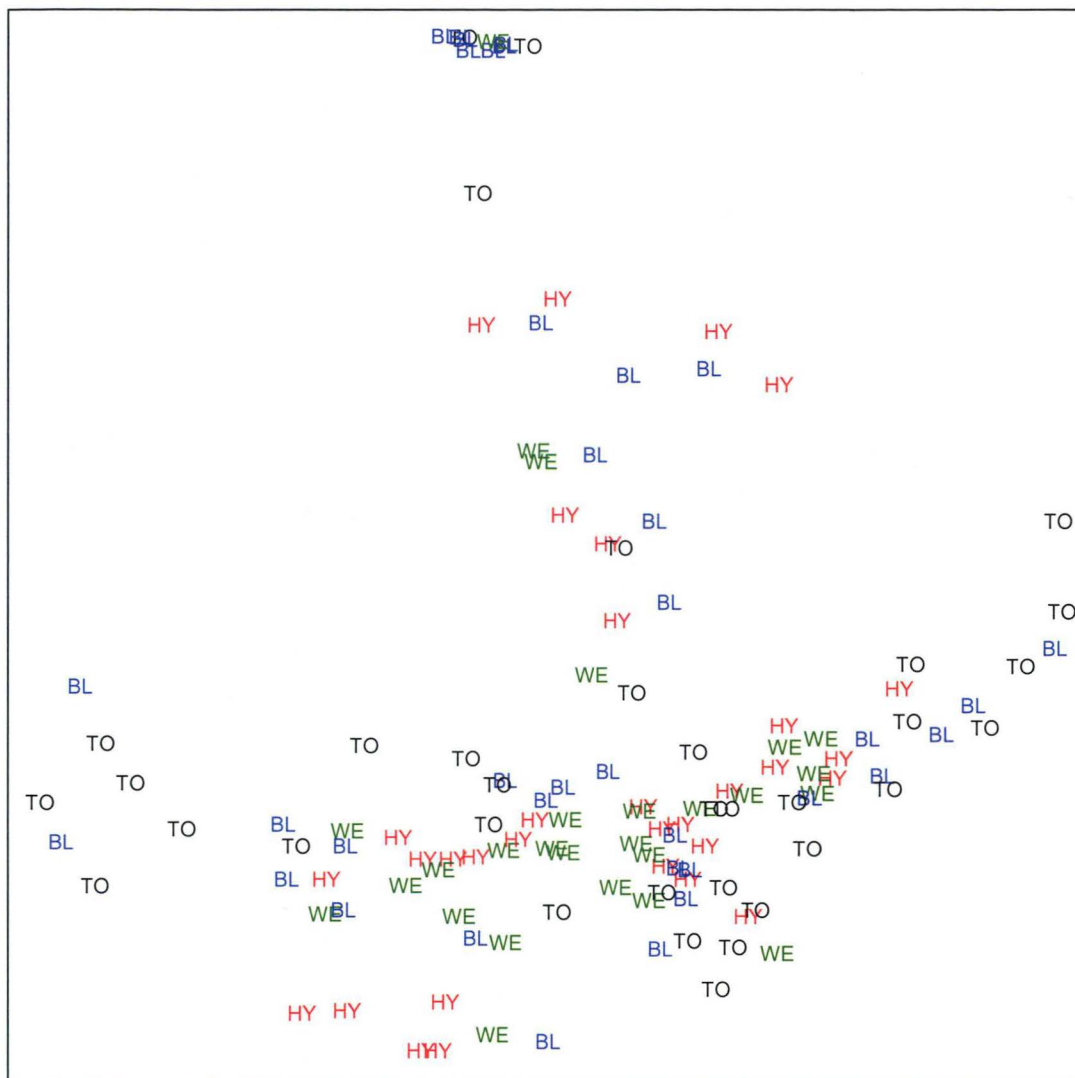


Figure 3.14 - MDS ordination in two dimensions of epiflora importance values (see Figure 3.13) reinterpreted using location. HY = Hydro, BL = Blake, TO = Tomalah and WE = Weld.

With distinctive epiflora compositions between most substrates regardless of site, the evaluation of edge effects may also be substrate specific. Surveys of epiflora within edges should thus remain aware of differences between substrates.

Distinct differences between sites were determined with an MDS analysis ignoring substrate (Figure 3.15). Given that substrates are influential irrespective of location (Figure 3.14), but the overall composition of a site is location specific (Figure 3.15), a study of edge effects using epiflora must remain cognizant of substrate differences.

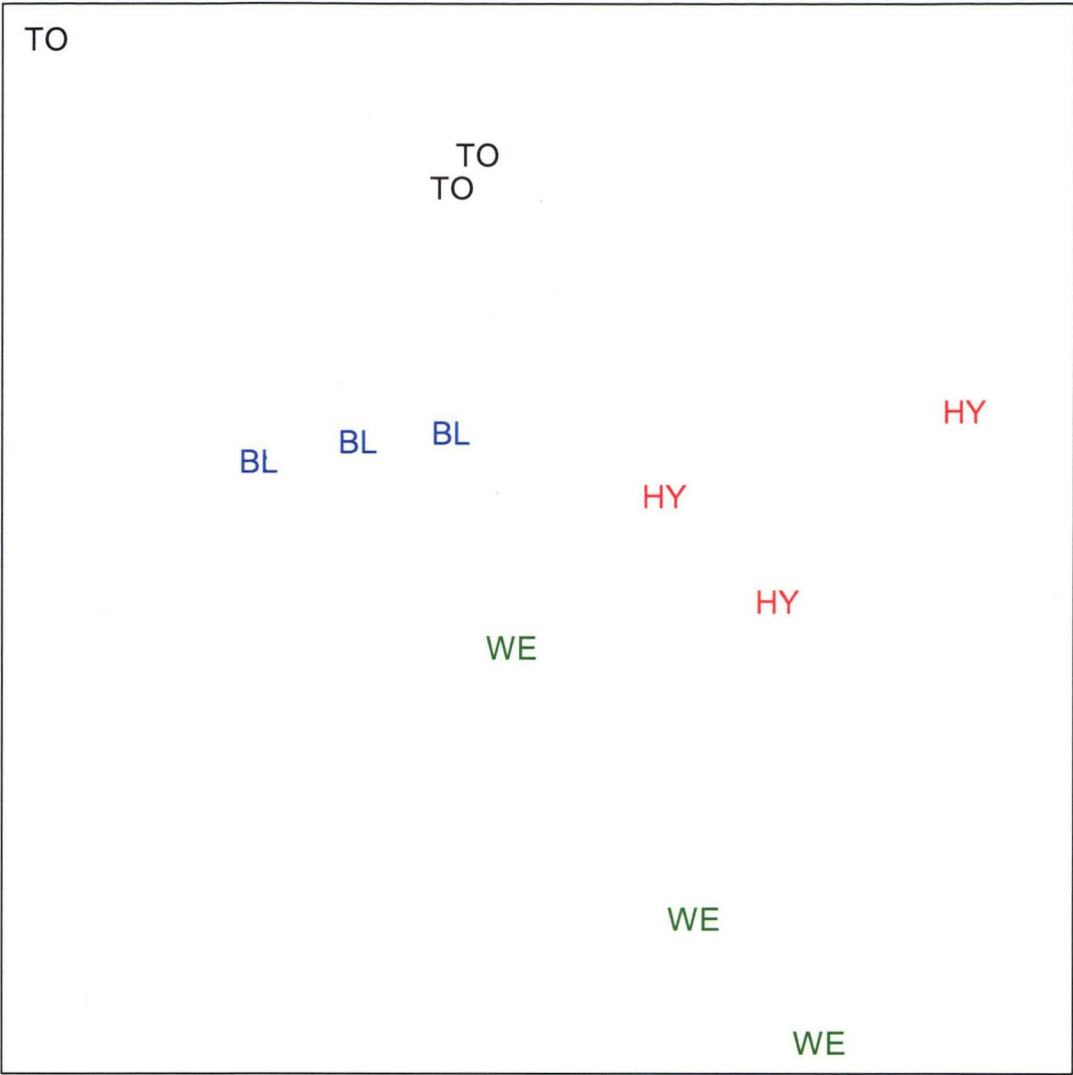


Figure 3.15 - MDS ordination in two dimensions of epiflora within each site irrespective of substrate. HY = Hydro, BL = Blake, TO = Tomalah and WE = Weld.

An MDS analysis of the large vascular flora using the number of each species rooted within each 20 × 2 m plot produced an ordination similar to the epiflora result at the same scale (Figure 3.15; Figure 3.16). Tomalah sites were more removed from other locations and aligned along a gradient on the left of the plot. Hydro and Blake formed discrete groups, while Weld sites were more dispersed (Figure 3.16). The vascular flora was thus largely location specific, with each site presenting a unique composition and architecture for the corresponding epiflora in terms of different tree and log substrates with concomitant effects on the local microclimate.

To test the role of tree species as substrate, a subset of the epiflora based on different tree species and manferns was created, combining information from both high and low maps on both substrates (i.e. tl and TL, th and TH, mfl and MFL, mfh and MFH). Manferns (MF) occurred as a distinct group as before (axes 1&2 and 1&3; Figure 3.17), confirming that manferns have a distinctive epiphyte composition.

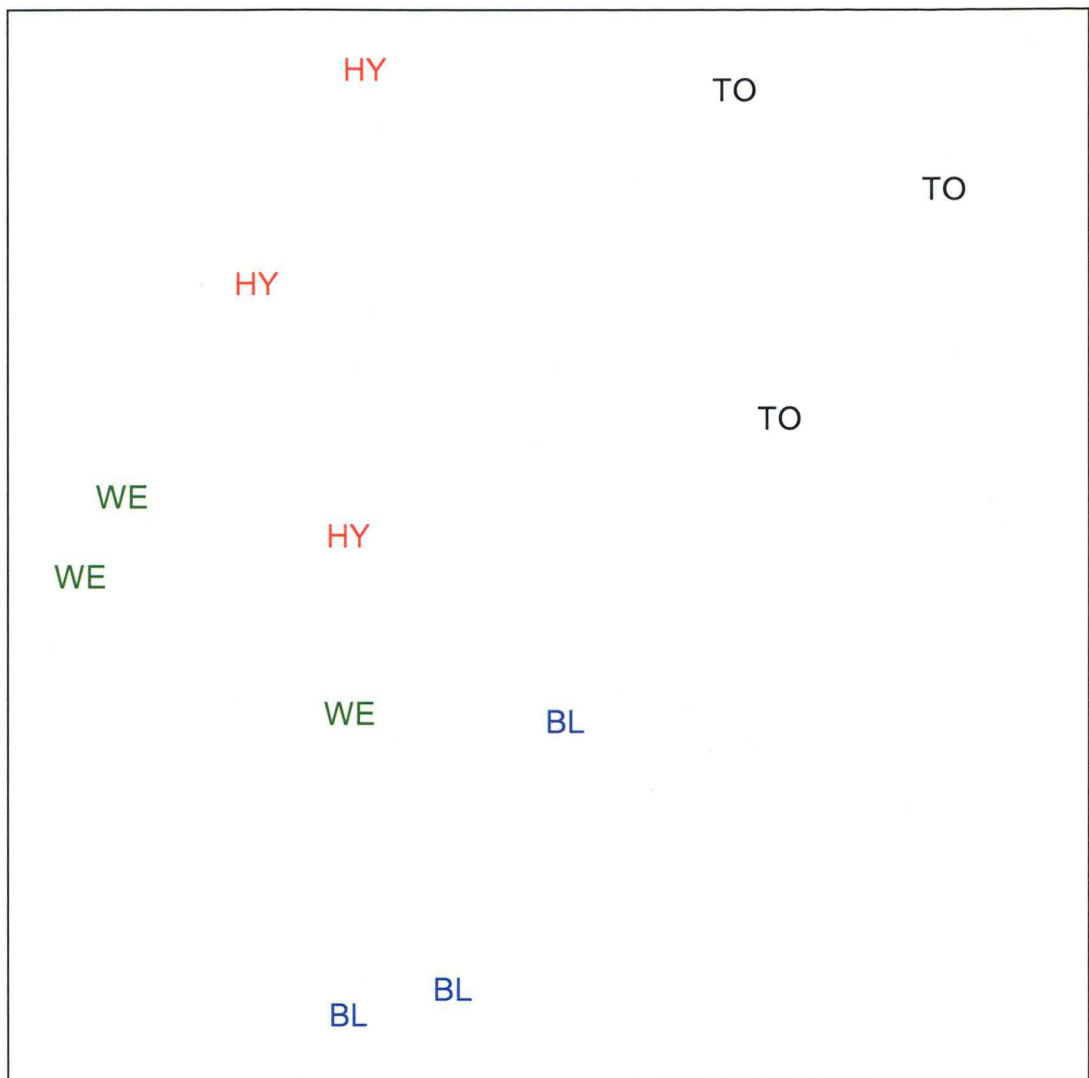


Figure 3.16 - MDS ordination in two dimensions of vascular plant composition at each site. HY = Hydro, BL = Blake, TO = Tomalah and WE = Weld.

Tree species form groups with varying degrees of size and overlap, but there were no discrete clusters (Figure 3.17). Rather, there appeared to be a gradient based on forest type, with trees from wet sclerophyll (broadleaf understorey) sites occurring in one section (axes 1&2 top left, 1&3 lower left and 2&3 lower right; Figure 3.17).

These trees were *Leptospermum lanigerum*, *Pomaderris apetala*, *Acacia melanoxylon*, *Nematolepis squamea* and *Cyathodes glauca*. Trees that are generally associated with older, more rainforest understoreys, comprising *Atherosperma moschatum*, *Eucryphia lucida*, *Anodopetalum biglandulosum* and *Anopterus glandulosus*, also occurred together (axes 1&2 lower left, 1&3 upper left and 2&3 upper left; Figure 3.17). Eucalypts were near the centre (axes 1&2 and 1&3; Figure 3.17), while *Nothofagus cunninghamii* formed a diffuse group spanning the forest type gradient (axes 1&2 and 2&3; Figure 3.17), probably owing to changes in bark texture with increasing age (Kantvilas and Minchin 1989).

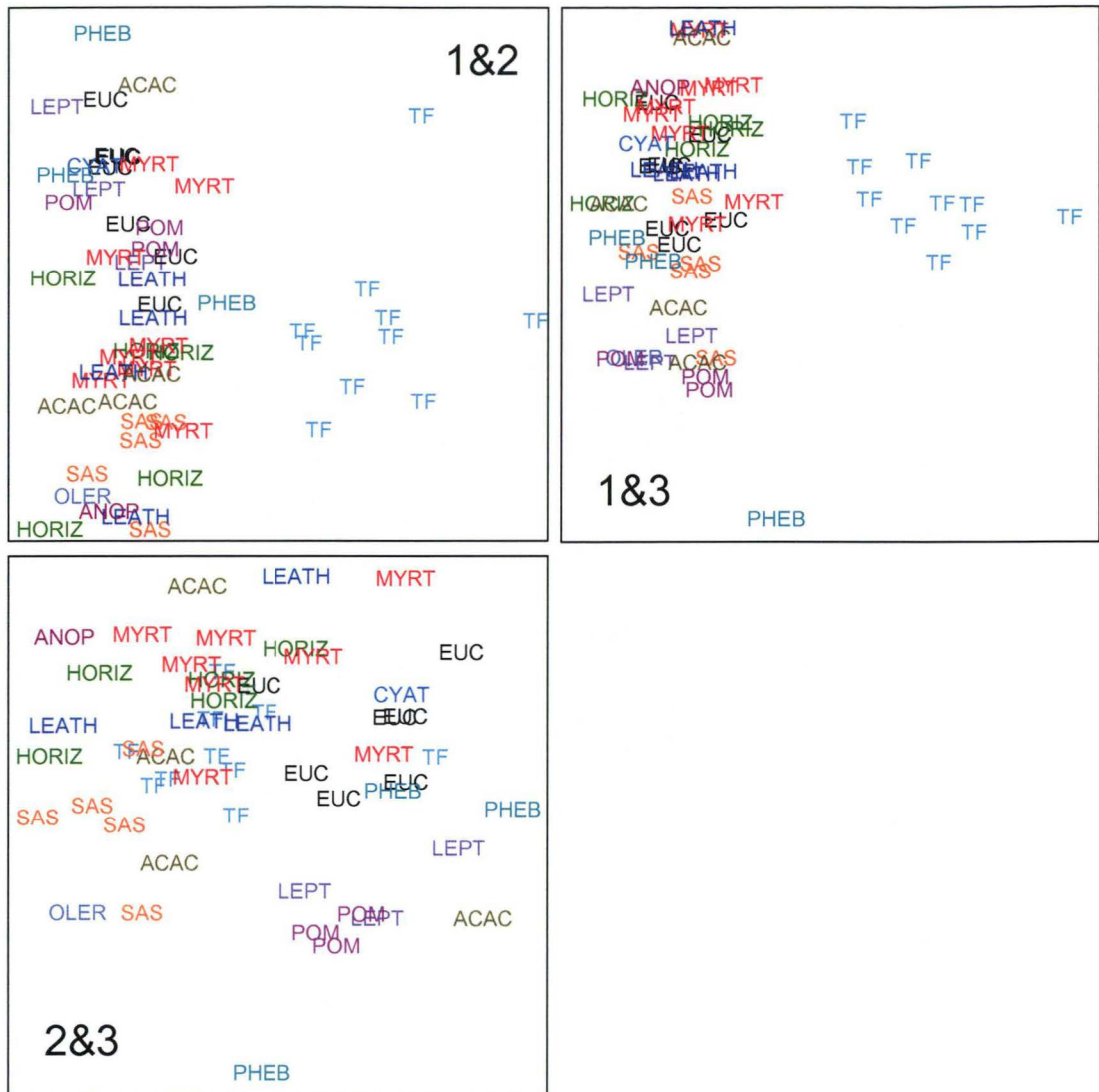


Figure 3.17 - MDS ordination in three dimensions of the epiflora composition on different tree substrates across all sites. TF = *Dicksonia antarctica*, EUC = Eucalypts, MYRT = *Nothofagus cunninghamii*, LEATH = *Eucryphia lucida*, SAS = *Atherosperma moschatum*, HORIZ = *Anodopetalum biglandulosum*, ANOP = *Anopterus glandulosus*, LEPT = *Leptospermum lanigerum*, POMA = *Pomaderris apetala*, ACAC = *Acacia melanoxylon*, PHEB = *Nematolepis squamea*, OLEA = *Olearia argophylla*, and CYAT = *Cyathodes glauca*.

Reconsideration of the same analysis using location reveals that most of the wet sclerophyll trees occur at Tomalah (axes 1&3 and 2&3; Figure 3.18). The Tomalah and Blake locations were burnt in 1898 (Hickey *et al.* 1999) and there is more overlap in these sites, but there are also differences in soil type between these locations. Tomalah is on an infertile boulder talus slope and comprises slow growing trees, while Blake has an alluvial sand substrate near the Huon River (Chapter 1; Figure 3.1).

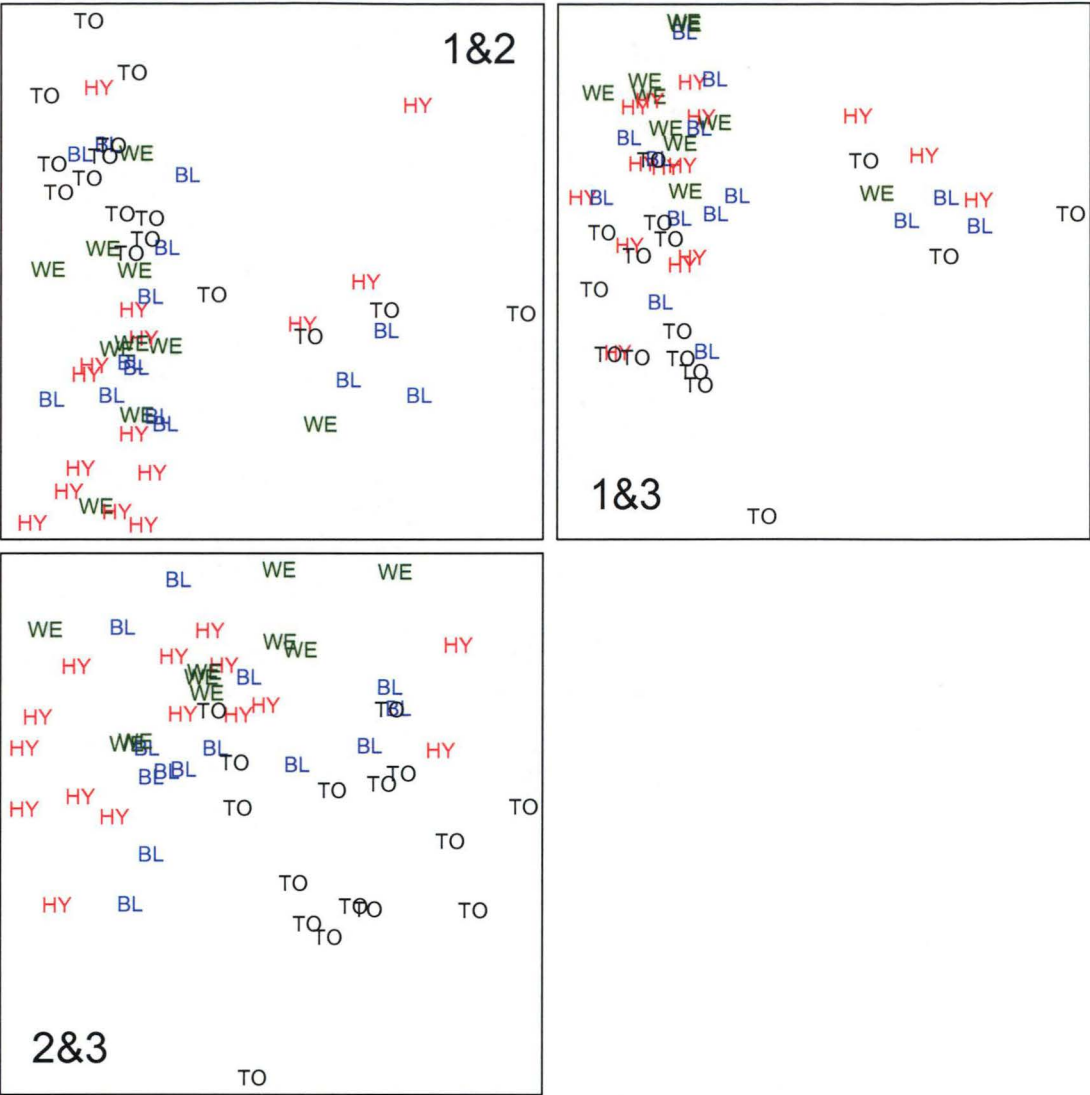


Figure 3.18 - Reinterpretation of the above MDS (Figure 3.17) labelled in terms of the location. HY = Hydro, BL = Blake, TO = Tomalah and WE = Weld.

The remaining locations, Hydro and Weld on the opposite side of the ordination (axes 1&2 and 2&3; Figure 3.18), are 300 - 400 year-old mixed forest or rainforest (Figure 3.1; Chapter 1). The dispersion of trees and locations within this analysis suggest that a mixture of location features (soil fertility and fire history), as well as specific tree species, are influential in determining the epiphytic community.

A nested Analysis of Variance (ANOVA) of Shannon diversity based on Location and Substrate indicated a significant interaction (Table 3.3), implying that there is a high degree of site-specific differences within substrates. Comparison of locations was thus likely to be substrate specific and hence each substrate was considered using ANOVA across locations. The rock substrate was only represented at the Tomalah site. Manferns were poorly represented at Tomalah and Weld, and these

were excluded from analyses. Significant differences were interpreted using the Tukey-Kramer HSD test.

Table 3.3 - Nested Analysis of Variance (ANOVA) of the Shannon diversity across locations and substrates. * Indicates highly significant differences ($P < 0.001$).**

Source	DF	Sum of Squares	F Ratio	Prob.>F	Significance
Location	3	23.82232	956.4029	0.000	***
Substrate	6	32.07776	214.6395	0.000	***
Location [Substrate]	16	24.83467	62.3154	0.000	***

Shannon diversity varied substantially on the ground between locations, but was generally lower than other substrates (Figure 3.19). Diversity at the Hydro and Weld locations was almost the same (~ 0.5), but both were significantly different to Blake and Tomalah (0.14 and 0.23 respectively; Table 3.4; Table 3.5). Logs had high diversity, ranging from 0.81 at Tomalah to 0.98 at Hydro (Figure 3.19) with no significant differences between sites (Table 3.4). The rock substrate occurred only at Tomalah and was generally similar to the ground in terms of composition, although rock substrate also had affinities to logs (Figure 3.13).

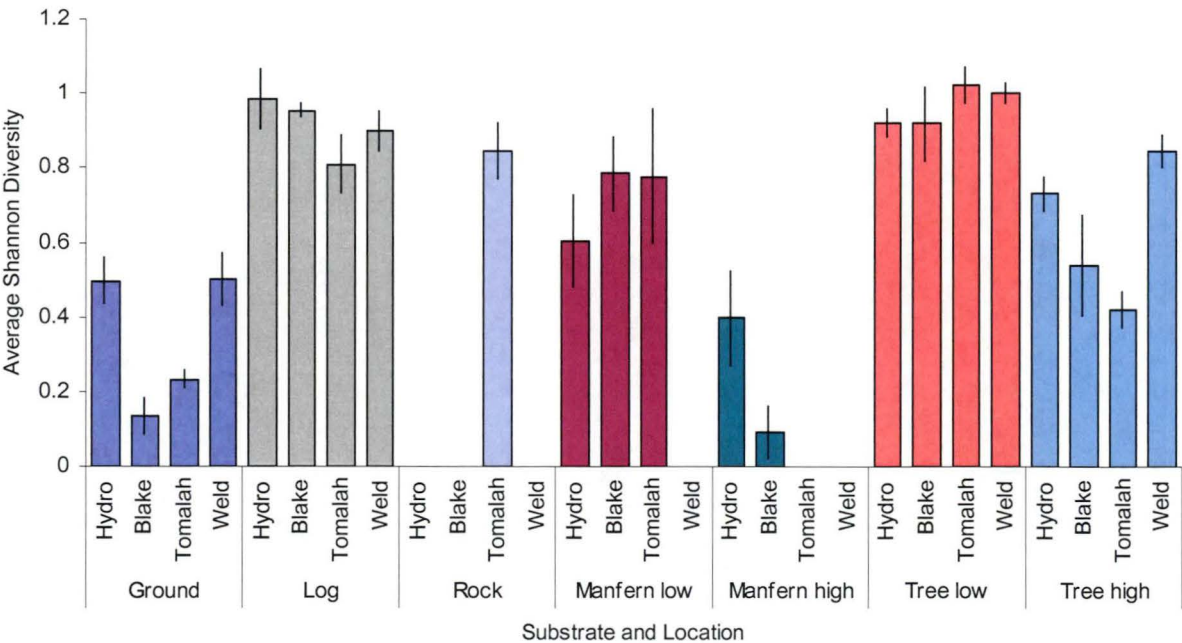


Figure 3.19 - Average Shannon-Weaver diversity on each substrate within each location. Bars are standard error.

The diversity low on manferns ranged from 0.06 (Hydro) up to ~ 0.78 (Blake and Tomalah) and was larger than high on manferns (0.4 and 0.1 at Hydro and Blake respectively), but was less than logs or low on trees (Figure 3.19). There were no

significant differences in Shannon diversity across locations in either low or high samples (Table 3.4). Low on trees (Tree low) was similar to logs, not only in terms of composition (Figure 3.13), but also with respect to Shannon diversity in that both were highly diverse (Figure 3.19). There were no significant differences between sites (Table 3.4) with 0.91 at Hydro and Blake, 1.02 at Tomalah and 1.0 at Weld (Figure 3.19). Diversity high on trees (Tree high) was more variable and less than low on trees, with significant differences between Weld (0.84) and Tomalah (0.42; Table 3.4; Table 3.5), but no differences from Hydro (0.73) and Blake (0.54).

Table 3.4 - Welch ANOVA between sites of the Shannon diversity within each substrate. Note that Rock was excluded as it occurred at only one location. * = significant differences ($P < 0.05$), NS = not significant.

Substrate	F Ratio	DF Num	DF Den	Prob.>F	Significance
Ground	8.3238	3	4.0651	0.033	*
Log	1.0372	3	3.753	0.471	NS
Rock	-	-	-	-	
Manfern low	0.61	2	2.8226	0.6023	NS
Manfern high	4.4816	1	3.0809	0.1222	NS
Tree low	1.1023	3	4.2176	0.4416	NS
Tree high	12.1531	3	4.3211	0.0145	*

Table 3.5 - Tukey-Kramer HSD results for Shannon diversity on the ground and high on trees across locations. "+" = significant differences, NS = not significant.

Ground				
	Weld	Hydro	Tomalah	Blake
Weld	NS			
Hydro	NS	NS		
Tomalah	+	+	NS	
Blake	+	+	NS	NS
High on trees				
	Weld	Hydro	Blake	Tomalah
Weld	NS			
Hydro	NS	NS		
Blake	NS	NS	NS	
Tomalah	+	NS	NS	NS

No single substrate (ground, logs, rocks, manferns or trees) or level (low or high) dominated in terms of Shannon diversity, although this factor was generally higher on substrates near ground level (log, rock, manfern low, tree low; Figure 3.19). While the ground had relatively low Shannon diversity, this substrate was often smothered in leaf litter, which may limit the growth of terrestrial bryophytes and obscure those that do occur. This suggests that horizontal surveys of edge effects are probably best achieved through a consideration of epiflora on substrates near ground level where higher diversity offers an increased opportunity for identifying indicator taxa.

3.6 Discussion

Gradients in light penetration were difficult to substantiate when only three heights have been considered at each point for PAR (0, 120 and 220 cm). Other studies of the vertical light climate in forests have examined few points over a short period (see Kira and Yoda 1989), yet considerable differences in PAR can be expected over comparatively small distances (Torquebiau 1988, Canham *et al.* 1990). This study found that the light regime within the first 2 m above ground was relatively stable compared to changes observed at exposed positions (within cleared coupes or roads), although the available data suggests that most deployments were undertaken during overcast conditions (eight of the twelve deployments had exposed maxima of less than $400 \mu\text{mol m}^{-2} \text{s}^{-1}$). This supports Hutchison and Matt (1977) who reported a more uniform light regime on cloudy days due to increased diffuse radiation. The relative stability of the light regime under the canopy relative to outside the forest can also be observed in Yoda (1978), Torquebiau (1988) and possibly Eliás *et al.* (1989). Other studies, however, report considerable spatial and temporal variation (Chazdon 1986, Canham *et al.* 1990).

Light climate results from this study compared well with other research in terms of percent penetration (from <1 to 10 % of the incident light reaches at ground level), although the latter are generally comparisons of ground level light intensity, with the amount received at the top of the canopy rather than at similar heights in an exposed position (Table 3.6).

Table 3.6 - Light penetration data from studies comprising several different locations and forest types. † Percentages based on millilangleys per minute, †† based on calories per centimetre per minute, otherwise based on photosynthetically active radiation.

Author	Location	Forest type	% light at ground level
Hutchison and Matt 1977	Appalachian Mtns	Tulip poplar	2.2 - 7.7 †
Aoki <i>et al.</i> 1978	West Malaysia	Tropical rainforest	3 ††
Yoda 1978	West Malaysia	Tropical rainforest	0.4 ††
Yoda <i>et al.</i> 1983	Salaerat, Thailand	Semi evergreen forest	2.2 - 2.7 ††
Chazdon 1986	Costa Rica	Tropical premontane wet forest	1.4
Torquebiau 1988	Sumatra	Lowland tropical rainforest	2
Eliás <i>et al.</i> 1989	Slovakia	Oak-hornbeam forest	≤ 5
Canham <i>et al.</i> 1990	Pacific Northwest USA	Douglas fir - hemlock	0.6
"	Ohio	Oldgrowth hardwood	1.9
"	Appalachian Mtns	Montane red spruce	4.4
"	Southeast USA	Oldgrowth mixed southern forest	1.4
"	Costa Rica	Tropical rainforest	0.5
Berry <i>et al.</i> 1997		Pine forest	6

Differences between studies can largely be attributed to variation in canopy architecture and disturbance regimes (Canham *et al.* 1990) between and within different forest types, as well as differences in solar angle and day-length (Monteith 1975, Chazdon 1986, Torquebiau 1988). The apparent stability of the light regime is not supported in terms of light penetration percentages, which ranged from < 1 to 22 % within a single site. This was likely to be the effect of transitory sun-flecks that are not reflected in an average response. Patches of intense radiation may be of profound importance, either in terms of supporting growth for under-canopy (Canham *et al.* 1990), or may actually be detrimental to sensitive light harvesting mechanisms that are adapted to shady circumstances (Bazzaz 1991).

The general (i.e. average) stability of the PAR regime, irrespective of the exposed levels, suggests that those gradients that occurred in temperature and humidity (VPD) were not related to the PAR environment within 2 m of the ground. Instead, these trends were possibly due to boundary layer effects on temperature and humidity which are driven by light absorption at the canopy level where the vast bulk of incident PAR is removed (e.g. Kittredge 1948, Yoda 1978, Eliás *et al.* 1989, Shuttleworth 1989). At low level (i.e. 2 to 3 m above ground), such gradients result from the boundary layer effect of shade tolerant shrubs and ferns, accumulated leaf litter and woody debris. This reduces the motion of air currents and light penetration over and above the buffering effect of the forest canopy, and is likely to result in very stable temperature and humidity regimes at ground level (Eliás *et al.* 1989). This may explain both the means by which gradients are formed, as well as the variability observed within and between locations in this study.

Temperature differences appeared to be the most dynamic of the parameters considered and was the best indicator of the level of canopy buffering. Conversely, while VPD is intimately linked to temperatures, it suggested buffering only during drier exposed conditions. As this factor is a bounded variable, damp ambient conditions will register as close to zero across all sites irrespective of the presence of canopy. Patterns in humidity are thus less easily established probably because of different levels of evaporation from the soil and plants on the forest floor (Oke 1978). Measurements are also complicated by the integration of differences in both VPD and air movement within the data.

VPD (or humidity) is possibly the most biologically important of the three variables examined as it determines levels of desiccation for all substrates and may buffer the effect of extreme temperatures. Bryophytes, especially liverworts, are known to be sensitive to water stress (Söderström 1988, Lesica *et al.* 1991, Kantvilas and Jarman 1993) and thus the humidity regime is critical to their establishment and growth.

Temperature, humidity (VPD) and light (PAR) in Tasmanian wet eucalypt forests has been shown to be highly variable both temporally and spatially from ground level to little more than 2 m high. Despite this, vertical gradients in maximum temperature and VPD under the canopy were common, although often very shallow and of short duration. There was, however, abundant evidence that higher exposed temperatures induce larger and more prolonged temperature and VPD gradients, which suggests that extreme conditions may have a structural influence on epiflora community structure (*sensu* Gaines and Denny 1993). In contrast, cooler, overcast weather, even in summer, promotes a very uniform forest microclimate that would appear unlikely to have much influence. The survey period (late February and March) did not cover a wide range of ambient climatic regimes and thus the ability to verify these assertions is limited.

In a forest edge, the increased light exposure at ground level is considered the main factor behind horizontal gradients that occur in temperature and humidity regimes (e.g. Kapos 1989, Matlack 1993, Chen *et al.* 1995). Any vertical gradients in microclimate are thus disrupted which, in turn, may result in floristic changes near ground which are not reflected in the epiphytes at higher levels, as the latter is, to some degree, already adapted to cope with more light, temperature and humidity swings and probably a drier substrate (see Mantovani 1999).

Very few studies of horizontal microclimate justify the height above ground that is to be used in data collection (although see Matlack 1993, Camargo and Kapos 1995, Renhorn *et al.* 1997). Matlack (1993) considered it important to take measurements from within the seedling layer (0.3 m above ground), while Renhorn *et al.* (1997) measured relative to their samples (3 m above ground), but these studies appear to be exceptional. From the current study, it is apparent that the height at which microclimate data are collected may have serious consequences for the taking of measurements on horizontal gradients, particularly in warmer weather.

Measurements of microclimate in edges would appear to be best done close to

ground level (i.e. 0.3 m - similar to Matlack 1993), where background levels are more stable.

Over the same spatial scale as microclimate changes, there were distinct and correlated changes in epiflora communities from the ground up to 2.2 m high on trees and manferns. The question remains as to whether there is any causal relationship between the microclimate and epiflora composition, as the distribution of bryophytes in any one location may depend on a wide range of factors, including altitude, drainage, exposure (Jarman and Fuhrer 1995) and the composition of the vascular flora (McCune and Antos 1981, 1982, Kantvilas and Minchin 1989, Jarman and Fuhrer 1995, Fensham and Streimann 1997, Frisvoll and Presto 1997). This last factor may incorporate additional substrate factors considered important in epiphyte distributions, including substrate age (Söderström 1988, Jarman and Kantvilas 1995), corrugation, pH, inclination, stability, moisture retention (Fensham and Streimann 1997, Frisvoll and Presto 1997), nutrient and chemical composition (Kantvilas and Minchin 1989). The high diversity and variability observed on logs, manferns and trees in this study may thus be due to the sampling regime that integrated a range of these factors across each site.

A few studies (Kenkel and Bradfield 1986, Kantvilas and Jarman 1993) have suggested that temperate rainforest cryptogams have high potential as environmental indicators, but published studies of the ecology of bryophytes in Tasmania appear to be rare. Jarman and Kantvilas (1995) described a high degree of epiphyte zonation along the length of a recently fallen Huon pine (*Lagarostrobos franklinii*) in western Tasmania, with distinct basal, middle and canopy floras, and a marked increase in the ratio of lichens to bryophytes with increasing height above ground. Notably, they found that the lowest portion of the trunk and its surrounding cone of organic soil (or peat) were dominated by bryophytes with the greatest richness near the forest floor, a view supported for other tree species observed in this study. While Jarman and Kantvilas (1995) noted an association between the presence of peat deposits and the richness of bryophytes, this was not quantified. Neither was the degree to which vertical microclimatic conditions may have influenced cryptogamic distributions. A similar gradient in bryophyte and lichen composition was observed on a fallen *Nothofagus cunninghamii* in central Victoria (Milne and Louwhoff 1999). However,

both studies were based on a sample of only one specimen and it is doubtful whether general inferences can be made.

Gradients in accumulated peat may be a factor in epiphyte distribution, especially with respect to older specimens of *Eucalyptus obliqua* and *Nothofagus cunninghamii* whose buttresses and longevity would allow the accumulation of substantial quantities of peat. In this study, a height gradient in epiphytes was observed on trees from a range of habitats and ages, as well as around the base of trees that either did not live long enough to accumulate much peat (*sensu* Jarman and Kantvilas 1995) or were relatively young.

In a study of the distribution of epiphytes at different heights on the trunks of *Acer macrophyllum*, Kenkel and Bradfield (1986) found a high degree of zonation with height. These were mostly attributed to gradients in microclimate (relative humidity and light), although they conceded that other factors, such as the bark chemistry (acidity) and nutrient levels, could not be discounted as influential in the zoning of the epiflora. It was also noted in their study that variation in epiphyte zonation was site specific and each tree was a microclimatically unique habitat, a view supported by the epiflora and climate information in this study. Kenkel and Bradfield (1986) studied the epiflora at six heights from 0 - 5 m above ground whereas this study employed only two sets of observations at 0 and 2 m. Height dependent changes like those noted in the former could not be observed with this level of sampling.

Page and Brownsey (1986) examined the epiflora on manferns (two species of *Dicksonia* and three species of *Cyathea*) in an attempt to establish if the dead frond "skirt" that developed on many species is a deterrent to epiphyte infestation of the crown with its delicate new foliage. Such a process could result in zonation of the cryptogams with the gradual exposure of the lower portion of the trunk. Their focus was on woody climbers and ferns as potential threats to the health of the manfern. Other epiphytes, such as bryophytes, orchids, filmy ferns and lichens, were considered no threat, although the processes they describe might well be applicable to the zonation of these groups across heights. A fringe of dead fronds is a common occurrence around the crowns of *Dicksonia antarctica* (Pers. Obs.) and hence it may be that microclimatic factors are not involved or may be complementary to the physical disturbance of the "skirt".

Manferns have been considered important in Tasmanian forest systems as a substrate for epiphytes, in particular the ferns *Tmesipteris* and *Hymenophyllum* and a unique suite of bryophytes (Beever 1984, Peacock 1994). Beever (1984) found this to be the case for only some manfern species, with others supporting epiflora communities similar to that found on trees. This study has indicated that the epiflora composition on *Dicksonia antarctica* is distinct from other tree substrates, yet also highly variable. Trees as substrate also differ substantially in the epiflora communities they support. However, when both tree and manfern substrates were examined in context with other substrates (logs, rocks, ground and each other) they form a variable but otherwise distinct group.

High Shannon diversity observed at lower levels on trees and manferns as well as on logs (that were generally close to ground level), suggests that these should be included in surveys of edge effects as they offer a wider range of species as potential indicators. While the ground was relatively low in diversity and rocks were poorly represented, it was deemed useful to include these substrates, as they may offer insights into changes in soil moisture, litter fall and soil disturbance as well in addition to offering a strong contrast to trees and manferns.

Because microclimate appears to be more stable near the ground, it is likely to be a more reliable measure of edge effects than at higher levels. The epiflora near ground level is also more diverse and may be more sensitive to climatic changes through the exposure of a larger range of taxa. These suggest that surveys of edge effects should be done at a similar level to Brothers and Spingarn (1992), Matlack (1993) and Cadenasso *et al.* (1998) i.e. around 0.3 m above the ground.

3.7 Conclusions

The choice of measurement height for microclimate may have serious implications for the outcomes of horizontal surveys, as gradients were common in the 0 – 2 m range, particularly in warmer weather. Conditions become warmer, drier and more variable across this range. Horizontal gradients in microclimate in edges are thus best evaluated near ground level (~ 30 cm), which will facilitate the comparison to background conditions that are likely to be more stable.

The epiflora associated with southern Tasmanian wet forests is a sensitive indicator of environmental change(s) over small distances (~ 2 m) and is thus likely to respond

to edge effects, although a direct correlation with microclimate is confounded by a range of complex substrate and site-specific influences (such as age and vascular composition). Hence neither height above ground or substrate type alone act in isolation as determinants of epiflora composition. The use of a specific substrate in edge effect studies is thus unlikely to be informative and a range of substrates will have to be considered.

4 Gradients in microclimate in a forest edge using a before and after, control and impact (BACI) approach

4.1 Introduction

Most literature describing microclimatic edge effects is concerned with the degree of penetration distance of change into undisturbed forest (Laurance and Yensen 1991). Such research requires data collected at increasing intervals with greater distance from the edge (e.g. Williams-Linera 1990, Brothers and Spingarn 1992, Matlack 1993, Young and Mitchell 1994, Camargo and Kapos 1995, Chen *et al.* 1995, Parry 1997, Renhorn *et al.* 1997, Turton and Freiburger 1997, Didham 1998, Williams-Linera *et al.* 1998, Gehlhausen *et al.* 2000).

Measurement intervals employed varies between studies, as does the level of control against which edge measurements are compared (Murcia 1995). Some research employs controls across the same spatial scales in the undisturbed forest as measurements obtained at the edge (e.g. Young and Mitchell 1994, Camargo and Kapos 1995, Parry 1997, Didham 1998). The majority of studies, however, compare data from near the edge to that collected at a few widely spaced distances (or even a single distance) in the undisturbed forest (e.g. Williams-Linera 1990, Brothers and Spingarn 1992, Matlack 1993, Chen *et al.* 1995, Turton and Freiburger 1997, Esseen and Renhorn 1998, Williams-Linera *et al.* 1998, Sizer and Tanner 1999, Gehlhausen *et al.* 2000).

Some of the latter studies attempt to minimise background heterogeneity by avoiding sources of variation, such as steep slopes, forest gaps (Esseen and Renhorn 1998),

fallen logs (Chen *et al.* 1995) and major changes in forest architecture (Matlack 1993, 1994, Sizer and Tanner 1999). By limiting the sources of variability, these studies may be overestimating both the penetration distance and severity of any edge effect. Further, the comparison of edge data with a single “interior forest” position also fails to incorporate a measure of background variation. Even within those studies that employ numerous control distances, there is a tendency to avoid sources of variation (e.g. Parry 1997).

Studies of edges vary extensively in terms of microclimate gradient penetration distances (Murcia 1995), but many of them are compromised by the lack of appropriate controls (*sensu* Margules *et al.* 1998). To fully comprehend edge effects, information should be obtained on the background variability and natural gradients in climate and vegetation over the same spatial scales against which edge data can be compared.

Closely related to this issue is a lack of studies that examine edges both before and after fragmentation. Information on the undisturbed system is often not obtainable as fragmentation has already occurred (see Chapters 6 & 7), but the results may be compromised by the lack of *a priori* data so that both the magnitude and significance of changes in edges cannot be placed in context with the nature of the system prior to disturbance. Amongst the current research on microclimate in edges, only Broszofske *et al.* (1998) and Sizer and Tanner (1999) investigated the same edges before and after fragmentation, but did not consider concurrent controls.

Ideally, assessments of environmental change should employ a before and after, control and impact (BACI) design (Stewart-Oaten *et al.* 1986, Underwood 1991, Smith *et al.* 1993, Margules *et al.* 1998). Such studies examine the system prior to disturbance at both the proposed impact site and a control, with the degree of change at the former established through the re-measurement of both sites after disturbance. While this is considered a superior approach to environmental monitoring, Underwood (1994) felt it important for a BACI design to employ numerous controls to obtain a solid baseline of background information on the undisturbed system (although see Stewart-Oaten and Bence 2001).

As well as lacking controls of an appropriate spatial extent, many microclimate studies in edges have a limited temporal range. Seasonal differences within a single

year have been compared (e.g. Young and Mitchell 1994, Parry 1997, Saunders *et al.* 1999, Sizer and Tanner 1999), while other research has examined the same season in consecutive years (e.g. Chen *et al.* 1995, Broszofske *et al.* 1997). Many studies however, have data from only a single period (Williams-Linera 1990, Brothers and Spingarn 1992, Matlack 1993, Camargo and Kapos 1995, Jose *et al.* 1996, Cadenasso *et al.* 1997, Didham 1998, Williams-Linera *et al.* 1998, Gehlhausen *et al.* 2000). A clear understanding of the dynamics of an edge requires information on seasonal variability both within the edge and within the undisturbed forest.

This chapter describes a study of seasonal changes in microclimate at both edges and control sites undertaken both before and after logging in a southern Tasmanian wet forest. A similar study related to vegetation changes in the same edge before and after edge creation is described in Chapter 5. There were three specific questions:

1. Is the BACI approach appropriate to the estimation of an edge effect?
2. What changes in microclimate are observed between impact and control transects as a result of edge creation?
3. What seasonal changes in microclimate occur within a young edge?

4.2 Methods

The Warra LTER Silvicultural Systems Trial incorporated a number of coupes at which different logging and/or regeneration regimes were to be investigated (Figure 4.1; Chapter 1). This allowed for the precise timing of logging operations that are otherwise difficult to predict and facilitated the collection of microclimate and vegetation data at the edge of one of the trial coupes both before and after logging.

The Warra 1B coupe on the Manuka Road, labelled Small (Figure 4.1), was established to research the costs and benefits of retained trees on coupe regeneration. To this end, 10 trees per hectare of *Eucalyptus obliqua* were to be left standing at the conclusion of logging. While these trees may have had some buffering affect on the climate in the edge, it was considered that this would be minimal due to the lack of a closed canopy. Nine months before logging, the surveyed line delineating the border of the coupe was used to estimate where the edge (or 0 m) was to be located. This was taken to be the outer canopy edge of the trees nearest the line, but outside of the coupe (Figure 4.2).

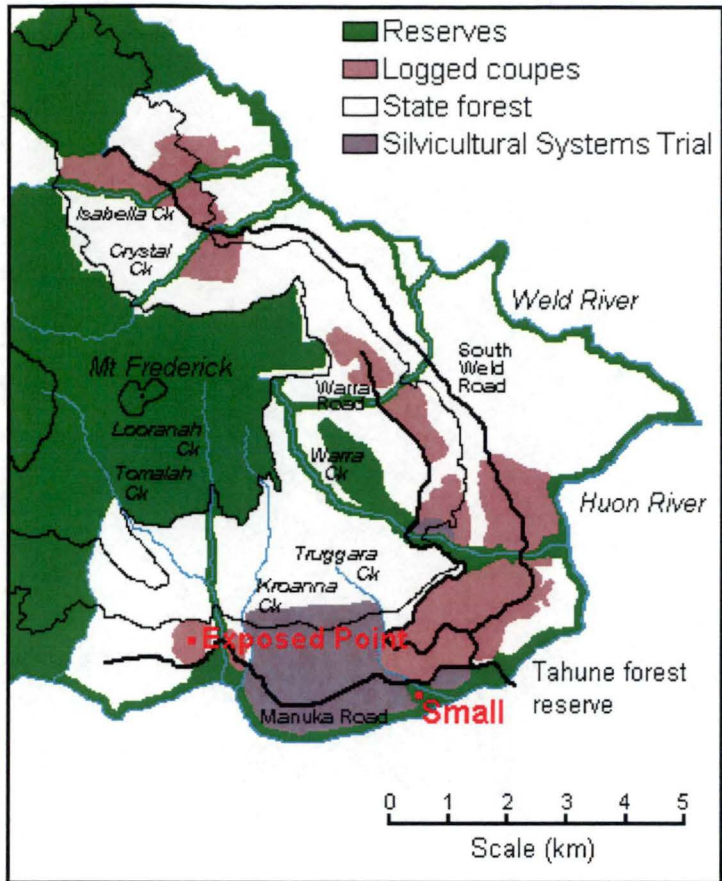


Figure 4.1 - The Warra LTER region showing the position of the Small coupe (Warra 1B) within the Silvicultural Systems Trial where the before and after, control and impact (BACI) survey was undertaken and the Exposed Point (Blakes 1B) where exposed climate data were collected. Map courtesy of Forestry Tasmania.

Prior to logging of the Small coupe, the nearest expanse of open ground from which exposed climate data could be collected was located 2 - 3 km from the BACI site at the centre of a regenerating coupe that was burnt and sown with *Eucalyptus obliqua* in 1998 (Figure 4.1). The geology, slope and pre-logging vegetation of the exposed microclimate measurement point was similar to the BACI site, although the elevation was higher (~ 350 m as apposed to 120 m, see Chapter 1).

At the BACI site, three transects were surveyed perpendicular to the estimated future edge, starting from a random position at least 100 m from any known non-natural disturbance. A further three transects were located in the undisturbed forest starting at least 100 m from the nearest edge (or potential edge) and parallel to the first three transects (Figure 4.2). Two transects in each group of three were 20 m apart and 100 m long, while the third was around 50 m from the others and 50 m long (Figure 4.2). Microclimate data were collected at the 0, 10, 20, 50 and 100 m points (where applicable) on impact transects and 100, 110, 120, 150 and 200 m (again where

applicable) on the controls (Figure 4.2). Control transects were displaced from the impact lines by approximately 100 m.

These distances from the edge and consequently, on the control, were selected based on the number and dispersion of points employed in other microclimate and vegetation studies in edges. The number of transects was limited by logistic concerns, mostly related to the doubling-up of information gathering by use of same number of control points dispersed at the same scale as impact transects. Personal observations suggested that the edge effect would be less than 50 m. However, should the edge effect penetrate further than 100 m it will be detected on the controls (and thus invalidate them as controls). Penetration of an edge effect beyond 200 m (the distance to the end of controls transects from the edge) was considered unlikely.

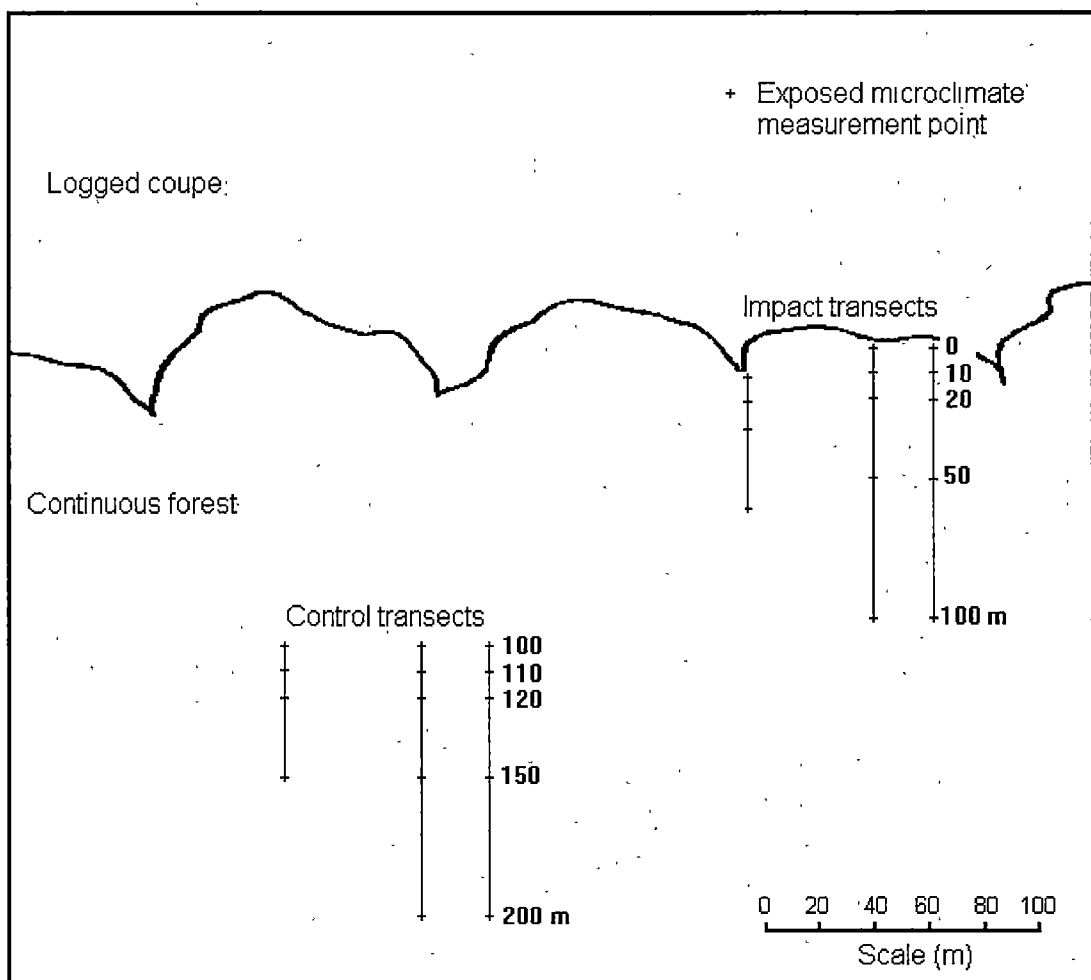


Figure 4.2 - Layout of the control and impact transects and microclimate measurement points relative to the edge of the Small coupe. Note the exposed microclimate measurement point was actually located on the Blakes 1B coupe some ~ 2 km from the BACI site (Figure 4.1).

Thirty Tinytag temperature probes (Gemini Data Loggers (UK) Ltd., Chichester, U.K.) were arranged as in the vertical profile experiment (Chapter 3; Appendix A),

with fifteen modified to act as an indicator of vapour pressure deficit (VPD).

Randomly selected temperature and modified temperature loggers were bolted onto short wooden stakes (~ 0.4 m long) making fifteen “sensor groups” (Figure 4.3).

Eight photosynthetically active radiation (PAR) sensors (Delta-T Quantum Sensors; Delta-T Devices, Cambridge UK) were fixed to the top of eight temperature sensor groups (Figure 4.3) and linked to a Campbell 21X multi-channel data logger (Campbell Scientific, Logan, Utah USA).

Following the results of the vertical survey of microclimate and epiflora (Chapter 3), the sensor groups were placed at 30 cm above the ground (Figure 4.3). Two deployments were required to cover all points at the site. Data were first obtained at the 100 m lines at the impact transects (0, 10, 20, 50 and 100 m points) and a 50 m line in the control area (100, 110, 120 and 150 m), and then the reverse (two 100 m control lines and a 50 m impact line). At the exposed position, a single sensor group was deployed to give an indication of the exposed temperature and humidity. Simultaneous measurements of all six transects was not possible due to the limited number of sensor groups. The eight sensor groups that had PAR sensors were always deployed on the first four points on the 100 m long transects (0, 10, 20 and 50 m or 100, 110, 120 and 150 m). This required the lines to be no more than 20 m apart, otherwise cables from the probes could not reach the Campbell data logger.



Figure 4.3 - One of the fifteen microclimate sensor groups. On the right of the stake is the temperature probe: on the left is the modified probe used to give an indication of VPD (see Appendix A). At the top of the stake (wrapped in red tape) is the PAR sensor.

Data were collected from all sensors at 5 min intervals across deployments lasting 3 - 5 days. Deployments were usually undertaken in the last month of each season from winter 1997 through to autumn 1999 (Table 4.1). Logging of the coupe was finished in April 1998 allowing for three pre-logging surveys over nine months and five post-logging over eighteen months.

Table 4.1 - Microclimate data collection dates at the Small coupe and Exposed Site between the winter of 1997 and autumn of 1999. Logging was completed in the autumn of 1998. Shaded portion represents climate data collected after the edge was created.

Season	Year	Start date	Finish date
Winter	1997	24/07/97	04/08/97
Spring	1997	07/10/97	17/10/97
Summer	1997	15/01/98	23/01/98
Autumn	1998	23/04/98	01/05/98
Winter	1998	09/08/98	17/08/98
Spring	1998	23/11/98	01/12/98
Summer	1998	09/02/99	18/02/99
Autumn	1999	23/05/99	04/06/99

Estimates of VPD were obtained from wet and dry temperature probe data using the formulae in Appendix A. All univariate statistics were calculated using the JMP software (Version 3.1.2, Sas Institute Inc. © 1989 - 1995) with analysis based on the combined data across the two deployments for each season. Analyses between seasons were not possible owing to a lack of independence. Significant Analyses of Variance (ANOVA) results were clarified using Tukey-Kramer Honestly Significant Difference (HSD) tests comparing all distances. As the aim of the study was to observe gradients across distances between the impact and control transects, a pairwise comparison between points was considered inappropriate.

As with the vertical microclimate survey (Chapter 3), PAR data were often incomplete. This was due to a combination of data logger failure and/or sensor problems, the latter due to small mammals chewing on the wiring. The average hourly maximal non-zero (i.e. daytime) PAR was used in analyses. This alleviated some of the problems with missing data.

4.3 Results

4.3.1 Photosynthetically active radiation

Seasonal changes in PAR were the dominant feature irrespective of edge creation (Figure 4.4). Prior to logging, there was a pattern of higher light intensity and variability observed around the 20 and 120 m points in most seasons (Figure 4.4). In

the winter of 1997, the 120 m point ($31 \mu\text{mol m}^{-2} \text{s}^{-1}$) was significantly different from all distances except 20 m ($18 \mu\text{mol m}^{-2} \text{s}^{-1}$ Table 4.2; Table 4.3). In the spring of 1997, these peaks appeared to shift toward the beginning of transects with $23 \mu\text{mol m}^{-2} \text{s}^{-1}$ recorded at 0 m and $34 \mu\text{mol m}^{-2} \text{s}^{-1}$ at 110 m, which was significantly different from 150 m (Table 4.2; Table 4.3). In the following summer, the 20 and 120 m peaks returned (41 and $33 \mu\text{mol m}^{-2} \text{s}^{-1}$ respectively), but there was a high degree of variability at both points and no significant differences (Table 4.2).

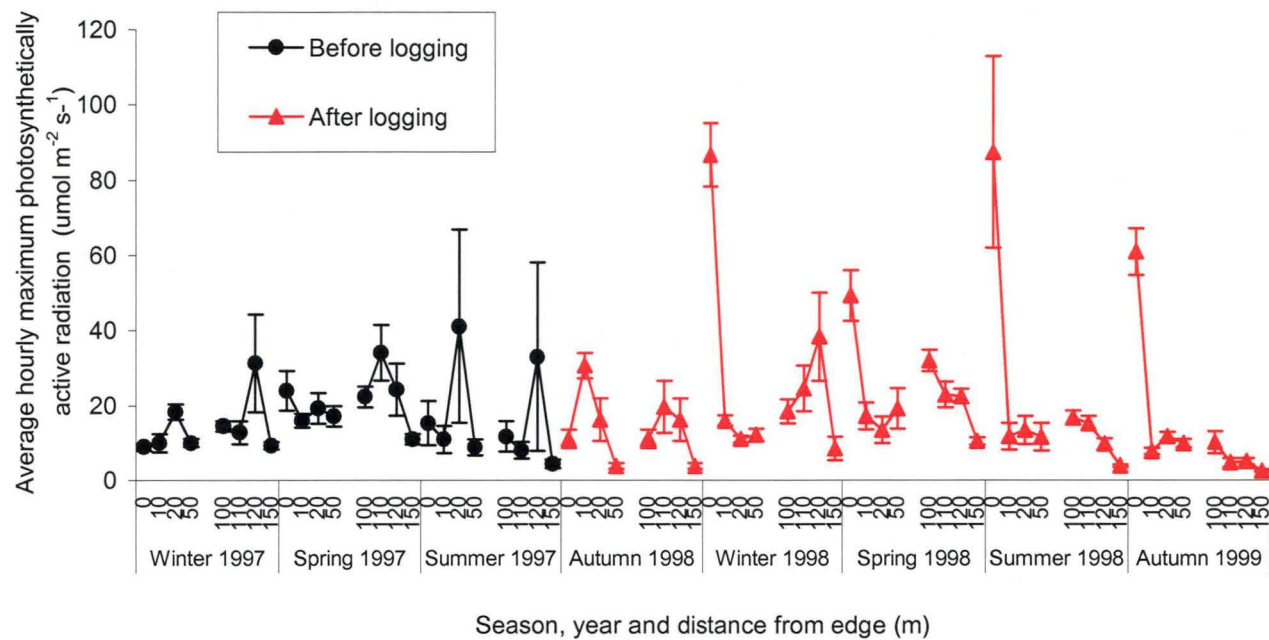


Figure 4.4 - The average hourly maximum PAR collected seasonally at the impact (0 - 50 m) and control transects (100 - 150 m) in each season from winter 1997 to summer 1997 (pre-logging - black) and from autumn 1998 to the autumn of 1999 (after logging - red). Bars are standard error.

Table 4.2 - Analyses of variance (ANOVA) of the average hourly maximum PAR across distances within each season. Shading indicates post-logging deployments. NS = not significant, * = significant ($P < 0.05$), ** = very significant ($P < 0.01$), *** = highly significant ($P < 0.001$).

PAR	DF	MS	MS Error	F Ratio	Prob.>F	Significance
Winter 1997	7	1346.76	426.52	3.1576	0.003	**
Spring 1997	7	2092.29	1015	2.0614	0.046	*
Summer 1997	7	17.92.45	2098.08	0.8543	0.547	NS
Autumn 1998	7	901.53	154.924	5.8192	0.000	***
Winter 1998	7	40427.4	1704.1	23.724	0.000	***
Spring 1998	7	9484.69	888.58	10.674	0.000	***
Summer 1998	7	8006.57	470.11	17.0314	0.000	***
Autumn 1999	7	15923	408.5	38.9811	0.000	***

Apart from the first deployment after logging (autumn 1998), there is an obvious shift in the PAR environment at the 0 m point of the newly exposed edge (Figure 4.4). In spite of no apparent response to fragmentation in autumn 1998, there were still significant differences between distances with the peak irradiance at 10 m

(30 $\mu\text{mol m}^{-2} \text{s}^{-1}$), distinct from the 0, 50, 100 and 150 m points (Table 4.2; Table 4.4). This matches similar peaks observed around this distance prior to logging (Figure 4.4).

Table 4.3 - Tukey-Kramer HSD test for differences in average hourly maximum PAR between distances within each season before logging. Shaded headings indicate control transects, NS = not significant, “+” = significant.

Winter 1997		0	10	20	50	100	110	120	150
0	NS								
10	NS	NS							
20	NS	NS	NS						
50	NS	NS	NS	NS					
100	NS	NS	NS	NS	NS				
110	NS	NS	NS	NS	NS	NS	NS		
120	+	+	NS	+	+	+	+	NS	
150	NS	NS	NS	NS	NS	NS	NS	+	NS
Spring 1997		0	10	20	50	100	110	120	150
0	NS								
10	NS	NS							
20	NS	NS	NS						
50	NS	NS	NS	NS					
100	NS	NS	NS	NS	NS				
110	NS	NS	NS	NS	NS	NS	NS		
120	NS	NS	NS	NS	NS	NS	NS	NS	
150	NS	NS	NS	NS	NS	NS	+	NS	NS

The winter 1998 deployment had a substantial peak at 0 m (87 $\mu\text{mol m}^{-2} \text{s}^{-1}$; Figure 4.4) which was significantly different from all distances (Table 4.2; Table 4.4) that were otherwise within the range of PAR levels observed prior to logging and on the controls after (Figure 4.4). A second peak on the control at 120 m (38 $\mu\text{mol m}^{-2} \text{s}^{-1}$) was also significantly different from the 20 m value (Table 4.2; Table 4.4).

The spring of 1998 had a more muted response to edge creation compared to most other post logging deployments, possibly due to the solar angle at that time of year (Figure 4.4). However, the peak at 0 m (49 $\mu\text{mol m}^{-2} \text{s}^{-1}$) was significantly different from all other distances (Table 4.2; Table 4.4). As with the pre-logging spring deployment, the peak on the control (32 $\mu\text{mol m}^{-2} \text{s}^{-1}$) shifted closer to the edge and was significantly different from 20 and 150 m (Table 4.2; Table 4.4). Large peaks in PAR occurred at 0 m in the summer 1998 and autumn 1999 deployments (87 and 61 $\mu\text{mol m}^{-2} \text{s}^{-1}$ respectively; Figure 4.4). Both peaks were significantly different from all other distances within their respective deployments (Table 4.2; Table 4.4) and there was little indication of changes on controls in either season (Figure 4.4).

Table 4.4 - Tukey-Kramer HSD test for differences in average hourly maximum PAR between distances within each season after logging. Shaded headings indicate control transects, NS = not significant, “+” = significant.

Autumn 1998									
	0	10	20	50	100	110	120	150	
0	NS								
10	+	NS							
20	NS	NS	NS						
50	NS	+	NS	NS					
100	NS	+	NS	NS	NS				
110	NS	NS	NS	NS	NS	NS			
120	NS	NS	NS	NS	NS	NS	NS		
150	NS	+	NS	NS	NS	NS	NS	NS	NS
Winter 1998									
	0	10	20	50	100	110	120	150	
0	NS								
10	+	NS							
20	+	NS	NS						
50	+	NS	NS	NS					
100	+	NS	NS	NS	NS				
110	+	NS	NS	NS	NS	NS			
120	+	NS	+	NS	NS	NS	NS		
150	+	NS	NS	NS	NS	NS	NS	NS	NS
Spring 1998									
	0	10	20	50	100	110	120	150	
0	NS								
10	+	NS							
20	+	NS	NS						
50	+	NS	NS	NS					
100	+	NS	+	NS	NS				
110	+	NS	NS	NS	NS	NS			
120	+	NS	NS	NS	NS	NS	NS		
150	+	NS	NS	NS	+	NS	NS	NS	NS
Summer 1998									
	0	10	20	50	100	110	120	150	
0	NS								
10	+	NS							
20	+	NS	NS						
50	+	NS	NS	NS					
100	+	NS	NS	NS	NS				
110	+	NS	NS	NS	NS	NS			
120	+	NS	NS	NS	NS	NS	NS		
150	+	NS	NS	NS	NS	NS	NS	NS	NS
Autumn 1999									
	0	10	20	50	100	110	120	150	
0	NS								
10	+	NS							
20	+	NS	NS						
50	+	NS	NS	NS					
100	+	NS	NS	NS	NS				
110	+	NS	NS	NS	NS	NS			
120	+	NS	NS	NS	NS	NS	NS		
150	+	NS	NS	NS	NS	NS	NS	NS	NS

4.3.2 Minimum temperature

Minimum temperature differences between distances approached the level of accuracy that the probes can measure (see Appendix B) and thus any gradients must be viewed with caution.

Seasonal differences are the most obvious response irrespective of edge creation, ranging from ~ 1.3 °C in winter 1998 to ~ 14.6 °C in the summer of the same year (Figure 4.5). Variation in the average minimum temperature was roughly the same within each season, but appeared to increase in warmer periods (Figure 4.5). Significant differences were restricted to the summer 1997 (prior to logging) with the 200 m (12.1 °C) significantly larger than both the impact 100 m value and the exposed minimum (7.6 °C) was significantly lower than the 120 m point (Table 4.5; Table 4.6). All of which suggest that significant differences in this parameter need not be edge-related, but do indicate something of the strength of canopy buffering. Other pre-logging deployments suggested little difference between distances, with ~ 4 °C across all points in winter 1997 and from 4.1 °C - 5.8 °C in the following spring (Figure 4.5).

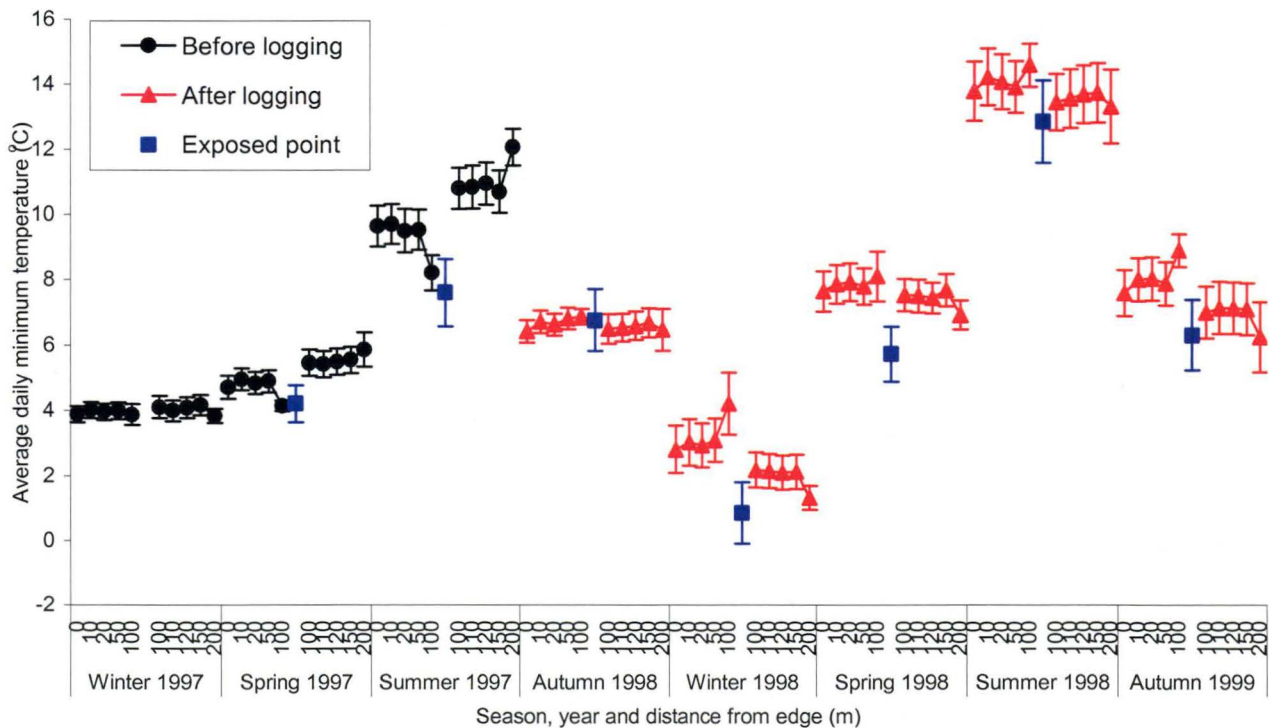


Figure 4.5 - Average daily minimum temperature at each distance (0 – 100 = impact transects, 100 – 200 = controls) in each season from winter 1997 to summer 1997 (pre-logging - black) and from autumn 1998 to the autumn of 1999 (after logging - red). Bars are standard error.

Table 4.5 - ANOVA of the average daily minimum temperature across distances within each microclimate deployment. Shading indicates post-logging deployments. NS = not significant, ** = very significant (P < 0.01).

Minimum temp.	DF	MS	MS Error	F Ratio	Prob.>F	Significance
Winter 1997	9	0.16435	1.38981	0.1183	0.9992	NS
Spring 1997	10	4.33236	2.4888	1.7407	0.0754	NS
Summer 1997	10	18.3156	5.9757	3.065	0.0015	**
Autumn 1998	10	0.27179	2.74762	0.0989	0.9998	NS
Winter 1998	10	8.71744	5.57094	1.5648	0.1233	NS
Spring 1998	10	5.2661	16.9312	0.311	0.9786	NS
Summer 1998	10	2.4989	13.538	0.19	0.9989	NS
Autumn 1999	10	9.674	11.3668	0.8511	0.5801	NS

Table 4.6 - Tukey-Kramer HSD test for differences in average daily minimum temperature between distances within summer 1997. Shaded headings indicate control transects, NS = not significant, "+" = significant.

Summer 1997											
	0	10	20	50	100	100	110	120	150	200	Exposed
0	NS										
10	NS	NS									
20	NS	NS	NS								
50	NS	NS	NS	NS							
100	NS	NS	NS	NS	NS						
100	NS	NS	NS	NS	NS	NS					
110	NS	NS	NS	NS	NS	NS	NS				
120	NS	NS	NS	NS	NS	NS	NS	NS			
150	NS	NS	NS	NS	NS	NS	NS	NS	NS		
200	NS	NS	NS	NS	+	NS	NS	NS	NS	NS	
Exposed	NS	NS	NS	NS	NS	NS	NS	+	NS	+	NS

After logging, the average minimum temperature increased with distance from the edge on impact transects and decreased with distance on most controls (Figure 4.5). There were, however, no significant changes in the average daily minimum temperature with distance across any of the post-disturbance deployments (Table 4.5). Increases relative to the edge were often small and well within the range of differences observed prior to logging. Controls were generally stable within each season, but with a slight decline in average minima at 200 m in all post-logging deployments. Exposed points were generally cooler than all other distances within each season except for autumn 1998 and 1999 (Figure 4.5).

Minimum temperature did not appear to be influenced by creation of an edge with changes (both significant and otherwise) across distances likely to be a response to changes in slope (Figure 4.6) and possibly vegetation structure (Chapter 5). The Small site mostly runs downhill with increasing distance, but is steeper on the earlier portion of the impact lines and dips slightly (~ 50 m) before the flatter controls before declining again on approaching the Truggara Creek (Figure 4.1; Figure 4.6). The change in aspect and overall downhill slope may promote the pooling of cooler

air as it passes downhill along the gully formed by the creek toward the Huon River (Figure 4.1).

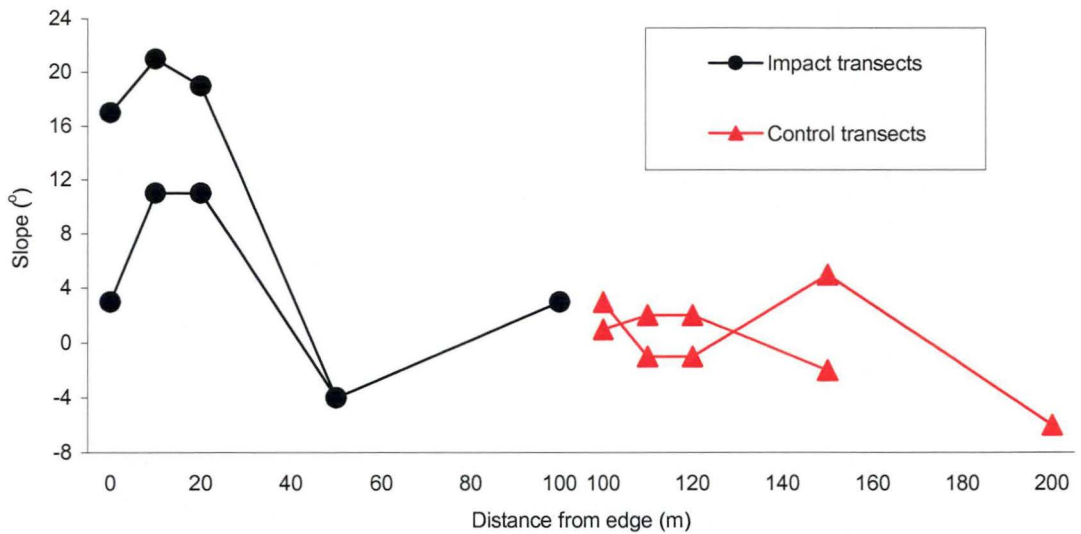


Figure 4.6 - Slope recorded between the 100 m transects and along the 50 m transects at each of the impact (black) and controls (red) at the edge of Small.

4.3.3 Maximum temperature

As with the minimum temperature, seasonal differences between deployments were predominant. However, the average daily maximum temperature was considerably more dynamic, with larger variation both within and between distances (Figure 4.7), with both control and impact transects indicating gradients in average daily maximum temperature in the absence of logging (Figure 4.7).

Before creation of the edge, maximum average temperature generally declined across both impact and control transects (Figure 4.7). There was substantial evidence of canopy buffering, although there were no exposed data from winter 1997, and the only significant differences prior to logging were in the spring of 1997 where the exposed (15.3 °C) was significantly different from all impact transect distances except 0 m (Table 4.7; Table 4.8). This may be counter the detection of edge effects, as it suggests that the 0 m point in the undisturbed forest is already similar to exposed levels.

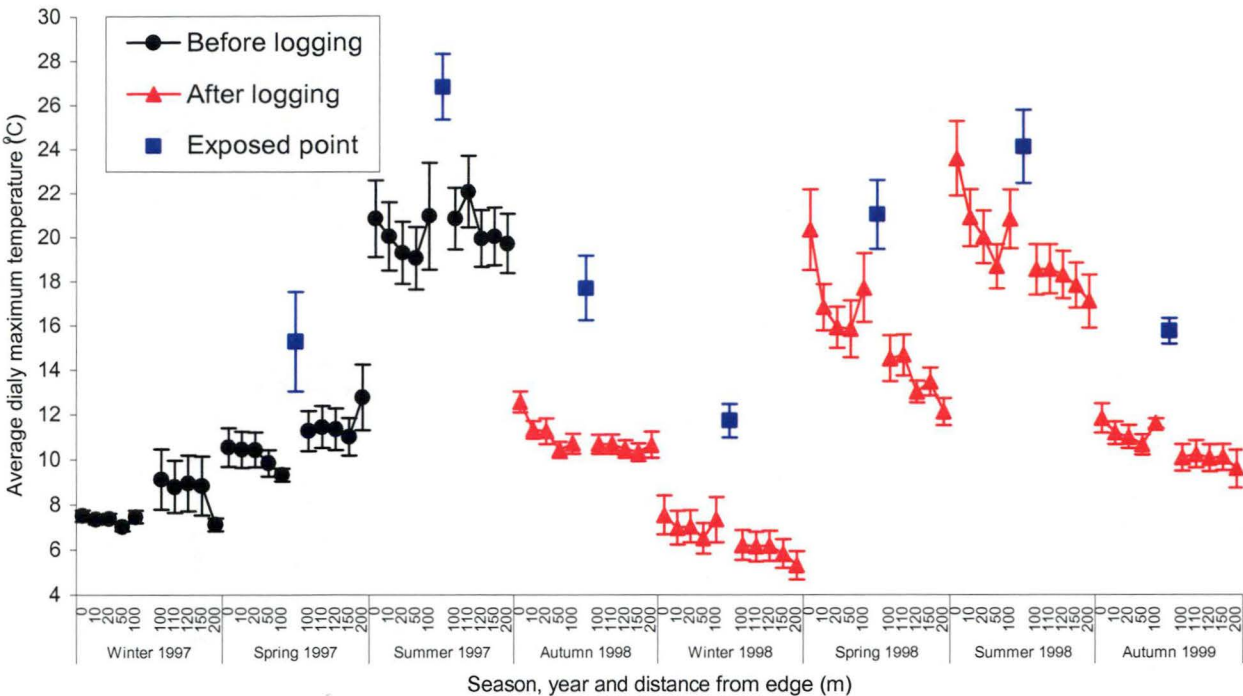


Figure 4.7 - Average daily maximum temperature at each distance (0 – 100 = impact transects, 100 – 200 = controls) from winter 1997 to summer 1997 (pre-logging - black) and from autumn 1998 to the autumn of 1999 (after logging - red). N = 3 – 5, bars are standard error.

Table 4.7 - ANOVA of the average daily maximum temperature across distances within each microclimate deployment. Shading indicates post-logging deployments. NS = not significant, * = significant (P < 0.05), *** = highly significant (P < 0.001).

Maximum temp.	DF	MS	MS Error	F Ratio	Prob.>F	Significance
Winter 1997	9	12.0728	11.5109	1.0488	0.404	NS
Spring 1997	10	33.4753	15.7356	2.1274	0.025	*
Summer 1997	10	50.6955	32.8171	1.5448	0.13	NS
Autumn 1998	10	48.834	4.0033	12.1885	0.000	***
Winter 1998	10	31.7081	7.0823	4.4771	0.000	***
Spring 1998	10	101.073	17.842	5.665	0.000	***
Summer 1998	10	72.8664	23.289	3.1288	0.001	***
Autumn 1999	10	43.2299	6.4635	6.6883	0.000	***

Table 4.8 - Tukey-Kramer HSD test for differences in average daily maximum temperature between distances within spring 1997 (see related ANOVA table). Shaded headings indicate control transects, NS = not significant, “+” = significant.

Spring 1997											
	0	10	20	50	100	100	110	120	150	200	Exposed
0	NS										
10	NS	NS									
20	NS	NS	NS								
50	NS	NS	NS	NS							
100	NS	NS	NS	NS	NS						
100	NS	NS	NS	NS	NS	NS					
110	NS	NS	NS	NS	NS	NS	NS				
120	NS	NS	NS	NS	NS	NS	NS	NS			
150	NS	NS	NS	NS	NS	NS	NS	NS	NS		
200	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	
Exposed	NS	+	+	+	+	NS	NS	NS	NS	NS	NS

There were substantial differences across impact transects however, as with minimum temperatures, differences in temperature must be viewed with caution given that many are within the limits of probe accuracy (see Appendix B). In the summer 1997 deployments, there was a decline across most impact distances (20.9 - 19.1 °C) before increasing at 100 m (21 °C). On the controls, maximum temperatures increased (20.8 - 22.1 °C) before declining at 200 m (19.7 °C) while the exposed maximum temperature was 26.8 °C (Figure 4.7). These differences are likely to be in response to differences in slope and aspect (Figure 4.6) and vegetation structure (see Chapter 5) similar to minimum temperatures. The summer 1997 survey was important in that it indicated a considerable degree of variation in the undisturbed forest maximum temperatures and a natural gradient across the impact transects. This suggests that those gradients observed at the edge after logging (see below) are not entirely edge-related and is thus a strong affirmation of the advantages of the BACI approach.

After logging, gradients relative to the edge were most apparent through the expansion of the pre-existing maximum temperature gradient such that the 0 m point was very similar to the exposed level (Figure 4.7). This was particularly apparent in the spring and summer of 1998, where the difference between average maxima at 0 m and the exposed point was < 1 °C, compared to ~ 5 - 6 °C in the spring and summer of 1997 before logging (Figure 4.7). Significant differences in the spring deployment support this view, with the 0 m temperature (20.3 °C) and the exposed maximum temperature (21 °C) both significantly different from all control measurements (Table 4.7; Table 4.9). In the summer, both the 0 m point (23.6 °C) and the exposed average (24.1 °C) were significantly different from the 150 and 200 m points (Table 4.7; Table 4.9). In both seasons, however, the range of maximum temperatures was within the span of those that occurred in summer 1997 (Figure 4.7). This suggests that, while the maximum temperature edge effect at these sites was within natural ranges and less likely to influence the biota in the edge, extreme exposed conditions are likely to be un-buffered at the edge and may induce changes in the flora and fauna.

These changes correspond to differences observed in PAR at 0 m (see above). The decrease in temperature buffering at the edge may thus be a response to the increased

Table 4.9 - Continued.

Autumn 1999	0	10	20	50	100	100	110	120	150	200	Exposed
0	NS										
10	NS	NS									
20	NS	NS	NS								
50	NS	NS	NS	NS							
100	NS	NS	NS	NS	NS						
100	NS	NS	NS	NS	NS	NS					
110	NS	NS	NS	NS	NS	NS	NS				
120	NS	NS	NS	NS	NS	NS	NS	NS			
150	NS	NS	NS	NS	NS	NS	NS	NS	NS		
200	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	
Exposed +	+	+	+	+	+	+	+	+	+	+	NS

Other post-logging deployments were less pronounced in terms of an edge response, with perhaps shallow edge gradients in autumn 1998 and 1999, but very little indication in winter 1998 (Figure 4.7). Most responses were well within the ranges observed in other seasons. Exposed differences within each of these surveys supported this notion, with the exposed point average maxima significantly higher than all other distances (Table 4.7; Table 4.9). This suggests a degree of canopy buffering even in the presence of the edge.

4.3.4 Vapour pressure deficit

In the colder seasons, as well as the spring of 1997, there was little response in average daily maximum vapour pressure deficit (VPD), with values generally less than 0.1 kPa regardless of the distance or presence of the edge (Figure 4.8). Significant differences between exposed points and all other distances occurred in the spring 1997, autumn 1998 and 1999 surveys, and all points except 50 m in winter 1998 (Table 4.10; Table 4.11; Table 4.12). While this indicates strong canopy buffering it also suggests that once an area of forest is waterlogged, it will register close to zero regardless of exposed changes until there is an opportunity to dry out. This was supported in the autumn 1999 deployment, where the 20 m point was significantly different from 0 and 100 m (Table 4.12), which reflects very low variation within the deployment rather than differences between distances. No data were obtained at the exposed point for the winter 1997 survey and there were no significant differences (Table 4.10).

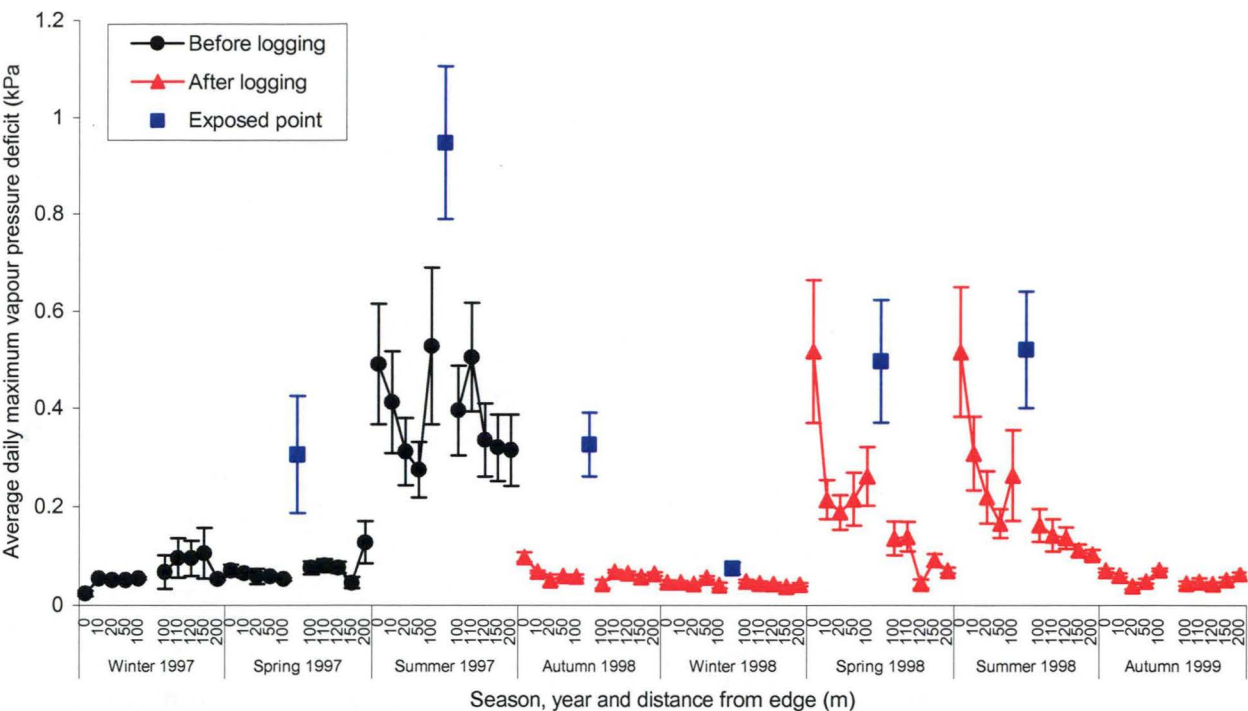


Figure 4.8 - Average daily maximum VPD at each distance (0 – 100 = impact transects, 100 – 200 = controls) from winter 1997 to summer 1997 (pre-logging - black) and from autumn 1998 to the autumn of 1999 (after logging - red). N = 3 – 5, errors are standard error.

Table 4.10 - ANOVA of the average daily maximum VPD across distances within each microclimate deployment. Shading indicates post-logging deployments. NS = not significant, * = significant (P < 0.05), ** = very significant (P < 0.01), *** = highly significant (P < 0.001).

Maximum VPD	DF	MS	MS Error	F Ratio	Prob.>F	Significance
Winter 1997	9	0.0116	0.0115	1.0087	0.435	NS
Spring 1997	10	0.0683	0.0143	4.7702	0.000	***
Summer 1997	10	0.3955	0.1347	2.936	0.002	**
Autumn 1998	10	0.0669	0.0033	19.944	0.000	***
Winter 1998	10	0.0011	0.0003	4.3633	0.000	***
Spring 1998	10	0.3238	0.0573	5.6484	0.000	***
Summer 1998	10	0.3168	0.0559	5.6633	0.000	***
Autumn 1999	10	0.0161	0.0008	20.116	0.000	***

The average daily maximum VPD in the summer of 1997 was similar to the maximum temperature in the same season, with a decreasing gradient across most of the impact transects (0.49 to 0.27 kPa from 0 to 50 m with 0.53 kPa at 100 m; Figure 4.8). The controls ranged from 0.31 to 0.5 kPa, while the exposed was 0.95 kPa (Figure 4.8), which was significantly different from all distances except the impact 100 m and 110 m points (Table 4.10; Table 4.11). Such differences confirm not only a considerable degree of buffering by the forest canopy, but also the capacity for substantial gradients in average daily maximum VPD in undisturbed forests in warmer periods, and that trends observed after logging are not entirely edge-related.

Table 4.11 - Tukey-Kramer HSD tests for differences in average daily maximum VPD between distances within spring and summer 1997 (see related ANOVA table). Shaded headings indicate control transects, NS = not significant, “+” = significant.

Spring 1997											
	0	10	20	50	100	100	110	120	150	200	Exposed
0	NS										
10	NS	NS									
20	NS	NS	NS								
50	NS	NS	NS	NS							
100	NS	NS	NS	NS	NS						
100	NS	NS	NS	NS	NS	NS					
110	NS	NS	NS	NS	NS	NS	NS				
120	NS	NS	NS	NS	NS	NS	NS	NS			
150	NS	NS	NS	NS	NS	NS	NS	NS	NS		
200	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	
Exposed	+	+	+	+	+	+	+	+	+	+	NS
Summer 1997											
	0	10	20	50	100	100	110	120	150	200	Exposed
0	NS										
10	NS	NS									
20	NS	NS	NS								
50	NS	NS	NS	NS							
100	NS	NS	NS	NS	NS						
100	NS	NS	NS	NS	NS	NS					
110	NS	NS	NS	NS	NS	NS	NS				
120	NS	NS	NS	NS	NS	NS	NS	NS			
150	NS	NS	NS	NS	NS	NS	NS	NS	NS		
200	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	
Exposed	NS	+	+	+	NS	+	NS	+	+	+	NS

The spring and summer of 1998 (after logging) indicated strong gradients in average daily maximum VPD relative to the edge (Figure 4.8). In the spring, these began at 0.52 kPa at 0 m relative to from 0.19 – 0.26 kPa across other distances. The 0 m value was significantly different from all other distances except the exposed and 100 m points (Table 4.10; Table 4.12). The control VPD averages were lower, ranging from 0.04 - 0.14 kPa (Figure 4.8). The exposed measure was actually slightly lower than the 0 m value (0.5 kPa) and was significantly different from all control distances (Table 4.10; Table 4.12).

In summer 1998, the edge gradient started with 0.52 kPa at the edge and declined to from 0.17 - 0.31 kPa across other distances while the controls ranged from 0.1 to 0.16 kPa (Figure 4.8). The exposed maximum VPD average (0.52 kPa) was significantly different from all control distances, as well as 50 m on the impact transects (Table 4.10; Table 4.12). The 0 m value was also significantly different from all other distances except 10 m, 100 m, and the exposed point (Table 4.10; Table 4.12)

Table 4.12 - Tukey-Kramer HSD tests for differences in average daily maximum VPD between distances within each season after logging (see related ANOVA table). Shaded headings indicate control transects, NS = not significant, "+" = significant.

Autumn 1998											
	0	10	20	50	100	100	110	120	150	200	Exposed
0	NS										
10	NS	NS									
20	NS	NS	NS								
50	NS	NS	NS	NS							
100	NS	NS	NS	NS	NS						
100	NS	NS	NS	NS	NS	NS					
110	NS	NS	NS	NS	NS	NS	NS				
120	NS	NS	NS	NS	NS	NS	NS	NS			
150	NS	NS	NS	NS	NS	NS	NS	NS	NS		
200	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	
Exposed	+	+	+	+	+	+	+	+	+	+	NS
Winter 1998											
	0	10	20	50	100	100	110	120	150	200	Exposed
0	NS										
10	NS	NS									
20	NS	NS	NS								
50	NS	NS	NS	NS							
100	NS	NS	NS	NS	NS						
100	NS	NS	NS	NS	NS	NS					
110	NS	NS	NS	NS	NS	NS	NS				
120	NS	NS	NS	NS	NS	NS	NS	NS			
150	NS	NS	NS	NS	NS	NS	NS	NS	NS		
200	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	
Exposed	+	+	+	NS	+	+	+	+	+	+	NS
Spring 1998											
	0	10	20	50	100	100	110	120	150	200	Exposed
0	NS										
10	+	NS									
20	+	NS	NS								
50	+	NS	NS	NS							
100	NS	NS	NS	NS	NS						
100	+	NS	NS	NS	NS	NS					
110	+	NS	NS	NS	NS	NS	NS				
120	+	NS	NS	NS	NS	NS	NS	NS			
150	+	NS	NS	NS	NS	NS	NS	NS	NS		
200	+	NS	NS	NS	NS	NS	NS	NS	NS	NS	
Exposed	NS	NS	NS	NS	NS	+	+	+	+	+	NS
Summer 1998											
	0	10	20	50	100	100	110	120	150	200	Exposed
0	NS										
10	NS	NS									
20	+	NS	NS								
50	+	NS	NS	NS							
100	NS	NS	NS	NS	NS						
100	+	NS	NS	NS	NS	NS					
110	+	NS	NS	NS	NS	NS	NS				
120	+	NS	NS	NS	NS	NS	NS	NS			
150	+	NS	NS	NS	NS	NS	NS	NS	NS		
200	+	NS	NS	NS	NS	NS	NS	NS	NS	NS	
Exposed	NS	NS	NS	+	NS	+	+	+	+	+	NS

Table 4.12 – Continued.

Autumn 1998		0	10	20	50	100	100	110	120	150	200	Exposed
0	NS											
10	NS	NS										
20	+	NS	NS									
50	NS	NS	NS	NS								
100	NS	+	NS	NS	NS							
100	NS	NS	NS	NS	NS	NS						
110	NS	NS	NS	NS	NS	NS	NS					
120	NS	NS	NS	NS	NS	NS	NS	NS	NS			
150	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS		
200	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	
Exposed	+	+	+	+	+	+	+	+	+	+	+	NS

The results from both spring and summer of 1998 indicate that the canopy buffering observed prior to logging has been reduced or eliminated within a narrow strip near the edge. The differences observed in both seasons were, however, within the ranges observed in the preceding summer (before logging) when the exposed conditions were driest, which suggests the capacity for larger and more influential gradients under similar conditions.

4.4 Discussion

The creation of an edge caused a major change in the PAR regime within 10 m of the edge whereafter differences were within the range of variability observed on the controls and both transect type prior to logging. The lack of response in the first deployment after logging (autumn 1998) was possibly due to either an overall lack of light or a lag period before canopy damage as a result of adjacent logging, which was manifest in subsequent foliage losses. Variation in PAR on both control and impact transects indicated something of the natural patchiness and complexity in canopy structure. Changes in the position of peaks are likely to reflect seasonal differences in the amount and angle of incident PAR. The apparent loss of peaks on the impact transects after logging indicated changes in canopy structure due to damage or even changes in the position of whole trees which had been pushed over by adjacent logging (see Chapter 5).

None of the changes apparent in either average daily maximum or minimum temperature prior to logging corresponds to the light climate over the same distances. This is in accord with the results of the vertical profile survey (Chapter 3), where the light regime near ground level was not directly translatable to temperature and VPD levels within the forest. Temperatures under the canopy appeared to correlate more

with the exposed conditions and were thus more indirectly related to the PAR regime. While the canopy offers a substantial buffering effect, warmer exposed conditions promote higher temperatures within the forest, allowing a larger range across which gradients can form.

In terms of both average daily maximum temperature and VPD, creation of the edge resulted in a loss of canopy buffering at the 0 m points. These changes correlated with the PAR regime and thus support the notion that exposure to direct light is a primary factor in other microclimate changes in edges. This supports other literature (Kapos 1989, Matlack 1993, Chen *et al.* 1995). However, the best expression of edge effects was during warmer seasons, a feature also observed in other studies, where seasonal information was collected (e.g. Young and Mitchell 1994, Parry 1997). However, many of the observed gradients approached the level of accuracy of the temperature probes. This was particularly the case for minimum temperatures. Higher PAR at the edge in winter 1998 and autumn 1999 had little apparent influence on either maximum temperature or VPD. This may be due to the damp conditions in cooler seasons acting to buffer the influence of increased light, as the VPD will remain close to zero under saturated conditions, regardless of the exposed level. Temperatures may be similarly unaltered until the edge begins to dry.

Edge effects at the Small coupe within 15 months of creation appear limited to warmer seasons and to a comparatively shallow depth (< 10 m). These effects may have little influence on biota in the edge except under extreme exposed conditions, as the changes observed in both maximum temperature and VPD were within the natural ranges observed prior to logging. The vegetative response to microclimate changes in the edge may thus depend on the frequency and severity of extremes of temperature and VPD rather than the observed differences in the mean (*sensu* Gaines and Denny 1993).

The penetration of microclimate changes as estimated in this study (less than 10 m) is in line with the 2.5 to 10 m penetration reported by Williams-Linera (1990) in a Panamanian tropical premontane wet forest, as well as the 8 m recorded by Brothers and Spingarn (1992) in deciduous forests in Indiana. This distance was, however, considerably less than the 30 to 240 m recorded from Douglas-fir forests in the western USA (Chen *et al.* 1995). Within other microclimate studies of edge effects, the distances range from 12 m (Renhorn *et al.* 1997), 15 m (Broszofske *et al.* 1997),

15 – 30 m (Jose *et al.* 1996), 30 m (Turton and Freiburger 1997), 40 m (Williams-Linera *et al.* 1998, Saunders *et al.* 1999), 50 m (Young and Mitchell 1994, Matlack 1993, Sizer and Tanner 1999), 40 – 80 m (Camargo and Kapos 1995), 80 m (Gehlhausen *et al.* 2000) and 68 – 100 m (Parry 1997). Generally, the penetration appears to be within 50 m, however, the variation within and between studies is considerable (Murcia 1995).

Variability in edge penetration distances is partly due to aspect (Matlack 1993, Young and Mitchell 1994, Murcia 1995, Parry 1997, Turton and Freiburger 1997, Cadenasso *et al.* 1997, Gehlhausen *et al.* 2000). In the Northern Hemisphere, edge effects are most apparent on edges with a southern aspect (Matlack 1993), with the opposite in the Southern Hemisphere (Young and Mitchell 1994, Parry 1997, Turton and Freiburger 1997). While increased sun exposure is considered the determining factor, Camargo and Kapos (1995) and Chen *et al.* (1995) suggested that the direction of prevailing wind relative to the edge was of high importance. Exposure of this edge at Small was to the southwest, which is a poor direction for the estimation of edge effects in the Southern Hemisphere in terms of differences in PAR and temperature, and may explain the low penetration estimate at the site. The southwest was, however, the prevailing weather direction in terms of wind, rain and snow. More replication of aspect and the consideration of other aspects is required before more generalised conclusions can be drawn. This problem is common to many edge effect studies (Murcia 1995).

Variation between studies may also be due to the criteria used to estimate the edge effect. In this study, the edge effect has been examined in the context of the pre-logging system and at undisturbed controls. The edge effect has thus been thought to be relevant only where it is distinct from background variation relative to the exposed conditions outside the forest. Other research operates on a similar principle, but with less information on background variability, there may be a tendency to overestimate the penetration of an edge effect, especially for those studies lacking controls over the same scales as impact transects (Williams-Linera 1990, Matlack 1993, Malcolm 1994, Chen *et al.* 1995, Jose *et al.* 1996, Renhorn *et al.* 1997, Turton and Freiburger 1997). A few studies apply various models or indices against which real data can be compared (e.g. Laurance and Yensen 1991, Chen *et al.* 1993,

Malcolm 1994, Parry 1997, Malcolm 1998). These also generally lack a sufficient level of control.

The degree of microclimate edge effect also varies substantially according to forest type, the form of the adjacent exposed area, the time of day and the time of year (Ranney *et al.* 1981, Williams-Linera 1990, Malcolm 1994, Chen *et al.* 1995, Murcia 1995).

In the absence of pre-logging seasonal data, the changes in both maximum temperature and VPD observed at the edge might have been entirely attributed to edge effects (although bearing mind the limits on the accuracy of the temperature probes), as there were natural gradients in temperature and VPD across the site, probably in response to slope and vegetation changes. This proves to be a strong affirmation of the Before and After, Control and Impact (BACI) design employed in this study.

BACI designs were first proposed by Green (1979) and have been a popular approach to environmental impact assessment ever since (Stewart-Oaten *et al.* 1986, Underwood 1991, Smith *et al.* 1993). In its simplest form, the BACI approach incorporates a single control and impact site examined either side of the impact period (Green 1979). However, Stewart-Oaten *et al.* (1986), Underwood (1991), Smith *et al.* (1993) and Underwood (1994) suggest that this approach, while an improvement over prior methodologies, is flawed in that there is still insufficient sampling on both temporal and spatial scales.

Stewart-Oaten *et al.* (1986) proposed an expanded version of the BACI approach, whereby the control and impact sites are observed at randomly spaced intervals both before and after the impact. This allows an indication of natural patterns of change through time to be incorporated into the results of both the before and after surveys. Environmental change is thus estimated in terms of an alteration of the dynamics of the impact site rather than simple differences from the control.

Underwood (1991, 1994) acknowledged that the Stewart-Oaten *et al.* (1986) approach was an improvement, but proposed that a further expansion of the method was required as differences between control and impact sites detected by either the Green (1979) or Stewart-Oaten *et al.* (1986) methods are still only correlative. Underwood (1991, 1994) suggested that the use of multiple controls, sampled at

random intervals before and after disturbance, was the most effective approach to establishing a causal link between changes in dynamics at the impact site relative to the patterns of change at the various controls.

The method employed in this study most closely resembles the Stewart-Oaten *et al.* (1986) approach, however microclimate data were collected seasonally rather than at random intervals. Stewart-Oaten and Bence (2001) concluded that the use of regular sampling intervals was both logistically and statistically more efficient than random sampling. While the use of multiple controls, as advocated by Underwood (1991, 1994) may be superior in terms of defining background variation, Stewart-Oaten and Bence (2001) argue that they are not required and may actually hinder the investigation process through the inclusion of unnecessary noise.

The use of more than one control was not possible at this edge of Small. A large area of uniform forest would have been required to house the extra transects, but space was limited by the Huon River to the south and roads and logging operations in other areas. Furthermore, the methodology was laborious and repeated at three further sites aimed at an examination of edges of different ages (see Chapter 6) and was already constrained by the number of sensor groups. Expansion of the sampling design would hence have required a prodigious sampling regime that was logistically prohibitive.

While there is no doubt that a forest canopy can have a profound buffering effect on exposed climatic conditions, the stability of forest climates has perhaps been overemphasised. Those studies of microclimate using only a single distance as a control (e.g. Williams-Linera 1990, Matlack 1993, Malcolm 1994, Chen *et al.* 1995, Jose *et al.* 1996, Renhorn *et al.* 1997) fall into this category. A consequence of this assumption has been to exaggerate any edge effect.

In fairness to other research on edge effects, it should be acknowledged that they seldom have the luxury of obtaining *a priori* data, while comparing for the edge effect against numerous undisturbed controls was also either not possible for either logistical reasons, or because the system was too fragmented. In heavily fragmented systems, there may also be the possibility of confusion between edge effects and those relating to fragment size.

4.5 Conclusions

The Before and After, Control and Impact method employed in this study has demonstrated that a sound knowledge of background variation is required to develop an appropriate understanding of any edge effect. The BACI approach is thus appropriate to the study of edge effects. The expansion of the design to the level recommended by Underwood (1991, 1994) would only confirm this view. Studies lacking in *a priori* data should acknowledge this as a potential weakness.

The edge effect in terms of microclimate was estimated to be less than 10 m from the edge and confined to the warmer seasons. Much of the differences associated with creation of the edge were encompassed within microclimate differences observed in the undisturbed forest. The influence of the edge effect may be spatially limited to near the edge and distinct from the undisturbed forest only during periods of extreme conditions in the open.

5 Gradients in vegetation in a forest edge using a BACI approach

5.1 Introduction

As has been observed in microclimate studies in forest edges, most vegetation research suffers from a lack of appropriate controls. Some employ controls at the same gradient of distances at the edge in the undisturbed “interior” forest (e.g. Whitney and Runkle 1981, Lovejoy *et al.* 1986, Laurance 1991, Malcolm 1994, Young and Mitchell 1994, Laurance *et al.* 1998), or consider gradients of change in vegetation across contiguous quadrats based at the edge (e.g. Ranney *et al.* 1981, Palik and Murphy 1991, Matlack 1994, Luczaj and Sadowska 1997, Ruben *et al.* 1999). Although some studies employ controls (e.g. Wales 1972), the bulk of research, however, uses only a single distance from the edge as representative of the undisturbed forest (e.g. Williams-Linera 1990, Brothers and Spingarn 1992, Chen *et al.* 1992, Fraver 1994, Jose *et al.* 1996, Williams-Linera *et al.* 1998, Sizer and Tanner 1999, Gehlhausen *et al.* 2000, Oosterhoorn and Kappelle 2000). Vegetation research in edges also often actively avoids sources of variation, including forest gaps and fallen logs (Whitney and Runkle 1981, Chen *et al.* 1992), steep slopes and streams (Fraver 1994, Esseen and Renhorn 1998, Sizer and Tanner 1999), and changes in large-scale forest architecture (Ranney *et al.* 1981).

Nearly all survey designs also lack information on what natural gradients/patch dynamics might exist in the system prior to edge creation. While Brosnoff *et al.* (1997) and Sizer and Tanner (1999) considered edges before and after disturbance, their designs lacked undisturbed controls. Another exception is Laurance *et al.* (1998), which described the progress of an ongoing study incorporating pre and post-

logging surveys in an Amazon forest. The focus of much of this research was, however, related to the effect of isolation and patch size rather than edge effects (Lovejoy *et al.* 1986). Information on background levels of change in forest systems relative to edge effects appears to be lacking.

This chapter describes a study of bryophytes, epiphytic ferns and flowering epiphytes (otherwise described jointly as “epiflora”) and large vascular vegetation at the same site before and after logging. The aims were to determine how these two vegetation strata in a Tasmanian wet forest responded to edge creation, to test the veracity of the BACI design with respect to vegetation studies in edges and to suggest potential indicators of edge effects that may be employed in the survey of edges of different ages (Chapter 7). The specific questions under test were:

1. Is the BACI approach appropriate for the study of edge effects in terms of both the epiflora and vascular vegetation and to what degree does an *a priori* understanding of the system influence the determination of an edge effect?
2. What are the short-term edge effects on the epiflora and vascular plant composition in terms of both the amount of change and distance these penetrate into the undisturbed forest?
3. What epiflora taxa epiflora are the best indicators of the edge effect?

5.2 Methods

Vegetation data were obtained at Small (see Chapter 1 for a site description) on the same transects as in the microclimate BACI study (see Chapter 4 for the protocol for transect establishment; Figure 5.1). Large-scale vegetational characteristics were determined with TASFORHAB plots (Peters 1984; Appendix C) surveyed at 10, 50, 100, 110, 150 and 200 m along the centre line between the 100 m transects and at 10 and 50 m on the 50 m transects (Figure 5.1). These were interpreted in terms of Kirkpatrick *et al.* (1988) forestry classifications (see Chapter 1).

A 10 × 2 m quadrat was located at 0, 10, 20, 50 and 100 m (where applicable) on the impact transects, and 100, 110, 120, 150 and 200 m (again where applicable) on the controls (Figure 5.1). Each quadrat was divided into five 2 × 2 m subplots within which the projected cover of all species overhanging each subplot was estimated using a Braun-Blanquet scale (Mueller-Dombois and Ellenberg 1974). At more

distant transect points (50, 100, 150 and 200 m), the density of the quadrats was relatively low. Hence either one or two extra quadrats were randomly located and surveyed so that there were at least three plots within 20 m of the transect plot (Figure 5.1). Only vascular plant information was collected from these plots.

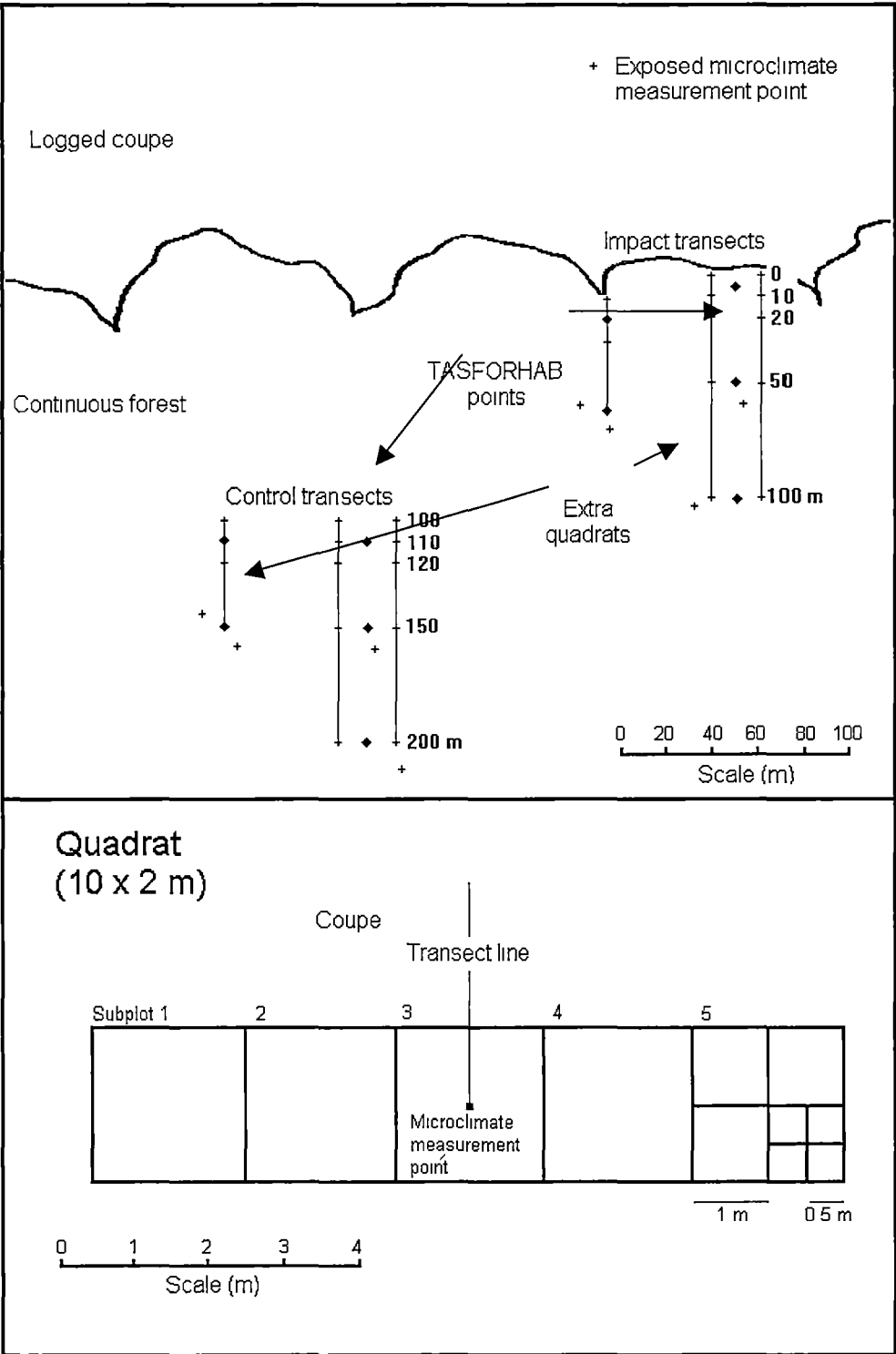


Figure 5.1 - Layout of the control and impact transects (see Chapter 4) and a detailed view of a one of the quadrats that were positioned at each of the microclimate measurement points. Each quadrat was equally divided into five subplots (used to sample vascular flora) that were each further divided into sixteen sampling units (used to survey epiflora).

Each 2×2 m subplot was divided into four 1×1 m regions, each of which was further divided into 0.5×0.5 m units, making sixteen sampling areas within each subplot and a total of eighty per quadrat (Figure 5.1). All moss, liverwort and epiphytic vascular plant taxa (considered jointly as “epiflora”) were considered for their presence below breast height (1.3 m above ground level) on any of the Ground, Rocks, Logs, Trees or Manferns within each of the eighty units.

Surveys before logging were undertaken from February to early March of 1998 with the logging and burning of the coupe completed by the end of April of the same year. Surveys of each quadrat after edge creation were conducted from February to March of 1999, approximately twelve months after logging. This incorporated the impact of a full range of seasons at the newly exposed edge, in particular the dry summer of 1998 - 1999. There were no methodological differences between surveys.

5.2.1 Data summaries and analysis

Epiflora data were summarised in terms of taxa frequency across the eighty units within each substrate for each quadrat, weighted by the frequency of that substrate. This allowed for differences in substrate availability between quadrats and might be analogous to an importance value (*sensu* Mueller-Dombois and Ellenberg 1974). Individual taxa differences were determined in terms of the change in frequency between surveys. Multivariate analyses were undertaken using the PC-ORD Analysis Package (Version 4.0 MjM Software Design © 1995 - 1999; McCune and Mefford 1999). Univariate statistics were calculated using the JMP software (Version 3.1.2, Sas Institute Inc. © 1989 - 1995).

Similar to the vertical survey, the taxonomic resolution in this study incorporated a number of summary groups or complexes (usually at the family or generic level) of specimens that were difficult to identify in the field (Table 5.1; see Chapter 3 for a justification of this approach). These include the Acrobolbaceae, Dicranaceae, Lepidozids (comprising members of the Lepidoziaceae other than *Bazzania*), *Rhizogonium*, the Schistochilaceae and Pelt/Cupr group (comprising *Hymenophyllum peltatum* and *H. cupressiforme*). Vascular taxa included in the epiflora assessment were *Blechnum*, *Chiloglottis*, *Ctenopteris*, *Dicksonia*, *Grammitis*, *Hymenophyllum* (six species), *Polystichum*, *Pterostylis*, *Rumohra*, *Senecio*, *Sticherus* and *Tmesipteris* (Table 5.1). *Blechnum*, *Dicksonia* and *Polystichum* were found as both sporelings

and adult plants on various substrates and for this reason were included in both epiflora and vascular plant analyses (Table 5.2).

Table 5.1 - List of the epiflora taxa in this study. Shaded groups were combined in analyses.

ANALYSIS_ID	Family	Genus or Species	ANALYSIS_ID	Family	Genus or Species
Acrobolbaceae	Acrobolbaceae	<i>Marsupidium</i> spp.	Lepidozid	Lepidoziaceae	<i>Acromastigum colensoanum</i>
Acrobolbaceae	Acrobolbaceae	<i>Marsupidium surculosum</i>	Lepidozid	Lepidoziaceae	<i>Lepidozia</i> spp.
Acrobolbaceae	Acrobolbaceae	<i>Tylimanthus</i> spp.	Lepidozid	Lepidoziaceae	<i>Lepidozia ulothrix</i>
Acrobolbaceae	Acrobolbaceae	<i>Tylimanthus pseudosaccatus</i>	Lepidozid	Lepidoziaceae	<i>Telaranea</i> spp.
<i>Bazzania</i>	Lepidoziaceae	<i>Bazzania</i> spp.	<i>Leptotheca</i>	Aulacomniaceae	<i>Leptotheca gaudichaudii</i>
<i>Blechnum</i>	Blechnaceae	<i>Blechnum wattsii</i>	<i>Leucobrium</i>	Leucobryaceae	<i>Leucobrium candidum</i>
<i>Blepharidophyllum</i>	Scapaniaceae	<i>Blepharidophyllum</i> spp.	<i>Lopidium</i>	Hypopterygiaceae	<i>Lopidium concinnum</i>
<i>Bryum</i>	Bryaceae	<i>Bryum</i> spp.	<i>Macromitrium</i>	Orthotrichaceae	<i>Macromitrium</i> spp.
<i>Chiloglottis</i>	Orchidaceae	<i>Chiloglottis</i> spp.	Pelt/Cupr	Hymenophyllaceae	<i>Hymenophyllum cupressiforme</i>
<i>Ctenopteris</i>	Grammitidaceae	<i>Ctenopteris heterophylla</i>	Pelt/Cupr	Hymenophyllaceae	<i>Hymenophyllum peltatum</i>
<i>Cyathophorum</i>	Hypopterygiaceae	<i>Cyathophorum bulbosum</i>	<i>Plagiochila</i>	Plagiochilaceae	<i>Plagiochila</i> spp.
<i>Dawsonia</i>	Dawsoniaceae	<i>Dawsonia longiseta</i>	<i>Polystichum</i>	Dryopteridaceae	<i>Polystichum proliferum</i>
<i>Dicksonia</i>	Dicksoniaceae	<i>Dicksonia Antarctica</i>	<i>Pterostylis</i>	Orchidaceae	<i>Pterostylis</i> spp.
Dicranaceae	Dicranaceae	<i>Campylopus</i> spp.	<i>Ptychomnium</i>	Ptychomniaceae	<i>Ptychomnium aciculare</i>
Dicranaceae	Dicranaceae	<i>Dicranoloma</i> spp.	<i>Rhizogonium</i>	Rhizogoniaceae	<i>Rhizogonium novae-hollandiae</i>
Dicranaceae	Dicranaceae	<i>Holomitrium</i> spp.	<i>Rhizogonium</i>	Rhizogoniaceae	<i>Rhizogonium pennatum</i>
Dicranaceae	Dicranaceae	<i>Trematodon</i> spp.	<i>Riccardia</i>	Aneuraceae	<i>Riccardia</i> spp.
<i>Gackstroemia</i>	Lepidolaenaceae	<i>Gackstroemia weindorferi</i>	<i>Rumohra</i>	Dryopteridaceae	<i>Rumohra adiantiformis</i>
<i>Glyphothecium</i>	Ptychomniaceae	<i>Glyphothecium sciuroides</i>	Schistochilaceae	Schistochilaceae	<i>Paraschitochila tuloides</i>
<i>Grammitis</i>	Grammitidaceae	<i>Grammitis</i> spp.	Schistochilaceae	Schistochilaceae	<i>Schistochila</i> spp.
<i>Grimmia</i>	Grimmiaceae	<i>Grimmia pulvinata</i>	Schistochilaceae	Schistochilaceae	<i>Schistochila lehmanniana</i>
Hookeriaceae	Hookeriaceae	<i>Distichophyllum</i> spp.	Sematophyllum	Sematophyllaceae	<i>Sematophyllum</i> spp.
HymenAust	Hymenophyllaceae	<i>Hymenophyllum australe</i>	Senecio	Asteraceae	<i>Senecio</i> spp.
HymenFlab	Hymenophyllaceae	<i>Hymenophyllum flabellatum</i>	Sticherus	Gleicheniaceae	<i>Sticherus</i> spp.
HymenMarg	Hymenophyllaceae	<i>Hymenophyllum marginatum</i>	Tayloria	Splachnaceae	<i>Tayloria gunnii</i>
<i>Hymenophyton</i>	Hymenophytaceae	<i>Hymenophyton flabellatum</i>	Tmesipteris	Psilotaceae	<i>Tmesipteris billardiarei</i>
HymenRaru	Hymenophyllaceae	<i>Hymenophyllum rarum</i>	Trichocolea	Trichocoleaceae	<i>Trichocolea mollissima</i>
<i>Hypnodendron</i>	Hypnodendraceae	<i>Hypnodendron comosum</i>	Weymouthia	Meteoriaceae	<i>Weymouthia</i> spp.
<i>Hypnum</i>	Hypnaceae	<i>Hypnum</i> spp.	Wijkia	Sematophyllaceae	<i>Wijkia extenuata</i>
<i>Hypopterygium</i>	Hypopterygiaceae	<i>Hypopterygium rotulatum</i>	Zygodon	Orthotrichaceae	<i>Zygodon</i> spp.

Vascular plant taxa included cotyledonary or seedling stages of *Acacia* spp., *Eucalyptus obliqua* and *Nothofagus cunninghamii* (AcaciaCot, EucCot and NothCot respectively; Table 5.2). These were included in the large-scale vascular surveys, rather than as part of the epiflora, so that they may be placed in context with their respective adults. Owing to confusion between species of *Leptospermum*, *Melaleuca* and *Trochocarpa*, these taxa were analysed at the generic level (Table 5.2).

Table 5.2 - List of taxa used in the vascular plant (non-epiflora) analysis. Shaded species were combined at the generic level. Cotyledonary stages of *Acacia*, *Nothofagus* and *Eucalyptus* were included as AcaciaCot, NothCot and EucCot.

ANALYSIS_ID	Family	Genus or Species	ANALYSIS_ID	Family	Genus or Species
AcaciaCot	Mimosaceae	<i>Acacia</i> spp.	<i>Gleichenia</i>	Gleicheniaceae	<i>Gleichenia</i> spp.
AcaciaMel	Mimosaceae	<i>Acacia melanoxylon</i>	1 <i>Gonocarpus</i>	Haloragaceae	<i>Gonocarpus</i> spp.
AcaciaVert	Mimosaceae	<i>Acacia verticillata</i>	<i>Histiopteris</i>	Dennstaedtiaceae	<i>Histiopteris incisa</i>
<i>Anodopetalum</i>	Cunoniaceae	<i>Anodopetalum biglandulosum</i>	<i>Hypolepis</i>	Gleicheniaceae	<i>Hypolepis rugosula</i>
<i>Anopterus</i>	Escalloniaceae	<i>Anopterus glandulosus</i>	<i>Leptospermum</i>	Myrtaceae	<i>Leptospermum lanigerum</i>
<i>Aristotelia</i>	Elaeocarpaceae	<i>Aristotelia peduncularis</i>	<i>Leptospermum</i>	Myrtaceae	<i>Leptospermum scoparium</i>
<i>Atherosperma</i>	Monimiaceae	<i>Atherosperma moschatum</i>	<i>Melaleuca</i>	Myrtaceae	<i>Melaleuca</i> sp.
<i>Bauera</i>	Cunoniaceae	<i>Bauera rubioides</i>	<i>Melaleuca</i>	Myrtaceae	<i>Melaleuca squarrosa</i>
<i>Blechnum</i>	Blechnaceae	<i>Blechnum watsii</i>	NothCot	Fagaceae	<i>Nothofagus cunninghamii</i>
<i>Cenarrhenes</i>	Proteaceae	<i>Cenarrhenes nitida</i>	<i>Nothofagus</i>	Fagaceae	<i>Nothofagus cunninghamii</i>
<i>Clematis</i>	Ranunculaceae	<i>Clematis aristata</i>	<i>Nematolepis</i>	Rutaceae	<i>Nematolepis squamea</i>
CoprQuad	Rubiaceae	<i>Coprosma quadrifida</i>	<i>Phyllocladus</i>	Podocarpaceae	<i>Phyllocladus aspleniifolius</i>
<i>Dicksonia</i>	Dicksoniaceae	<i>Dicksonia Antarctica</i>	<i>Pimelea</i>	Thymelaeaceae	<i>Pimelea drupacea</i>
<i>Drimophyla</i>	Liliaceae	<i>Drimophyla cyanocarpa</i>	<i>Polystichum</i>	Dryopteridaceae	<i>Polystichum proliferum</i>
<i>Eucalyptus</i>	Myrtaceae	<i>Eucalyptus obliqua</i>	<i>Pomaderris</i>	Rhamnaceae	<i>Pomaderris apetala</i>
EucCot	Myrtaceae	<i>Eucalyptus obliqua</i>	<i>Tasmannia</i>	Winteraceae	<i>Tasmannia lanceolata</i>
<i>Eucryphia</i>	Eucryphiaceae	<i>Eucryphia lucida</i>	<i>Trochocarpa</i>	Epacridaceae	<i>Trochocarpa cunninghamii</i>
<i>Gahnia</i>	Cyperaceae	<i>Gahnia grandis</i>	<i>Trochocarpa</i>	Epacridaceae	<i>Trochocarpa gunnii</i>
<i>Galium</i>	Rubiaceae	<i>Galium australe</i>			

Braun-Blanquet covers of the vascular vegetation from each subplot were reverted to percentages by taking the midpoint of each cover class (Hickey 1993) such that 1 = 0.05 %, 2 = 3 %, 3 = 15 %, 4 = 37.5 %, 5 = 62.5 % and 6 = 87.5 %. Analyses were thus based on estimates of the average cover of each species within each quadrat before and after edge creation.

Changes in the vascular flora before and after logging were determined using the difference in percentage cover of all taxa within each distance between surveys. As these values were based on converted Braun-Blanquet estimates and thus

incorporated a level of error, each difference was truncated to a multiple of five. This ensured a conservative underestimation of changes in cover by reducing small differences to 0 or 5 % and highlighted larger changes (10 % at least). Small differences were generally considered only for their potential cumulative affect (as in the epiflora) unless the taxon was new to the location in the second survey.

5.3 Results

5.3.1 Epiflora responses before and after edge creation

Non-metric multidimensional scaling (MDS - see Chapter 3 for a summary of this technique) was based on the weighted frequency of taxa on substrates within each quadrat (indicated as a distance along a transect). Vectors indicated the position of each quadrat before and after edge creation and indicated the relative changes within each quadrat (i.e. the shift of each quadrat in ordination space).

Substrate type had a more profound influence on epiflora composition than distance from the edge (Figure 5.2). Logs and Stems (black and green vectors) form almost discrete clusters indicating specific epiflora compositions, while the Ground and Rocks (red and blue) tend to overlap, a feature noted in the vertical survey (Chapter 3). There is also some similarity between Log and Ground substrates (Figure 5.2; previously observed in the vertical survey - Chapter 3) that may be due to residual Log-based taxa persisting on the Ground after the log had rotted away. The single manfern (pink) observed in the study was of little relevance and was excluded from any further consideration.

The height gradient across substrates that was observed in the vertical study (Chapter 3) is less pronounced with the epiflora on the Ground and Rocks grading into the flora on Logs, but not to Stems (Figure 5.2). This may be due to differences in methodology (maps of epiflora colonies vs. frequency counts), including the lack of substrate “pseudotaxa” employed in Chapter 3. Outliers at the lower right of the plot were both found on Rock, with this substrate being widely distributed across the plot, indicating a relatively high degree of variability in epiflora composition on this substrate. The epiflora on Rocks is thus unlikely to be a useful indicator of edge effects either in terms of total composition or with respect to specific taxa.

Distances from the edge appear to be randomly distributed within each of the more discrete substrate groups, although the combining of all data from before and after disturbance may obscure such trends (Figure 5.2). There is some grouping of distances within substrates (0 m points on Logs - upper left and 120 m on the Ground - centre), but there is no gradient of epiflora compositional changes with distance, and neither is there a response in terms of impact and control transects (Figure 5.2). This suggests that environmental gradients in temperature and vapour pressure deficit observed across the site (see Chapter 4) were not influential at this scale.

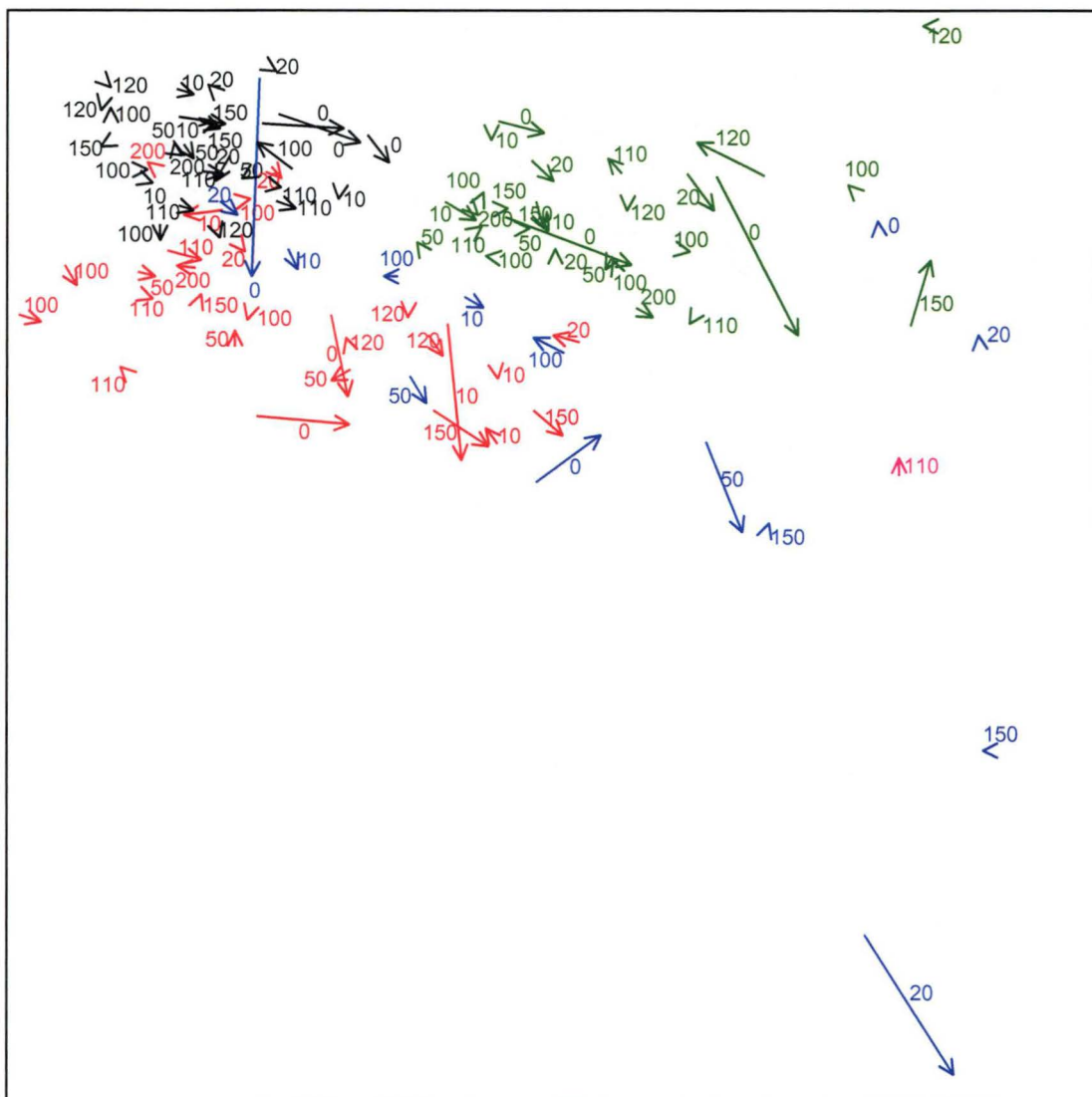


Figure 5.2 - MDS ordination in two dimensions of epiflora considered across distances and substrates with vectors indicating quadrat positions before and after logging. Numbers indicate distances along transects. Black vectors = Logs, green = Stems, red = Ground, blue = Rocks and pink = Manferns.

Of key interest was the change at each distance on each substrate before and after logging. The 0 m quadrats on all substrates generally indicated a greater level of change than most other distances, although large differences occurred at a 10 m

quadrat on the Ground (centre of the plot; Figure 5.2) and at a 20 m point on Rocks (lower right of plot; (Figure 5.2). These differences were not consistently spread over other 10 and 20 m points within these substrates. On Logs and Stems, the 0 m points have all shifted to the right and downwards (Figure 5.2). Rock and Ground 0 m points are more diverse in terms of direction, but these vectors also tend to the right of the plot. Rocks had both the largest and smallest differences at 0 m, indicating a variable response to edge effects as might be expected with the inconsistent epiflora composition on this substrate.

Because differences between MDS points may be smothered and/or distorted by the combining of all substrates within a single analysis, each was ordinated separately to determine the edge effect in isolation (Figure 5.3). While the substrates cannot be compared to each other using this approach, as there are differences in scale for each MDS analysis, the edge effect is more truly reflected within each substratum.

Separate analysis of substrates confirmed the view that epiflora composition on Rocks was a poor indicator of edge effects, at least in part due to low representation of this substrate at many distances, especially on control transects. There is no consistent pattern to changes in the 0 m points (black vectors) both in terms of the amount and direction of changes, nor does there appear to be any gradient across distance (Figure 5.3). Large differences observed at some distance in the analysis of all substrates together (such as at 20 m; Figure 5.2) have been absorbed in the two dimensional analysis.

The Ground was similar to Rocks, with no consistent directional changes in 0 m points (of which only two were available owing to a lack of data in the third both before and after logging; Figure 5.3). The largest difference on the Ground was at a single 10 m quadrat and may not be edge related. There is some grouping of other quadrats (in particular 0 and 100 m on impact transects), but no general pattern either within distance or between control and impact transects (Figure 5.3). Differences between surveys on the Ground must incorporate a degree of anthropogenic disturbance in the form of observer trampling during both the vegetation and microclimate surveys (Chapter 4).

Stems and Logs both indicated a consistent shift in 0 m points, as was observed in the combined analysis (Figure 5.2; Figure 5.3), with no similar changes at other

distances. This suggests that the edge effect in terms of the epiflora on either substrate was restricted to less than 10 m. The epiflora composition on Stems and Logs thus appears to be good indicators of edge effects. On Stems, there appears to be a trend across the impact and control transects, with the former tending toward the lower portion of the plot relative to the latter, which are more diverse Figure 5.3). This probably relates to differences in vascular composition across the site, which will have a direct influence on Stem-based epiflora (*sensu* McCune and Antos 1981, 1982, Kantvilas and Minchin 1989). No such patterns were apparent on Logs.

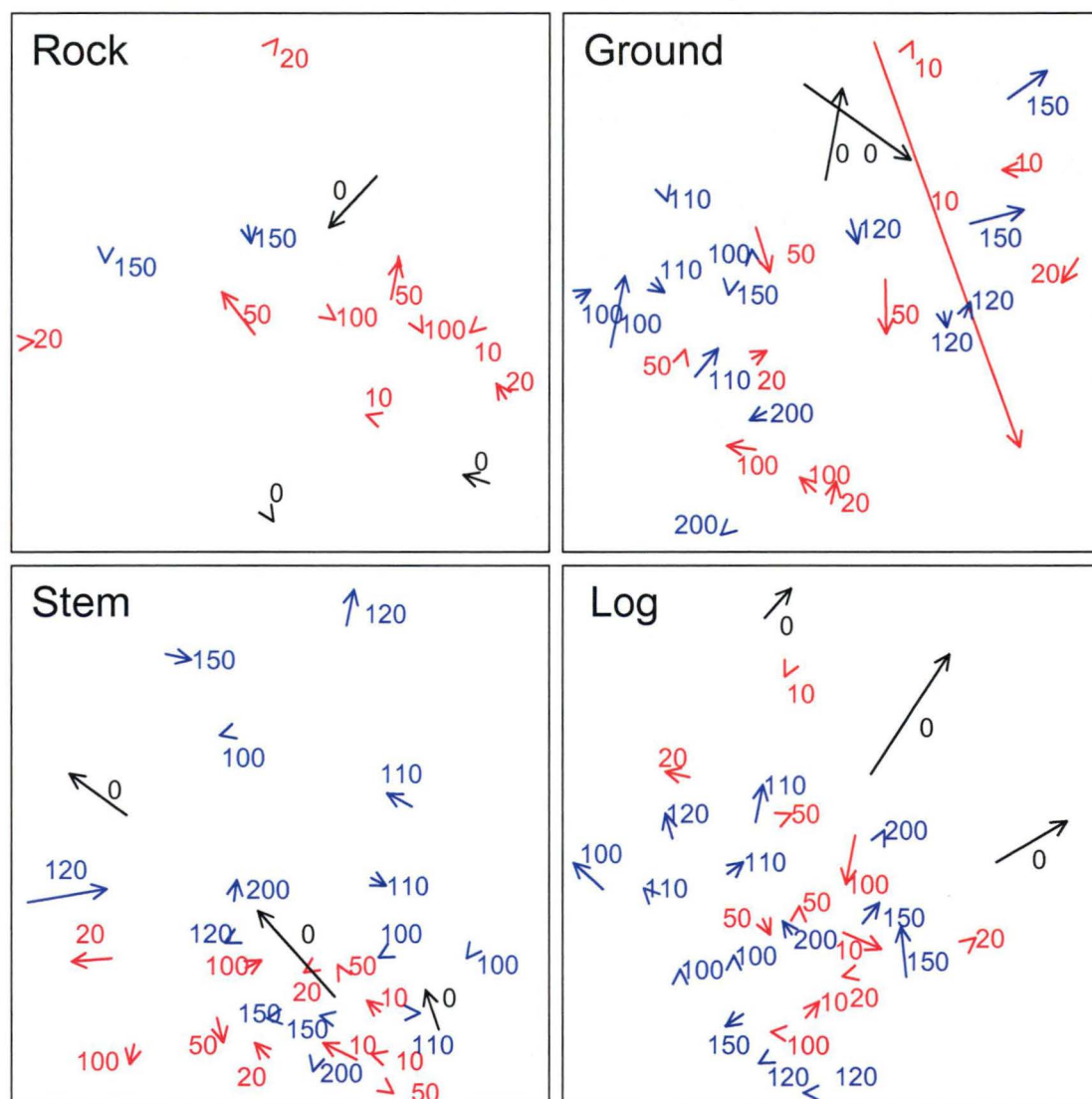


Figure 5.3 - Four separate MDS ordinations in two dimensions of the frequency of taxa within each quadrat. Vectors indicate the position of each quadrat before and after edge creation. Red = impact transects, blue = controls while black = 0 m points.

A simpler approach to visualising differences between surveys was to consider the average Euclidean distance between the position of each quadrat before and after logging (i.e. the average vector length for each distance; Figure 5.4), although as

MDS plots represent more complex multidimensional spaces, a degree of distortion is thus entrained in the result. Univariate analysis of distances for each substrate required the non-parametric Kruskal-Wallis (Kruskal and Wallis 1952 in Zar 1984) test, owing to heterogeneous variances and non-normal data. The use of a less powerful test was also prompted by the small sample size, as this was considered a more conservative approach.

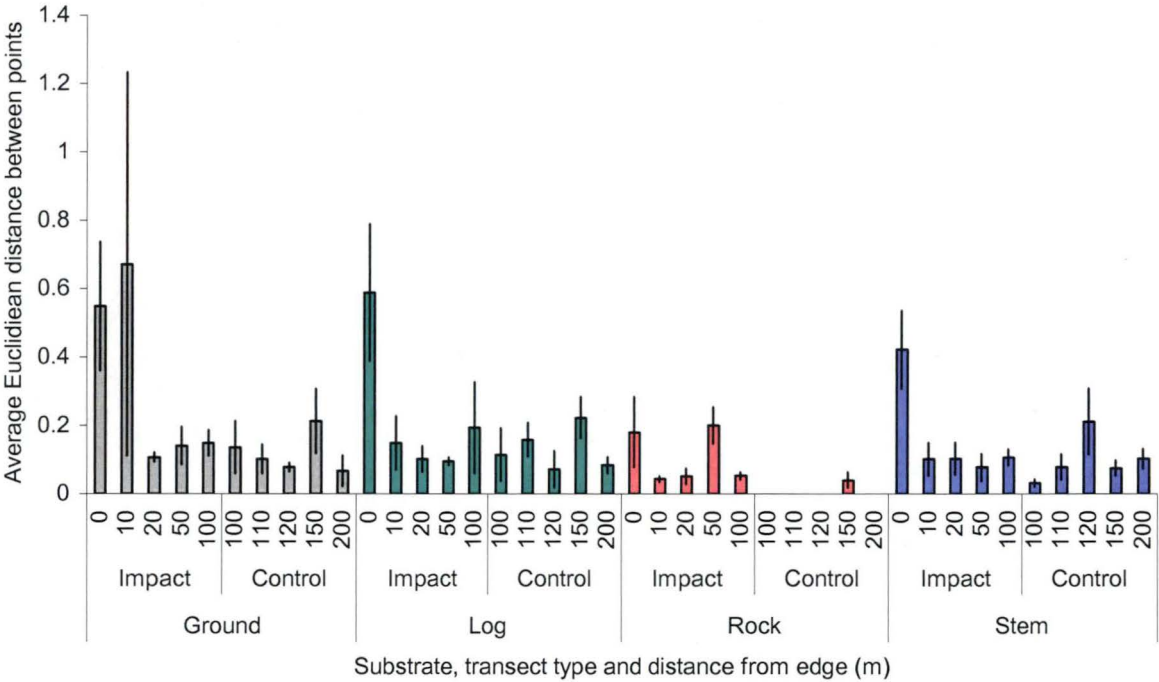


Figure 5.4 - Average Euclidean distance between the positions of each quadrat before and after logging (i.e. length of the vectors) within each of the four separate MDS ordinations (Figure 5.3). Bars are standard error.

The Ground substrate showed a larger edge effect than either Logs or Stems with large differences at 0 and 10 m. The value at 10 m was, however, in response to a very large change in one quadrat (Figure 5.3), which was reflected in the large standard error for this distance (Figure 5.4). There were no significant differences between any distances (Table 5.3). As anticipated, there were no useful indications on Rocks (Figure 5.4; Table 5.3). Logs and Stems indicate large differences at 0 m, but there was also no significant difference between these and other distances (Figure 5.4; Table 5.3). In spite of the lack of statistically significant differences, these substrates are considered to offer the best epiflora response for the detection of edge effects as changes on Stems and Logs were more directionally consistent on the ordination plots than the Ground or Rocks (Figure 5.3), suggesting that similar changes are occurring at all 0 m quadrats for each substrate.

Table 5.3 - Kruskal-Wallis test for significant differences in the Euclidean distances between pre and post-logging MDS points for each substrate (Figure 5.4). NS = Not significant.

Substrate	Chi Square	DF	Prob. > Chi Square	Significance
Ground	8.069	9	0.5272	NS
Rock	4.133	5	0.5304	NS
Stem	11.86	9	0.2213	NS
Log	11.14	9	0.2662	NS

To determine whether there were any patterns in response to distance from the edge in the absence of substrate, the frequency of each taxon was calculated for each quadrat irrespective of strata (i.e. Across substrates). The resulting MDS indicated a directional trend in 0 m points similar to that observed on Logs and Stems (Figure 5.3; Figure 5.5). There was some separation of the impact and control transects (axes 1&2 and 1&3), but no effect of distance.

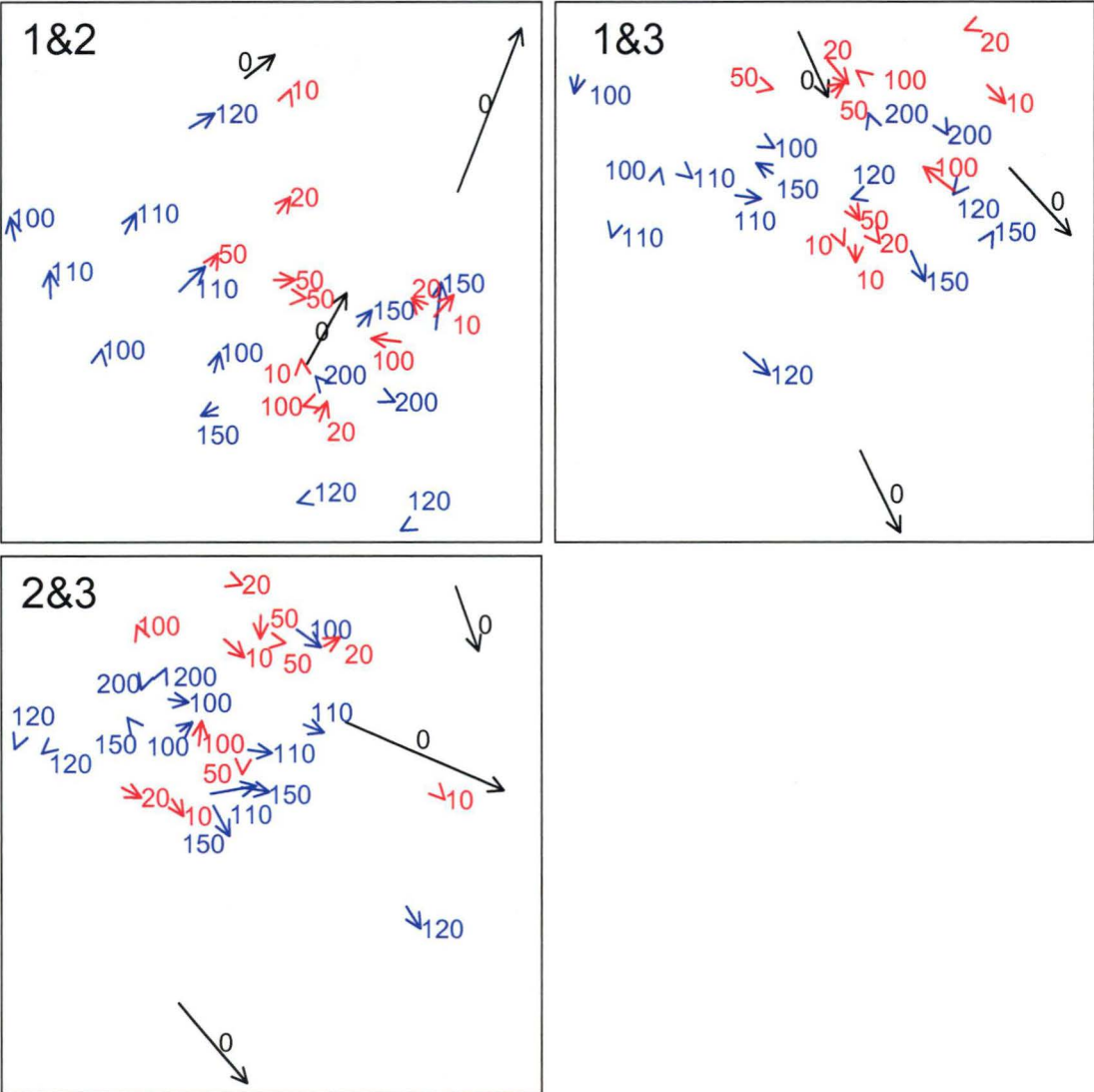


Figure 5.5 - MDS ordinations in three dimensions of the frequency of taxa within each quadrat before and after edge creation. Red and blue vectors = control and impact transects respectively while black = 0 m points. 1&2, 1&3 and 2&3 refer to the axes on the ordination.

The 0 m points have all moved away from the more general composition (axes 1&2 and 2&3), suggesting a shift in epiflora composition to a combination of taxa that is not typical of the site (Figure 5.5). This may be manifest through the loss of common taxa, an increase in formerly rare taxa or the invasion of species foreign to the site, and probably reflects drier conditions at the edge. As with the separate consideration of Logs and Stems (Figure 5.3), there were no similar trends at any other distance, suggesting an edge effect of less than 10 m (Figure 5.5).

Calculation of the average Euclidean distance between MDS points for each quadrat before and after disturbance (note again that in MDS plots all vectors are at least slightly distorted), reveals that the 0 m points have changed considerably more than other distances (Figure 5.6). These were analysed using a Kruskal-Wallis test for the same reasons as before, but were not significantly different (Table 5.4) in spite of the obvious difference at 0 m. This was probably due to the small number of samples ($n = 3$ in most distances) and the associated lack of analytical power. Studies of the epiflora composition without concern for substrates may thus represent a good indication of edge effects, but there is a need for substantially more replication than that employed in this study.

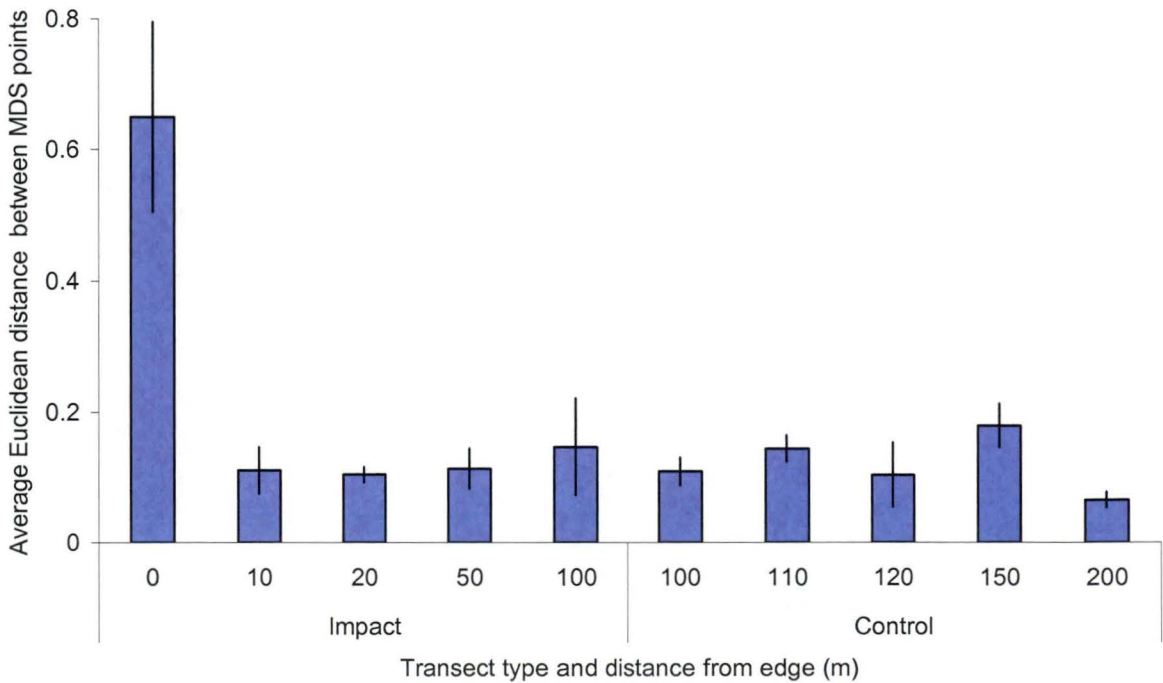


Figure 5.6 - Average Euclidean distance between the positions of each quadrat before and after logging (i.e. length of vectors) within the MDS ordination of epiflora composition irrespective of substrate (Figure 5.5). Bars are standard error.

Table 5.4 - Kruskal-Wallis test for significant differences in the Euclidean distances between pre and post-logging MDS points irrespective of substrate (Figure 5.6). NS = Not significant.

Substrate	Chi Square	DF	Prob. > Chi Square	Significance
Combined data	13.948	9	0.1245	NS

To determine the changes that have occurred at the level of individual taxa, the difference in average frequency between surveys was considered for each taxon at all transect distances on Stems, Logs and Across substrates. Differences were then classified into one of ten classes (Table 5.5). Other than in terms of the number of occurrences within each distance, any increase or decrease that was less than 0.025 (classes 4 and 6) has been considered as noise.

Table 5.5 - The classification of differences in average frequency for each taxon before and after edge creation based on data from Stems, Logs and Across substrates. Colours indicate the degree of change (see Table 5.6; Table 5.7; Table 5.8).

Class	Ranges	Stems	Logs	Across substrates
1	Freq Difference < -0.075	-	1	2.8
2	-0.075 ≤ Freq Difference < -0.05	-	3.1	4
3	-0.05 ≤ Freq Difference < -0.025	0.8	7.5	9.5
4	-0.025 ≤ Freq Difference < 0	27.8	36.7	38.5
5	Freq Difference = 0	59.8	23.1	21.4
6	0 ≤ Freq Difference < 0.025	11.2	20	14.7
7	0.025 ≤ Freq Difference < 0.05	0.4	6.1	6.1
8	0.05 ≤ Freq Difference < 0.075	-	0.7	2.4
9	0.075 ≤ Freq Difference < 0.1	-	0.7	0.3
10	Freq Difference ≥ 0.1	-	1.1	0.3
Total		100 %	100 %	100 %

Regardless of the substrate type (Stems, Logs or Across substrates), there was no invasion by new taxa not observed prior to logging, neither were any taxa eliminated (Table 5.6; Table 5.7; Table 5.8). There was also a large number of locally rare species (five or fewer distances represented) on each substrate type (~ 33 % of species on Stems and Logs with 37.5 % of taxa Across substrates), which were thus unlikely to provide useful information on edge effects.

Stems exhibited very little change between surveys relative to either Logs or Across substrate differences (Table 5.6; Table 5.7; Table 5.8). The majority (59.8 %) of distance/taxa combinations indicated zero change (class 5), 27.8 % indicated small decreases and 11.2 % showed small increases (classes 4 and 6; Table 5.5). When combined, this covers 98.8 % of distance/taxa combinations, even accounting for the lack of occurrence of all taxa at all distances. Only three taxa changed by an increment larger than or equal to ± 0.025 (classes 3 and 7). *Wijkia* and *Sematophyllum* decreased at 0 m and the Pelt/Cupr complex increased at 120 m (class 6; Table 5.6).

There were twenty-one decreases at 0 m while the next highest was nine at 10 and 20 m (Table 5.6). The number of increases within each distance ranged from 1 to 5 with no pattern relative to the edge (Table 5.6). The observed edge effect in the ordination results (Figure 5.3; Figure 5.5) is thus a response to the accumulation of many small differences, rather than large changes within few taxa. Identification of indicator taxa from this group is thus problematic and the question remains open as to whether this trend (or indeed any others) is maintained at other locations.

Table 5.6 - Differences in average frequency for each taxon found on Stems before and after edge creation. Orange shading = decreases, blue = increases (see Table 5.5 for ranges).

Stems	Impact	Control								
	0	10	20	50	100	100	110	120	150	200
<i>Wijkia</i>	-0.044	-0.008	0	0.008	0	0	0	0	0	-0.006
<i>Sematophyllum</i>	-0.038	-0.013	0.015	-0.013	0	0	0	0	-0.004	0
<i>Weymouthia</i>	-0.025	-0.006	0	-0.006	0	0	0	0	0	0
<i>Gackstroemia</i>	-0.025	-0.006	0	0	0	0	0.013	0	0.013	0
<i>Trichocolea</i>	-0.019	0	-0.006	0	0	0	0	0	0	0
<i>Grammitis</i>	-0.017	-0.021	-0.004	0	0	-0.004	0.004	0	-0.004	-0.006
Dicranaceae	-0.017	0	-0.008	0.004	0	0.004	-0.004	0	0	0
Acrobolbaceae	-0.013	-0.008	-0.004	0	0	0	0.006	0	0.004	0
<i>Pelt/Cupr</i>	-0.013	-0.006	0	0	0	0	0	0.025	-0.013	0
Lepidozids	-0.013	0	0	0.004	0	0	0	0	0.013	-0.006
Schistochilaceae	-0.013	0	0	-0.008	0	0	0	-0.002	-0.004	0
<i>Plagiocbila</i>	-0.013	0	0.013	0	0	0	0	0	0	0
<i>Blepharidophyllum</i>	-0.013	0	0	0	0	0	0	0	0	0
<i>Hymenophyllum australe</i>	-0.013	0	0	0	0	-0.015	0	0	0	0
<i>Leucobrium</i>	-0.013	0	0	0	0	0	-0.013	0	0	0
<i>Hymenophyton</i>	-0.013	0	0	0	0	0	0	0	0	0
<i>Ptychomnium</i>	-0.008	0	0.004	0	-0.013	0	0	0.004	-0.008	0
<i>Ctenopteris</i>	-0.006	0	0	0	0	0	0	0	0	0
<i>Leptotheca</i>	-0.006	0	0	0	0	0	0	0	0	0
<i>Bazzania</i>	-0.004	-0.006	-0.008	-0.004	0	0	-0.013	0.013	0.006	0
<i>Glyphothecium</i>	-0.004	0	-0.006	0	0	0	-0.006	-0.004	-0.013	0
<i>Hymenophyllum rarum</i>	0	-0.013	0	0	0.013	0	0	-0.002	-0.006	0
<i>Hypopterigium</i>	0	0	0	0	0	0.008	0	0	0	0
<i>Rhizogonium</i>	0	0	0	0.008	0	-0.013	0	0	0	0
<i>Blechnum</i>	0	0	0	0	0	0	0	0	0	0
<i>Hymenophyllum flabellatum</i>	0	0	0	0	0	0	0	0	0	0
<i>Zygodon</i>	0	0	0	0	0	0	0	0	0	0
<i>Hypnum</i>	0.004	0	-0.008	0.013	0	0.004	0.013	0.013	-0.013	0
<i>Macromitrium</i>	0	0	-0.013	0	0	0	0.006	0	0	0
<i>Cyathophorum</i>	0	0	0	0	0	0	0	0	0	0
<i>Hypnodendron</i>	0	0	0	-0.006	0	0	0	0	0	0
Hookeriaceae	0	0	0	0	0	0	0	0	0	0.013
<i>Hymenophyllum marginatum</i>	0.013	-0.013	0	0	0	-0.013	-0.013	0	0	-0.013
<i>Chiloglottis</i>	0	0	0	0	0	0	0	0	0	0
<i>Lopidium</i>	0	0	0	0	0	0	0	0	0	0
Number of increases	1	1	3	5	1	3	5	4	4	1
Number of decreases	21	9	9	5	1	3	5	4	8	4

In spite of the impression of greater levels of change on Logs, the bulk of differences (~ 80 %) were still less than ± 0.025 (classes 4 to 6) with 23.1 % of taxa/distance combinations indicating no change (Table 5.5). Decreases were again concentrated near the edge, with twenty-four at 0 m and seventeen at 10 m. There were also seventeen decreases at the control 100 m distance and sixteen at 110 and 150 m (Table 5.7). Differences at 10 m are thus not different to levels of change that can

occur elsewhere. Increases in frequency after logging were spread more haphazardly across the matrix, but tended to occur away from the edge (Table 5.7). Most increases were small (< 0.025 - class 6) and could be attributed to sampling noise.

Table 5.7 - Differences in average frequency for each taxon found on Logs before and after edge creation. Orange shading = decreases, blue = increases (see Table 5.5 for ranges).

Logs	Impact					Control				
	0	10	20	50	100	100	110	120	150	200
<i>Blepharidophyllum</i>	-0.125	-0.038	0	-0.038		-0.017	-0.019	-0.025	0	
<i>Wijkia</i>	-0.088	-0.008	0.017	-0.008	0.025	-0.050	-0.029	-0.062	-0.042	-0.038
Lepidozids	-0.088	-0.004	0.013	0.025	0.025	0.021	-0.008	0	0.004	0
Schistochilaceae	-0.075	-0.025	0	0.008	0.044	-0.046	-0.021	-0.013	-0.004	-0.013
<i>Sematophyllum</i>	-0.069	-0.004	-0.008	-0.008	-0.006	-0.025	-0.017	-0.013	-0.017	-0.075
<i>Grammitis</i>	-0.067	-0.038	-0.025	-0.038	0.013	-0.025	-0.038	-0.004	-0.017	0.013
Dicranaceae	-0.054	-0.004	-0.013	0.013	0.063	-0.008	-0.013	0.013	-0.004	-0.019
Acrobolbaceae	-0.050	-0.021	0.033	0.004	0.038	0.004	0	0.006	-0.006	0.025
<i>Leptotheca</i>	-0.050	0	0	-0.006		0				
<i>Bazzania</i>	-0.042	-0.025	-0.004	0.017	0.044	-0.025	-0.008	0.029	-0.021	-0.013
Pelt/Cupr	-0.038	-0.029	-0.006	-0.025	0.019	-0.017	-0.021	0.008	0.156	0
<i>Ptychomnium</i>	-0.029	-0.004	0.021	0.004	-0.038	-0.017	-0.029	0.004	0.106	-0.006
Hookeriaceae	-0.025	0	0	0		0	0	-0.025	0.106	0.013
<i>Plagiochila</i>	-0.025	0	0	0.006	0.025				-0.013	0.006
<i>Weymouthia</i>	-0.025	0	0.044	-0.013	0.013	0.013	0	0	0.013	0
<i>Rhizogonium</i>	-0.019	-0.006	-0.004	-0.013	0	0.025	0	0.008	-0.017	-0.013
<i>Hypopterigium</i>	-0.019	0		0.013	0.013	0.008	0.008	-0.013	0.075	
<i>Glyphothecium</i>	-0.013	-0.013	-0.013	-0.004	-0.013	-0.050	-0.013	0.013	-0.075	0
<i>Ctenopteris</i>	-0.013	0	-0.013	-0.013		0	-0.025	0	0	
<i>Blechnum</i>	-0.013	0	0	0.013	0.025	0.013	0	0.013	0.013	0.013
<i>Leucobrium</i>	-0.013	0	0	0.025	0	-0.013	0	-0.038	-0.013	0.013
<i>Hypnum</i>	-0.013	0.004	-0.004	0.021	0.006	-0.017	0.004	0.054	-0.054	-0.006
<i>Hymenophyllum australe</i>	-0.013		-0.013	-0.013		0	-0.006			0
<i>Hymenophyllum marginatum</i>	-0.013		0.006	0	0.013	-0.006		0		
<i>Gackstroemia</i>	0	0	0.004	-0.017	0.013	0.008	0.006	0	0.010	
<i>Hypnodendron</i>	0	0	0.006	0.029	0.031	-0.008	0.004	0	0.075	-0.006
<i>Hymenophyllum rarum</i>	0	0.006	-0.056	-0.013	0.019	-0.008	-0.008	0.019	-0.031	0.013
<i>Hymenophyllum flabellatum</i>	0.013	0	0			-0.013	0	0	-0.025	
<i>Macromitrium</i>		-0.025	-0.019	-0.013	-0.013	0	-0.006	-0.013	-0.050	
<i>Lopidium</i>		-0.013	0.013							
<i>Riccardia</i>		-0.013								
<i>Trichocolea</i>		-0.006	-0.004	-0.008	0.019	0.004	0	0.013	-0.013	0
<i>Tmesipteris</i>		0	-0.013			0.004		0		
<i>Cyathophorum</i>		0	0			-0.013	0			0
<i>Dicksonia</i>		0	0							
<i>Hymenophyton</i>			-0.013				0			
<i>Bryum</i>			0							
<i>Rumohra</i>			0.013							
<i>Grimmia</i>			0.025							
<i>Chiloglottis</i>								0		
<i>Polystichum</i>							-0.013	0	0.025	
<i>Tayloria</i>					-0.013					
<i>Zygodon</i>						0	0			
Number of increases	1	2	11	11	18	9	4	10	10	7
Number of decreases	24	17	15	15	5	17	16	9	16	9

The largest decreases (class 1) occurred only at 0 m for *Blepharidophyllum*, *Wijkia* and the Lepidozids (Table 5.7). Class 2 differences were concentrated at 0 m and included the Schistochilaceae, *Sematophyllum*, *Grammitis* and the Dicranaceae, but also occurred at 20 m (*Hymenophyllum rarum*), 120 m (*Wijkia*), 150 m (*Glyphothecium* and *Hymenophyllum australe*) and 200 m (*Sematophyllum* again; Table 5.7).

Class 3 had five representatives at 0 m, Acrobolbaceae, *Leptotheca*, *Bazzania*, Pelt/Cupr and *Ptychomnium* (Table 5.7) and, although it was otherwise widespread across the taxa/distance matrix, it appeared to be concentrated amongst taxa that responded more to the edge (i.e. the upper portion of the table; Table 5.7). This may be because taxa, which are sensitive to an edge effect, may also respond to smaller scale disturbances and suggests that the best indicators of edge effects are also likely to be variable at other distances.

With frequency data integrated Across substrates, the difference between surveys for each taxon was similar to Logs (Table 5.7; Table 5.8). The level of no changes was 21.4 % of taxa/distance combinations (Table 5.5), which, when combined with small changes (classes 4 and 6), encompassed the bulk (74.6 %) of combinations (Table 5.5). The level of little or no change across the taxa/distance matrix is thus the dominant factor, regardless of the strata (Stems, Logs or Across substrates).

Decreases were again most common near the edge with thirty at 0 m compared to twenty-four at 20 and 110 m, but was as low as five at the impact 100 m distance (Table 5.8). Class 1 decreases occurred mostly at 0 m where it comprised seven taxa: *Grammitis*, the Acrobolbaceae, *Blepharidophyllum*, Lepidozids, the Schistochilaceae, *Wijkia* and the Dicranaceae (Table 5.8). The only other representative of class 1 occurred at control 100 and 110 m for the orchid *Chiloglottis* that otherwise occurred only at 50 m. Class 2 decreases comprised *Sematophyllum*, *Hymenophyllum australe*, *Blechnum*, and *Plagiochila* (Table 5.8). This class also occurred at 10 m (*Grammitis* and *Blepharidophyllum*), 20 m (*Grammitis*), 50 m (*Wijkia*), 120 m (*Wijkia* and *Leucobrium*), 150 m (*Hypnum*) and 200 m (*Wijkia*).

Class 3 comprised six taxa; *Weymouthia*, Pelt/Cupr, the Hookeriaceae, *Leucobrium*, *Leptotheca*, and *Ptychomnium*, but, as with Logs, this class was well dispersed across other distance/taxa combinations (Table 5.8). Increases also followed a similar pattern to Logs (i.e. tending to occur away from the edge), although perhaps not as strongly, with up to eighteen at the impact 100 m point (Table 5.8).

Table 5.8 - Differences in average frequency for each taxon Across substrates before and after edge creation. Orange shading = decreases, blue = increases (see Table 5.5 for ranges).

No substrate	Impact					Control				
	0	10	20	50	100	100	110	120	150	200
<i>Grammitis</i>	-0.15	-0.063	-0.058	-0.033	0.031	-0.029	-0.033	-0.021	-0.029	0
<i>Acrobolbaceae</i>	-0.127	-0.042	0.021	-0.021	0.038	-0.004	0.006	0.006	0.033	0.025
<i>Blepharidophyllum</i>	-0.125	-0.063	-0.013	-0.013	0	-0.017	-0.019	-0.021	0	
<i>Lepidozids</i>	-0.117	0	-0.004	0.013	0.025	0.025	-0.008	0.021	0	0.013
<i>Schistochilaceae</i>	-0.113	-0.033	-0.008	0.008	0.075	-0.033	0.004	-0.008	0	0.025
<i>Wijkia</i>	-0.108	-0.017	-0.017	-0.054	0.038	-0.05	-0.029	-0.054	-0.042	-0.069
<i>Dicranaceae</i>	-0.075	-0.013	-0.042	0.021	0.050	-0.008	-0.017	0.008	0.004	0.013
<i>Sematophyllum</i>	-0.075	-0.013	-0.004	-0.008	-0.013	-0.025	-0.017	-0.013	-0.021	-0.038
<i>Hymenophyllum australe</i>	-0.075	0.025	-0.006	-0.013	0	-0.013	-0.035		0	0
<i>Blechnum</i>	-0.063	0	-0.025	0.013	0.013	0	-0.004	0.013	0.025	0.013
<i>Bazzania</i>	-0.058	-0.029	-0.017	0.013	0.050	-0.029	-0.017	0.025	-0.021	0.006
<i>Plagiochila</i>	-0.056	0	0.013	0.006	0.025	0	0		0.006	0.006
<i>Weymouthia</i>	-0.05	-0.006	0.050	-0.025	0.013	0.006	-0.013	0.006	0	0
<i>Pelt/Cupr</i>	-0.038	-0.046	-0.013	-0.025	0.019	-0.042	-0.017	0.017	0.163	0
<i>Hookeriaceae</i>	-0.038	-0.017	0	-0.038	0	-0.017	-0.013	-0.025	0.025	0.038
<i>Leucobrium</i>	-0.031	0	-0.013	0	0	-0.038	0	-0.063	-0.013	-0.006
<i>Leptotheca</i>	-0.031	0	0	-0.008		0	0			
<i>Ptychomnium</i>	-0.029	-0.004	-0.004	-0.017	0.031	-0.008	-0.033	-0.021	0.004	-0.006
<i>Trichocolea</i>	-0.025	-0.013	-0.013	-0.021	0.006	0	0	0.013	-0.013	0
<i>Hymenophyton</i>	-0.025		-0.013	0			0			
<i>Hypnum</i>	-0.017	0.004	-0.004	0.004	-0.013	-0.033	0	0.065	-0.058	-0.013
<i>Hymenophyllum rarum</i>	-0.013	-0.021	-0.042	-0.006	0.025	-0.008	-0.008	0.021	-0.025	-0.006
<i>Glyphothecium</i>	-0.013	-0.013	-0.035	-0.004	-0.019	-0.017	-0.013	0.008	-0.025	0
<i>Gackstroemia</i>	-0.013	-0.004	0.004	-0.017	0.056	0.013	-0.002	0	0.008	
<i>Ctenopteris</i>	-0.013	0	-0.013	-0.013		0	-0.013	0	0	
<i>Hymenophyllum flabellatum</i>	-0.013	0	0			-0.013	0	0	-0.025	
<i>Hypopterigium</i>	-0.013	0	0	-0.004	0.013	-0.013	-0.008	-0.025	0.063	
<i>Hymenophyllum marginatum</i>	-0.013	0.013	0.006	0	0.013	-0.006		0		-0.013
<i>Gahnia</i>	-0.013									
<i>Rhizogonium</i>	-0.002	-0.006	-0.013	-0.013	0.013	0.044	-0.013	0.008	-0.017	-0.013
<i>Hypnodendron</i>	0	0	-0.017	-0.033	0.044	-0.008	-0.017	0.025	0.050	-0.013
<i>Zygodon</i>	0					0	-0.004			
<i>Bryum</i>	0.013		0							
<i>Macromitrium</i>		-0.025	-0.006	-0.013	-0.013	0	-0.006	-0.013	-0.05	
<i>Lopidium</i>		-0.013	0.050	0					0	
<i>Pterostylis</i>		-0.013								
<i>Riccardia</i>		-0.013								
<i>Tmesipteris</i>		0	-0.013				0	0		
<i>Cyathophorum</i>		0	0			-0.006	0			0
<i>Dicksonia</i>		0	0	0.013						
<i>Sticherus</i>		0						0		
<i>Dawsonia</i>			-0.013							
<i>Tayloria</i>			0		-0.013					
<i>Rumohra</i>			0.013							
<i>Grimmia</i>			0.025							
<i>Chiloglottis</i>				0		-0.213	-0.096	-0.025	-0.025	
<i>Polystichum</i>						0	-0.019	0	0.025	
<i>Senecio</i>							0.013			
Number of increases	1	3	8	8	18	4	3	13	11	8
Number of decreases	30	21	24	20	5	22	24	11	13	9

5.3.2 Analysis at higher taxonomic levels

To test if analysis at higher taxonomic level might still suggest an edge effect with respect to epiflora composition, the combined data (Across substrates) was reconsidered at the family level. The resulting ordination (Figure 5.7) indicated much the same result as in the finer scale analysis (Figure 5.5). The 0 m points still indicated the largest change between surveys (axes 1&2 and 2&3), while impact and control transects also tend to separate (axes 1&3 and 2&3; Figure 5.7). The

directional nature of changes at 0 m observed on Logs, Stems and Across substrates was also maintained.

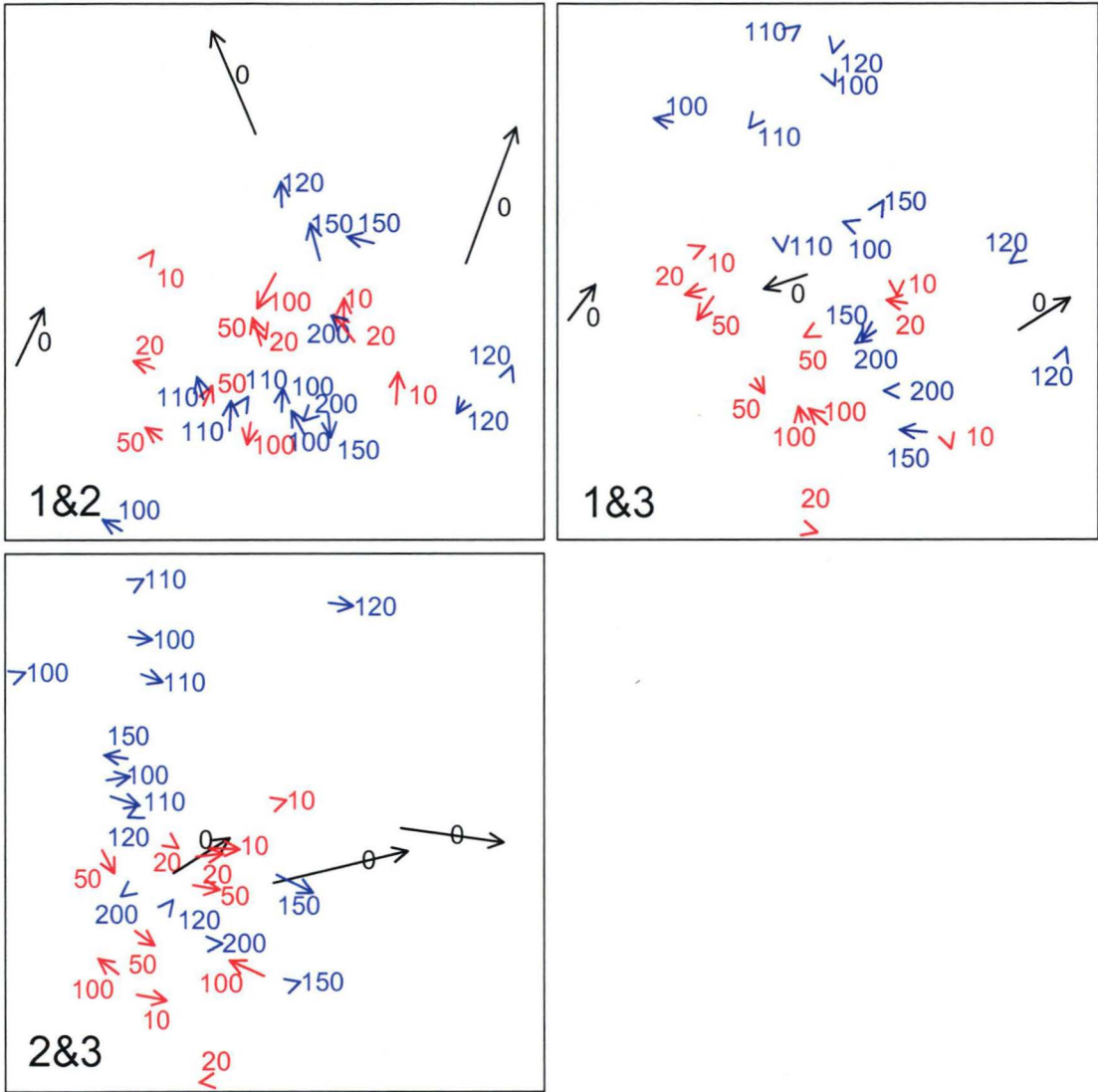


Figure 5.7 - MDS ordination in three dimensions of the epiflora composition irrespective of substrate with taxa considered at the family level. Red and blue vectors = control and impact transects respectively while black = 0 m points.

5.3.3 Vascular plant responses before and after edge creation

Ordination of vascular taxa percentage covers for each quadrat before and after logging indicated a separation of impact and control transects (red and blue vectors respectively), in line with large-scale flora changes observed in TASFORHAB surveys (axes 1&2 and 1&3; Figure 5.8; Chapter 1). There was little by way of clustering on the basis of distance in these broader groups, apart from 0 and 10 m points which were in relatively close proximity (axes 1&2 and 1&3; Figure 5.8).

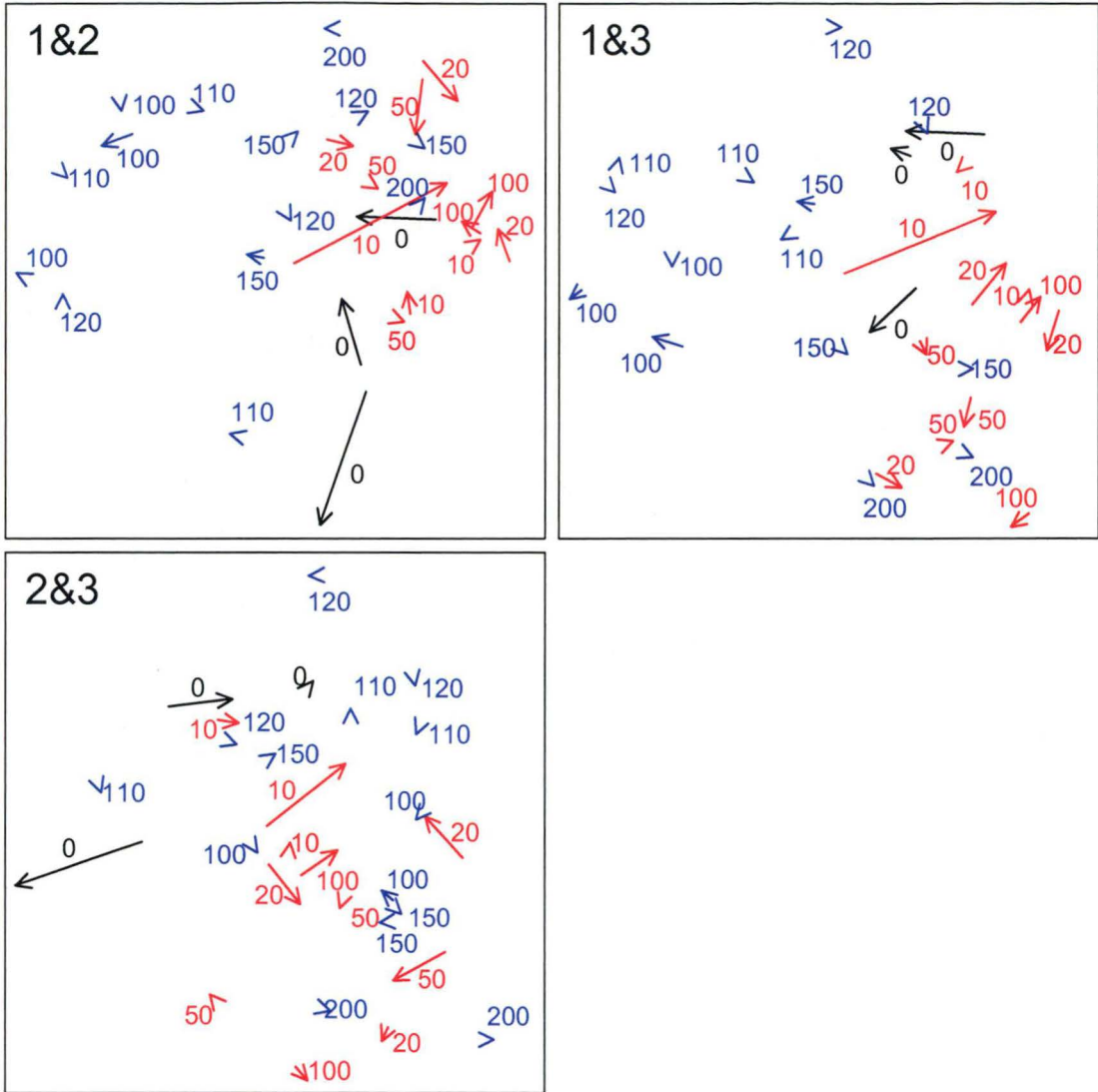


Figure 5.8 - MDS ordination in three dimensions based on percent covers of the broad scale vascular vegetation from pre and post-logging surveys with vectors indicating both direction and distance of quadrat changes. Red and blue vectors = control and impact transects respectively while black = 0 m points. 1&2, 1&3 and 2&3 refer to the axes on the ordination.

Points at the edge (black vectors) appear to have altered more than most other distances, although large differences occurred elsewhere (10, 20 and 50 m; axes 1&2, 1&3 and 2 &3; Figure 5.8). There is little directionality to the changes at any distance, suggesting that differences are specific to each quadrat, unlike differences in epiflora composition observed on Stems, Logs and Across substrates (Figure 5.3; Figure 5.5; Figure 5.8).

The average Euclidean distance (length of the vectors as before) indicated a gradient of decreasing difference in the vascular cover and composition with distance from the edge (Figure 5.9). In spite of a Kruskal-Wallis analysis indicating a significant difference (Table 5.9), a non-parametric Tukey-Kramer multiple comparison based on the same rank sums (using the protocol in Zar 1984) indicated no significant

differences. Both the Kruskal-Wallis and Tukey-Kramer multiple comparisons of ranks sums have substantially less power than their parametric counterparts. Significance may also have been compromised by the small sample size ($n = 3$ in each distance) spread over a large number of groups ($k = 10$).

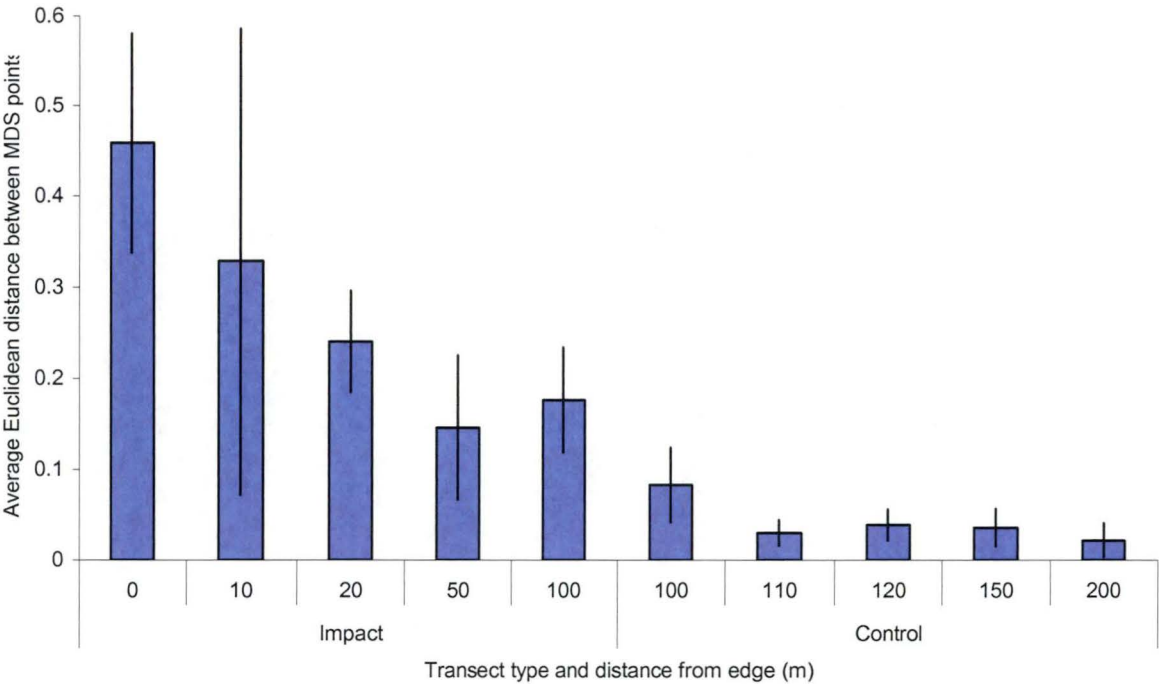


Figure 5.9 - Average Euclidean distance between the positions of each quadrat in terms of vascular plant composition and cover, before and after logging (i.e. length of the vectors; Figure 5.8). Bars are standard error.

Table 5.9 - Kruskal-Wallis test for significant differences in across distances in the Euclidean distances from pre and post-logging MDS points within the macro-flora (Figure 5.9). * = significant ($p < 0.05$). Subsequent non-parametric multiple comparisons found no changes.

Strata	Chi Square	DF	Prob. > Chi Square	Significance
Large vascular	18.0493	9	0.0346	*

If the controls indicate a suitable level of background change (and they seem to be consistent), this implies that the impact of logging on the vascular flora extended the full length of the impact transects (i.e. up to 100 m; Figure 5.9). Variability was generally larger on impact transect distances, especially at 10 m, reflecting the large difference at one quadrat at this distance on the MDS plot (Figure 5.8).

Apart from the 0 m distance, there was no correlation between differences in the macro-vegetation and epiflora changes which were generally confined to less than 10 m (Figure 5.6; Figure 5.9). While it should be remembered that it is not possible to directly compare these two analyses, the implication is that differences in the

epiflora are not a direct (or perhaps immediate) response to changes in the larger scale vegetation. Analyses based on the ordination data are entirely relative, so that, while it is apparent that quadrats on impact transects have changed more than on controls, it cannot be determined what this may imply in terms of the magnitude of changes in the system.

Differences in the average percentage cover of individual taxa (Table 5.10) indicated an appearance of a 15 % cover of *Atherosperma moschatum* at 0 m after logging, as well as a 5 % increase in the cover of *Eucalyptus*, a 25 % decline in the cover of *Acacia melanoxylon* and a 10 % drop in *Tasmannia lanceolata*. There were also large changes at 10 m, with a 30 % decrease in *Leptospermum* spp., a 10 % decrease in *Gahnia grandis* and a 15 % gain in *Eucalyptus* cover. At 20 m, there was another 10 % decline in *Gahnia* and a 30 % increase in *Hypolepis* cover (Table 5.10). At 50 m, *Gleichenia* decreased by 10 % and there were 10 % increases in *Eucryphia* and *Anodopetalum*. At 100 m, there was 10 % more *Nothofagus* and *Trochocarpa* cover and 15 % more *Cenarrhenes*.

On the controls, there were generally fewer large differences with 10 % more *Tasmannia* and *Hypolepis* at 100 m, a 10 % decline in *Nematolepis* at 110 m and a 15 % decrease in the cover of *Eucryphia* at 150 m (Table 5.10). These must represent a background level of canopy changes, with growth of some foliage and the loss of branches to small-scale disturbances. The majority of large changes in cover occur on the impact transects, suggesting an edge effect of 50 to 100 m.

The total number of changes at 0 m, regardless of size, was seventeen and included four groups appearing at 0 m for the first time (*A. moschatum*, AcaciaCot, EucCot and *Gonocarpus* spp. Table 5.10). Distances after 0 m had fewer changes (from four to twelve) and most had only one to two new taxa (usually AcaciaCot and NothCot, *Drimophyla* or *Galium*; Table 5.10). Specific indicators of edge effects within the macro-flora are problematic owing to inconsistent representation of taxa across the site and variable responses within taxa.

Of the four new taxa at the edge (*Atherosperma*, *Gonocarpus*, AcaciaCot and EucCot), the latter two were cotyledonary and seedling stages of *Acacia* spp. (either *A. melanoxylon* or *A. verticillata*) and *E. obliqua* (Table 5.10). The third tree seedling group, *Nothofagus cunninghamii* (NothCot), occurred at 10 m (Table 5.10).

The presence of *Atherosperma* has been attributed to damage caused by the windthrown tree (see Discussion- this chapter) while *Gonocarpus* appears to be new to the site.

Table 5.10 - Changes observed in vascular vegetation cover between surveys before and after logging. Note results have been truncated to multiples of 5 - a value 0 thus represents a change of less than 5 % (either increase or decrease). Shading indicates taxa found only in the second survey.

ANALYSIS_ID	Impact					Control				
	0	10	20	50	100	100	110	120	150	200
<i>Eucalyptus</i>	5	15				0		0		
<i>Nematolepis</i>	0	0	0		0		-10			
<i>Nothofagus</i>	0	0	-5	0	10			-5	0	0
<i>Gahnia</i>	0	-10	-10	-5			0			0
<i>Pimelea</i>	0		0		0	0	0			
<i>Aristotelia</i>	0						0			
<i>CoprQuad</i>	0					0	0		0	
<i>Pomaderris</i>	0			-5		-5	0	0	0	
<i>Eucryphia</i>	-5	0	0	10	0				-15	
<i>Bauera</i>	-5	0		0						
<i>Phyllocladus</i>	-5	0			5			0		
<i>Tasmannia</i>	-10					10				5
<i>AcaciaMel</i>	-25					-5				
<i>Anodopetalum</i>		0	0	10	0	-5				
<i>Leptospermum</i>		-30				0				
<i>Hypolepis</i>			30			10				
<i>Anopterus</i>			0	5		0			0	
<i>Histiopteris</i>			-5			0				
<i>AcaciaVert</i>										
<i>Blechnum</i>				0	5		0			
<i>Cenarrhenes</i>					15					
<i>Clematis</i>						0		0		
<i>Dicksonia</i>				0				0		
<i>Gleichenia</i>				-10						
<i>Melaleuca</i>										
<i>Polystichum</i>							0			
<i>Trochocarpa</i>					10					
<i>AcaciaCot</i>	0	0	0	0	0		0	0	0	0
<i>EucCot</i>	0									
<i>Gonocarpus</i>	0									
<i>Atherosperma</i>	15									
<i>NothCot</i>		0								
<i>Drimophyla</i>									0	
<i>Galium</i>							0	0		
Number of changes	17	11	10	11	10	12	10	8	7	4

5.4 Discussion

5.4.1 Vascular plant responses to edge creation

Shortly after the completion of logging, but prior to the regeneration burn, a modest sized eucalypt (~ 50 – 60 m tall) adjacent to the beginning of the impact transects was blown over. It fell diagonally through the 0 m point of one transect, angling across the other two. With damage to adjacent trees, the impact of the fallen tree extended to at least 50 m on two of the three transects (Pers. Obs.; Figure 5.10; Figure 5.11).



Figure 5.10 - The edge of the Small coupe showing the eucalypt tree that fell through the site shortly after logging.



Figure 5.11 - The same eucalypt as in Figure 5.10 indicating something of the damage resulting from its fall. The small red smudge at the right of the image is a marker at the edge (0 m).

Increased tree falls at newly created edges have been noted elsewhere (Oliveira-Filho *et al.* 1997, Restrepo and Vargas 1999, Sizer and Tanner 1999), and may impact on

the adjacent vegetation and microclimate, making a forest patch more prone to further disturbance (Laurance 1997). Mechanical damage as a result of this windthrown tree accounts for the substantial changes in cover observed across the impact transects. Increases in cover may result from stimulated canopy growth due to more light or as a result of coppicing from broken boughs, but could still be the direct result of damage, in that entire trees may be pushed out of position which would explain the large increase in the canopy cover of *Atherosperma* at 0 m in the second survey. The result is a sudden and radical alteration of canopy structure.

Within the shrub and tree component, the edge effect was found to be up to 100 m from the coupe boundary. This would appear to be largely due to the influence of the fallen tree, which was an edge effect, albeit a mechanical rather than microclimatic disturbance. The damage caused by this tree fall is likely to have smothered more subtle edge related responses in the macro-flora. Therefore, the influence of the microclimatic edge effect within this stratum is unknown.

Differences in the large-scale forest structure between control and impact areas were apparent, even including the disturbance at the edge. This would be largely due to the fire history of the site, which is known to comprise a complex mosaic of three large fires in 1898, 1914 and 1934, and include some surviving veteran trees from an undated burn (Hickey *et al.* 1999). There are, however, numerous other potential sources of change within the system, including (amongst others) responses to slope, soil moisture and type, nutrient availability and smaller scale disturbances resulting in varying degrees of forest gap.

Such dynamics may explain the substantial differences in vascular forest composition observed over comparatively short distances (~ 10 m) and the lack of consistent direction in multivariate changes with time. This suggests that the vascular vegetation at any particular point is unique and likely to respond individually to disturbances (such as edge creation) according to the susceptibility of its component flora. Hence, while there may be larger differences nearer the edge, there was unlikely to be a consistent pattern of response, particularly over a relatively short temporal scale (~ 12 months). For these reasons, no single taxon could be identified as a specific indicator of the edge effect, although this does not preclude the possibility that the longer-term influence of the edge may result in substantial changes within particular vascular groups (see Chapter 7). However, within the

current framework, the development of generalist views on responses of larger vegetation to edges in Tasmanian wet forests appears to be problematic.

There was no apparent invasion by any pest species at the time of the study. Apart from *Atherosperma*, the only other species that appeared to be new to the site was *Gonocarpus*, which also appeared at 0 m. The latter also appeared at the edge of the coupe at Warra (see Chapter 2; Chapter 1) and might suggest that this species prefers disturbed habitats. Other recruits (cotyledons of *Acacia*, *Eucalyptus* and *Nothofagus* - *AcaciaCot*, *EucCot* and *NothCot* respectively) were already present as adults. Within the epiflora, there were no new taxa, although the weedy *Senecio* genus was present in the system prior to logging.

Acacia seedlings occurred at most distances and is thus unlikely to be in response to edge creation. *Acacia* is known to remain present within a system as seed for considerable periods (Gilbert 1959, Cremer and Mount 1965, Hickey 1993). Apart from wildfires, it may respond to smaller disturbances, such as the eucalypt fall at the edge, but may also include a response to trampling during plot measurement.

In terms of recruitment, early successional, shade intolerant tree and shrub species have been found in high abundance in edges (Wales 1972, Ranney *et al.* 1981, Laurance 1991, Laurance *et al.* 1998, Sizer and Tanner 1999, Gehlhausen *et al.* 2000, Oosterhoorn and Kappelle 2000) although Williams-Linera (1990) and Williams-Linera *et al.* (1998) found no such patterns, and Restrepo and Vargas (1999) found no change in seed germination with distance from the edge. While cotyledonary stages of *Eucalyptus* and *Nothofagus* were found at the edge, there was no suggestion of a large influx of recruits, although more time may have been required to establish this point. However, the successional status of Tasmanian forest systems is considered largely dependent upon the frequency and intensity of fires (Gilbert 1959, Jackson 1968, Read 1999). As this edge was unburnt, its ability to act as a zone for recruitment may be limited relative to forest edges in other systems.

In any case, *Nothofagus cunninghamii* and *Eucalyptus obliqua* tend to be poorly dispersed and are not generally present in seed banks (Cremer and Mount 1965, Hickey *et al.* 1982, Neyland and Brown 1994). Hence, the germination of eucalypt and myrtle seedlings at the edge is likely to have derived from nearby sources. While *E. obliqua* responds rapidly to disturbance, the survival of seedlings at 0 m is

considered doubtful even with increased light (see Chapter 4), particularly in the absence of an ash bed (Gilbert 1959, Jackson 1968, Hickey 1993). *Nothofagus* at the edge may have resulted from seed fall around February (Hickey *et al.* 1982), some of which may survive, but any influence on the composition of the edge may take many years to become manifest. This possibility has been explored in the study of vegetation in edges of different ages (Chapter 7).

The vascular plant based estimate of edge effect at the Small site (50 to 100 m) compares favourably with other research: i.e. 20 to 45 m (Palik and Murphy 1990; Michigan), 40 m (Matlack 1994; Delaware and Pennsylvania; Neyland and Brown 1994; Tasmania), 10 to 50 m (Fraver 1994; North Carolina), 50 m (Young and Mitchell 1994; New Zealand; Ruben *et al.* 1999; Northern USA), 40 to 80 m (Camargo and Kapos 1995; Amazon), 80 m (Gehlhausen *et al.* 2000; Illinois) and 16 to 137 m (Chen *et al.* 1992; Pacific Northwest). With similar penetration distances, this raises the question as to whether edge effects detected elsewhere using the vascular flora are driven more by physical disturbance (canopy damage, greater windthrow, etc) than by changes in microclimate, as would appear to be the case in this study. Ongoing damage at edges from increased wind exposure (*sensu* Laurance 1991) may continue to smother any climatic responses. This may penetrate up to 200 m from the edge (Laurance 1991; Queensland).

In the longer term, there may be an effect of microclimate on either the physiology of remaining trees, in terms of the development of a vertical canopy (*sensu* Ranney *et al.* 1981, Williams-Linera 1990, Matlack 1994, Camargo and Kapos 1995, Cadenasso *et al.* 1997, Kapos *et al.* 1997, Luczaj and Sadowska 1997, Sizer and Tanner 1999) and/or in terms of the composition of the border vegetation through the invasion of shade intolerant species. A more noticeable edge effect may thus develop after a number of years; however this may require the maintenance of the adjacent cleared area for an extended period. With the regeneration of the coupe, an edge effect may become blunted (Mesquita *et al.* 1999, Gascon *et al.* 2000) and then disappear (Matlack 1994). Only Chen *et al.* (1992) considered vegetation changes at coupe edges, but these were all more than twelve years old. While Matlack (1994) and Mesquita *et al.* (1999) examined overgrown edges, the edges in question had been maintained for a period before being abandoned. Comparison with this study is thus confounded.

Although Lovejoy *et al.* (1986) observed a decline in the health of border vegetation within a few days of logging, it remains questionable as to what changes in either vascular or non-vascular flora can be attributed to short term exposure to microclimate changes, and what differences are the result of physical damage caused as a result of the felling of trees and/or creation of firebreaks. Large trees and shrubs may not respond to any microclimate change in the short term, except possibly in terms of recruitment. Epiflora composition that is intimately tied to substrate availabilities and the microclimate regime (that is itself integrated with macro-flora composition) may lag even further behind edge creation than large vascular plants.

5.4.2 Epiflora responses to edge creation

Changes in the epiflora within twelve months of edge creation were best observed on Logs, Stems and Across substrates. Multivariate analyses for all three strata indicated a consistent edge effect of less than 10 m, probably based on the prevailing drier conditions. The sheltered aspect of the edge (facing the northwest) and the dense thamnian understorey may have ameliorated the edge effect extremes. When combined with the influence of the regeneration on the coupe (*sensu* Mesquita *et al.* 1999, Gascon *et al.* 2000), the future directions for epiflora at the edge are difficult to predict, although some inferences can be drawn from the study of coupe edges of different ages (Chapter 7). There was little correlation with macro-flora changes, although these may take longer than twelve months to develop.

The epiflora on Logs was considerably more dynamic than that occurring on Stems, in spite of the fact that all taxa on the latter also occurred on Logs. Hence, while Logs may support a similar epiflora composition to that on Stems, they have different levels of background variation, suggesting different rates and/or degrees of disturbance. This may be due to the increased activity of vertebrate and invertebrate herbivores, collateral changes associated with decay process within the logs (*sensu* Söderström 1988) and/or the accumulation of larger amounts of leaf litter, as well as exposure to sun, rain, hail and snow with logs generally presenting more flat surface than stems to these forms of disturbance. Epiflora changes Across substrates were similarly more dynamic than Stems, and incorporated the Log-based differences, in addition to changes from the Ground, which was likely to be similarly more disturbance prone and include a level of anthropogenic influence.

Kantvilas and Jarman (1993) reported a personal communication from G.A.M. Scott (who has made substantial contributions to the study of bryophytes in southern Australia) to the effect that;

“...comparative richness of liverworts provides a measure of the humidity of the site”.

Within the analysis of the epiflora Across substrates, the majority (four of the six) of the bryophyte groups that were most responsive to the edge effect were liverworts rather than mosses. These included the Acrobolbaceae, *Blepharidophyllum*, the Lepidozids (all Lepidoziaceae other than *Bazzania*) and the Schistochilaceae. Apart from supporting G.A.M Scott's inference, this is also in line with other research on community structure of bryophytes, which has consistently found liverworts to be more sensitive to environmental stress than mosses. Kantvilas and Jarman (1993) indicate that liverworts proliferate in undisturbed, moist habitats with filtered or discontinuous light and shelter from desiccating wind. Söderström (1988), Lesica *et al.* (1991) and Kantvilas and Jarman (1993) compared the bryophyte communities between regenerated and unlogged forest, and found that liverworts were more adversely affected by logging than mosses, largely through altered humidity regimes (although substrate availability was also considered important). Pharo and Beattie (1997), in a more general study of bryophyte and lichen communities in southern Australia, found that the majority of liverworts (70 %) were found in riparian habitats (although they occurred elsewhere as well), and that this group had higher rates of species turnover than mosses, which they attributed to narrower habitat tolerances.

Mosses and liverworts both have leaves that are mostly one cell thick (Richardson 1981, Scott 1985) which should make them sensitive to desiccation and thus edge effects. Higher sensitivity of liverworts to water stress may be due to a lack of conductive tissue in all non-thallose forms (Scott 1985). Conversely, many mosses (described as endohydric) have a strand of elongated cells that act to move water from rhizoids to leaves (Richardson 1981). Other mosses (ectohydric) absorb water directly through stem and leaf tissues (Richardson 1981) and are possibly more similar to liverworts in terms of responses to water stress. Ectohydric mosses tend to form mats over large areas of substrate that act to restrict water loss (Richardson

1981). Many of the bryophyte groups that responded edge creation (see below) adopt this growth habit, suggesting that they may be prone to water stress.

5.4.3 Potential indicator taxa for edge effects

Regardless of the stratum considered (Logs, Stems or Across substrates), there were no definitive indicator groups at the level of individual taxa. Those taxa that responded most to the edge, also changed at other distances on both impact and control transects, probably in response to smaller scale disturbances. The trends observed in multivariate analyses were thus a cumulative response to large numbers of often small decreases at 0 m relative to other transect distances. On Logs and Across substrates, there was also a propensity for increases in taxa frequency to occur away from the edge.

Taxa that generally responded more to creation of the edge were *Grammitis* spp. *Blepharidophyllum*, the Lepidozids, Schistochilaceae, Dicranaceae, Acrobolbaceae, *Wijkia* and *Sematophyllum*, Pelt/Cupr, *Bazzania* and possibly *Blechnum*. While other taxa could be considered, these were either unevenly represented on some strata (*Leptotheca* and *Plagiochila*) or were thought to maintain physiologies that suggested a capacity for accommodating drier edge zones (i.e. the papery texture of *Ptychomnium*). Taxa were largely selected based on the differences observed Across substrates, which has the advantage of considering all taxa irrespective of substrate preferences and substrate availability.

Curiously, of the five taxa that incorporate species at (or near) the family level, four occur within this group (Acrobolbaceae, the Lepidozids, Schistochilaceae and Dicranaceae), and may suggest that indicators of an edge effect may be best considered at the family levels. It has been suggested elsewhere that anthropogenic disturbances tend to influence systems at higher taxonomic levels rather than natural variables which tend to operate in terms of species replacement (Warwick 1988a, 1988b, Agard *et al.* 1993), but the bulk of research in this area has focussed on marine systems where there is a relatively high diversity of phyla. While analysis of epiflora composition at the family level provided a useful result, there is a risk of losing information. The use of epiflora composition as an environmental indicator of edge effects is likely to be more readily advanced by such an approach, as it accounts

for some spatial variability in composition, although its use in the broader context (i.e. to other locations) is unknown.

Lack of edge response in many of the filmy ferns (*Hymenophyllum* spp.) was at odds with other research that has suggested that this group is sensitive to edge effects (e.g. Neyland and Brown 1994, Peacock 1994). Personal observations at the edge suggest that these taxa were stressed, with many dead and dying fronds. The tendency for long rhizoids in this family may allow a means of escaping harsh conditions by obtaining moisture from a broad area and through sprouting of new fronds in moist refuges. Large changes in *Hymenophyllum* species on *Dicksonia antarctica* (manfern) trunks in edges that were observed by Peacock (1994) may have been due to the more open callidendrous forest in that study. The lack of manferns at the site is likely to have limited the detection of an edge effect, as these act as important substrate for mosses, liverworts and epiphytic ferns (Chapter 3; Peacock 1994, Ough and Murphy 1997).

The Pelt/Cupr complex (comprising *H. peltatum* and *H. cupressiforme*) was a better indicator on Logs and Stems than other filmy ferns. The serrate (non-entire) frond margins from both species may assist with water runoff, similar to drip tips on leaves (although see Ellenberg 1985) and might imply a propensity toward wetter habitats, making this group more vulnerable to edge effects. There is, however, ongoing debate as to the role of non-entire leaf margins (e.g. Gottschlich and Smith 1982, Wilson *et al.* 1991, Baker-Brosh and Peet 1997) and this inference is speculative.

Although the Hymenophyllaceae other than the Pelt/Cupr group were largely unresponsive at Small, it was considered likely that this group might be an important indicator at older edges. The final group of indicators thus comprised nine families: the Acrobolbaceae, Lepidoziaceae, Schistochilaceae, Dicranaceae, Scapaniaceae, Sematophyllaceae, Grammitidaceae, Hymenophyllaceae and Blechnaceae. These will be further examined in the survey of edges of different ages (Chapter 7)

5.4.4 Before and after, control and impact designs

The chief advantage of the BACI approach to investigating edge effects, regardless of the vegetation strata, is an ability to identify differences rather than simply describing gradients. This makes fewer assumptions about the pre-disturbance system and may offer more inferences about both temporal and/or spatial processes.

Laurance *et al.* (1998) considered tree mortality within tropical forest fragments with five surveys over an eighteen-year period, including measurements prior to logging and controls in undisturbed forest. This is thus a rare instance of a BACI study involving edge effects. Sizer and Tanner (1999) and Brosnahan *et al.* (1999) also considered the same sites before and after edge creation, but did not incorporate concurrent controls.

The degree of control within edge surveys varies substantially, but the majority of research appears to use a single distance to represent undisturbed forest (Williams-Linera 1990, Brothers and Spingarn 1992, Chen *et al.* 1992, Fraver 1994, Jose *et al.* 1996, Esseen and Renhorn 1998, Williams-Linera *et al.* 1998, Sizer and Tanner 1999, Gehlhausen *et al.* 2000, Oosterhoorn and Kappelle 2000) and thus fails to adequately measure background levels of variation at the same scale as sites close to the edge. Another advantage of this study was the observation of background levels of change in both epiflora and large vascular plants, which allowed the placement of the edge effect within a broader context.

In terms of design, the method employed in this study is the same as the original Green (1979) approach, with single impact and control locations surveyed once before and once after disturbance. Underwood (1994) felt that it was necessary to consider multiple controls before and after logging to better understand the nature of variation in the undisturbed system. It has been argued, however, that single samples were statistically and logistically more achievable and that extra sampling may only incorporate unnecessary noise (Stewart-Oaten and Bence 2001). There is still quite vigorous debate as to the best approach to impact assessment designs (see Chapter 4 for a larger discussion).

While the design employed at the Small coupe might not match Underwood (1991, 1994) in terms of experimental rigour, it is considered an improvement over nearly all earlier vegetation research on edges for which there are no *a priori* data (e.g. Wales 1972, Ranney *et al.* 1981, Williams-Linera 1990, Laurance 1991, Chen *et al.* 1992, Fraver 1994, Young and Mitchell 1994, Jose *et al.* 1996, Williams-Linera *et al.* 1998, Gehlhausen *et al.* 2000, Oosterhoorn and Kappelle 2000). Improvements to the current design would incorporate a greater number of transects to increase the number of quadrats within each distance (both impact and controls). Within the

framework of the current project, this was not logistically possible, and the veracity of these results at other sites before and after logging is unknown.

5.5 Conclusions

Other studies of edge effects rarely have the luxury of obtaining data on the undisturbed system. This study offers a strong indication that the lack of a BACI approach may severely compromise the identification of both the degree of expression of the edge effect at the border and the penetration distance into undisturbed forest. Edge research in the wider context would appear to benefit from multiple surveys even within established edges, as this may infer more about processes than current approaches that have adopted a static view (Murcia 1995).

Multivariate analysis of epiflora composition on Logs, Stems and Across substrate were the best indicators of an otherwise narrow (less than 10 m) edge effect at the site after around twelve months edge exposure and correlated with the microclimate gradient observed across the site in warmer months (Chapter 4). This penetration distance was shown to be a response to small changes in a large number of taxa in the edge and the identification of indicator taxa was thus problematic. Despite this, nine potential indicators groups were identified: the Acrobolbaceae, Lepidoziaceae, Schistochilaceae, Dicranaceae, Scapaniaceae, Sematophyllaceae, Grammitidaceae, Hymenophyllaceae and Blechnaceae.

Examination of the epiflora composition at the family level still returned a strong multivariate indication of the edge effect and it is recommended that future analyses of epiflora composition in edges be conducted at this level (see Chapter 7). The veracity of the specific indicators should also be examined.

Within the large vascular flora, the detection of an edge effect was also readily achieved through a multivariate approach. The effect itself was found to be up to 100 m, however the impact of a single large windthrown tree is likely to have smothered any response to microclimate. The designation of indicators within this stratum was not possible due to the mechanical rather than microclimatic nature of the disturbance and the uneven spread of species across the site.

6 Gradients in microclimate in forest edges of different ages

6.1 Introduction

Research on microclimate gradients in forest edges has considered borders that are as little as one year up to more than one hundred years old (Young and Mitchell 1994, Gehlhausen *et al.* 2000), but, while the time since edge creation is widely thought to be important in edge dynamics (Williams-Linera 1990, Matlack 1993, Kapos *et al.* 1997, Parry 1997, Turton and Freiburger 1997, Esseen and Renhorn 1998, Sizer and Tanner 1999), few studies have attempted to measure temporal changes in edge microclimates. Edges are thus generally regarded as static situations (Murcia 1995, Gascon *et al.* 2000) from which generalisations are rare (Murcia 1995).

In spite of little research in this area, the microclimatic effects are thought to decline with age (e.g. Wales 1972, Ranney *et al.* 1981, Matlack 1993, Cadenasso *et al.* 1997, Kapos *et al.* 1997, Williams-Linera *et al.* 1998). This may be because younger edges lack the closing “side canopy” that is common to older borders (Ranney *et al.* 1981, Williams-Linera 1990, Brothers and Spingarn 1992, Matlack 1993, 1994, Camargo and Kapos 1995, Cadenasso *et al.* 1997, Kapos *et al.* 1997, Luczaj and Sadowska 1997, Sizer and Tanner 1999) which appears to largely restrict microclimatic changes (Matlack 1993, 1994, Cadenasso *et al.* 1997, Kapos *et al.* 1997) through provision of a level of buffering of the exposed climate in the adjacent exposed matrix, similar to that of an undisturbed forest canopy. However, edge dynamics in general are also thought to become more complex (Matlack 1993, Kapos *et al.* 1997). While side canopies are often reported, the time required for their development and the level of edge effect amelioration are largely unknown (although see Ranney *et al.*

1981, Williams-Linera 1990). There is little information on the nature of microclimate in edges that are not maintained (i.e. edges of regenerated coupes, but see Chen *et al.* 1995, Parry 1997).

Research with a specific focus on age-related microclimate changes in edges is correspondingly limited. Williams-Linera (1990) investigated different edges of five different ages (0.8, 5, 7, 10 and 12 years old) in the Panamanian tropics and reported a more open canopy at greater distances from young edges. Matlack (1993) in the eastern USA, considered three different age-related classes of edge, but also found larger penetration distances at younger sites. The Matlack (1993) study was better replicated than Williams-Linera (1990), but the combining of all younger edges as a single “recent” group (1 - 4.5 years old) may have smothered smaller scale temporal trends (i.e. responses on the scale of 1 - 2 years) at a stage when fluxes in the edge are likely to be largest (see below). There was also a substantial age difference between the “recent” and “closed” edges with a fully developed side canopy (~ 60 years), which may further confound the detection of age-related gradients. Matlack (1993) included an “Embedded” class of edges (> 44 years) comprising maintained edges that had been abandoned and overgrown by secondary forest. Each of the Matlack (1993) age class also combined data from edges with a range of aspects (although mostly southerly). Edge aspect is known to have a strong influence on the microclimate regime (e.g. Laurance and Yensen 1991, Matlack 1993, Fraver 1994, Young and Mitchell 1994, Murcia 1995, Parry 1997) and the integrating of information across aspects may also have confounded the results.

Kapos *et al.* (1997) examined the same edge in the Brazilian Amazon before and after a 5-year interval, with the simple edge gradient in VPD observed in the initial survey of the edge (at less than 6 months) virtually lost in the second survey. The development of the side canopy was again regarded as the factor limiting microclimate changes as the edge aged. Williams-Linera (1990) and Kapos *et al.* (1997) found side-canopy closure to take as little as 5 years in the tropics, in contrast to temperate forests, where up to 20 years was required (Ranney *et al.* 1981).

Consideration of the successional dynamics in edges is complicated at the border of regenerating clearfelled coupes, as the exposed area is itself undergoing substantial micro-environmental change with vegetation regrowth. The nature of the abutting matrix has been regarded as a critical factor in edge effects dynamics (Kapos *et al.*

1997, Mesquita *et al.* 1999, Gascon *et al.* 2000), and edges of coupes thus combine concomitant changes in vegetation and microclimate in both the unlogged forest and the exposed area (Fraver 1994, Mesquita *et al.* 1999). Younger coupe edges are thus likely to be in a state of flux, the degree of which will depend upon the level of exposure, the degree of disturbance to vegetation in the edge, the regeneration on the adjacent coupe and the time required for the development of side canopy.

In this chapter, changes in the seasonal microclimate will be considered at the edges of four regenerating Tasmanian wet forest coupes that vary in age from less than 6 months to 15 years. The specific questions are:

1. What are the seasonal patterns in microclimate in edges of different ages?
2. Is there a moderation in the fluctuation of microclimate in forest edges as adjacent coupe regenerates?

6.2 Methods

Four edges of different ages were selected from within the Warra LTER region; One-year (from the BACI study; Chapter 4) at 0 - 6 months old, Two-year (2 - 3 years old), Five-year at ~5 years old and 15-year at ~15 years old at the time of the study (Chapter 1; Figure 6.1). Selection of sites was based on the age of the edge (time since the coupe regeneration burn), ease of access and its proximity to an area of undisturbed forest to house controls. An exposed position at least 100 m in diameter was also required for exposed climate measurements. Most sites had an edge facing a south-southwest aspect, with the exception of the One-year site, where it was to the northwest. A full description of each site is included in Chapter 1.

Microclimate measurements comprising photosynthetically active radiation (PAR), temperature and vapour pressure deficit (VPD) estimates were obtained, using the same microclimate data collection regime as in the BACI study, with the same sensor groups and an identical positioning of transects relative to the edge (see Chapter 4). The only difference to the BACI study was that climate data at locations other than One-year were collected from the winter of 1997 to the winter of 1998 and not to the autumn of 1999 (Table 6.1). The One-year site was unlogged for most surveys and hence differences in this edge after 6 months are sourced from Chapter 4.

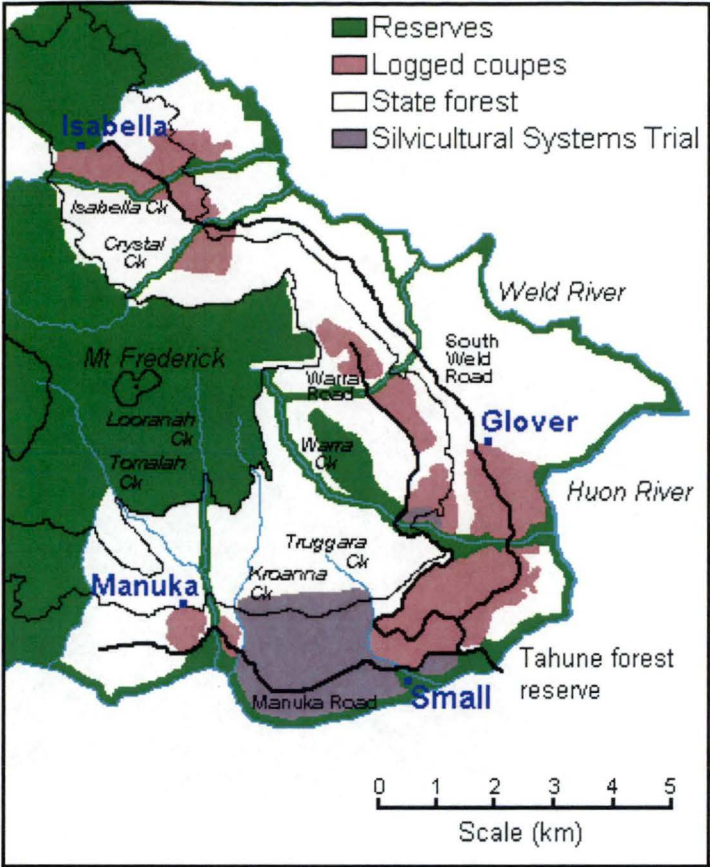


Figure 6.1 - The location of the four edges within the Warra LTER region. One-year coupe was the youngest (0 - 6 months) followed by the Two-year site (2 - 3 years), the Five-year (5 years) and the 15-year site (15 years). Map courtesy of Forestry Tasmania copied with permission.

Table 6.1 – Microclimate data collection dates. Surveys occurred from the winter of 1997 to the winter 1998 at all sites except for the 15-year site, where equipment was unavailable for winter 1997. Shaded area indicates deployments where logging was concluded at the One-year site.

Location	Season & year	Start date	Finish date	Location	Season & year	Start date	Finish date
One-year	Winter 1997	31/07/1997	01/08/1997	Five-year	Winter 1997	01/07/1997	11/07/1997
	Spring 1997	07/10/1997	17/10/1997		Spring 1997	04/11/1997	13/11/1997
	Summer 1997	15/01/1998	23/01/1998		Summer 1997	17/02/1998	25/02/1998
	Autumn 1998	28/04/1998	01/05/1998		Autumn 1998	12/05/1998	21/05/1998
	Winter 1998	09/08/1998	17/08/1998		Winter 1998	01/09/1998	31/08/1998
Two-year	Winter 1997	12/07/1997	23/07/1997	15-year	Winter 1997	-	-
	Spring 1997	19/10/1997	29/10/1997		Spring 1997	18/11/1997	30/11/1997
	Summer 1997	04/02/1998	13/02/1998		Summer 1997	31/01/1998	01/02/1998
	Autumn 1998	01/06/1998	31/05/1998		Autumn 1998	02/05/1998	11/05/1998
	Winter 1998	19/08/1998	30/08/1998		Winter 1998	01/08/1998	31/07/1998

VPD was calculated using the protocol in Appendix A. Data summaries and analyses were also similar to the BACI study and thus included average hourly maximum non-zero (i.e. daytime) PAR, average daily maximum and minimum temperatures and average daily maximum VPD. Owing to the lack of concurrent data between sites, data were analysed *within* each site for each season rather than across sites. Comparisons between sites are confounded by differences in weather between each sampling period but it was anticipated that microclimate differences

relative to the exposed positions would account for some of these changes. The average daily maximum temperature and VPD and the average slope across sites within the impact and control transects for each season, was calculated. Temperature and VPD maxima were linearly regressed against distance on for both the control and impact transects. The average slope per transect type could plotted for each season to give a better indication of temporal changes in any edge effect. Univariate statistics were calculated using the JMP software (Version 3.1.2, SAS Institute Inc. © 1989 – 1995).

6.3 Results

6.3.1 Photosynthetically active radiation

Photosynthetically active radiation (PAR) data were often incomplete (see Chapter 3 for an explanation), but seasonal differences in the magnitude of the PAR edge effect were readily apparent, with spring and summer levels at all logged edges substantially larger than autumn and winter measurements (Figure 6.2).

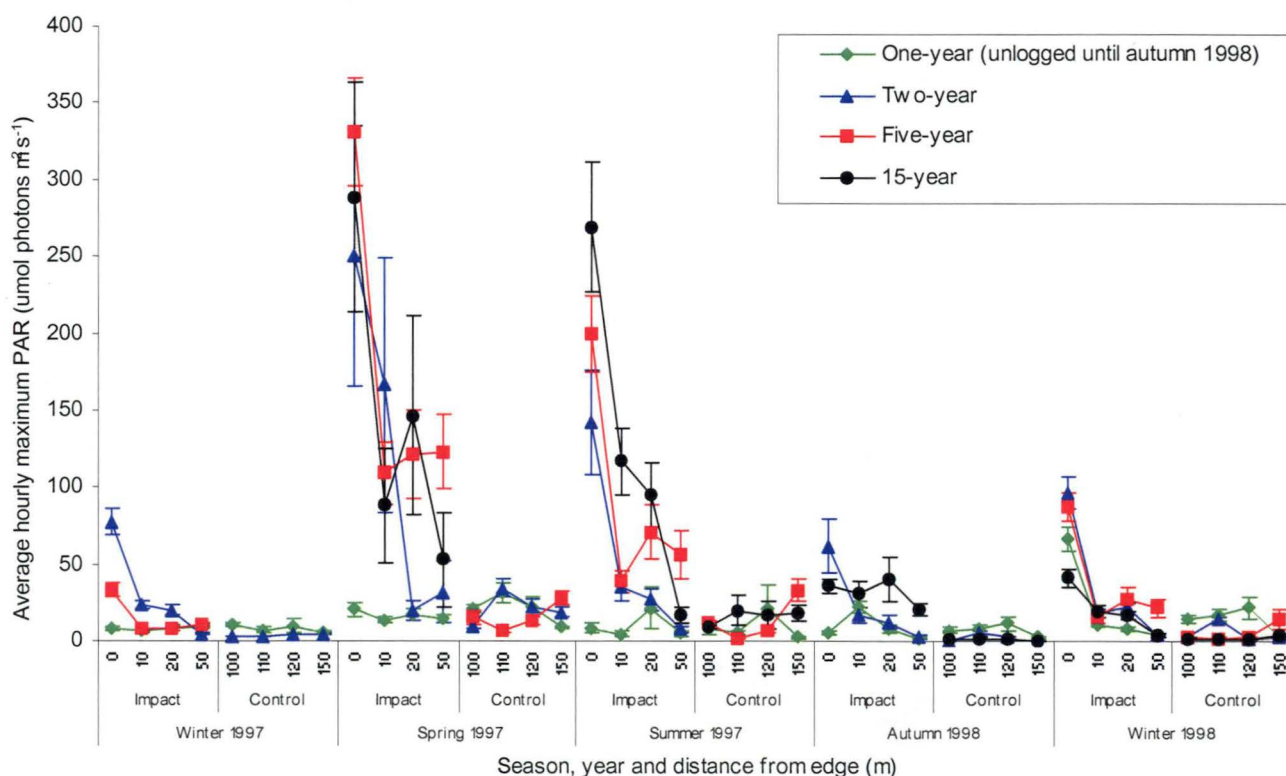


Figure 6.2 - Average hourly maximum daytime photosynthetically active radiation across five seasons (Winter 1997 – Winter 1998) at impact transects (0 – 50 m) and controls (100 – 150 m) at the One-year, Two-year, Five-year and 15-year sites. Bars are standard error.

Although the winter 1997 surveys were limited, an edge effect was apparent at the Two-year and Five-year sites (Figure 6.2) as 0 m points at both sites (77 and 33 μmol

$\text{m}^{-2} \text{s}^{-1}$ respectively) were significantly different from all other distances (Table 6.2; Table 6.3). The 10 and 20 m points at the Two-year site ($\sim 20 \mu\text{mol m}^{-2} \text{s}^{-1}$ at each; Figure 6.2) were also significantly different from the 50 m impact distance and all control distances (Table 6.2; Table 6.3). There were no significant differences at the One-year site (Figure 6.2) and no age trends.

Table 6.2 - Analysis of Variance (ANOVA) results for average hourly maximum PAR at each site within each season. NS = not significant, * = significant ($P < 0.05$), ** = very significant ($P < 0.01$), * = highly significant ($P < 0.001$).**

Season and site	DF	MS	MS Error	F Ratio	Prob. > F	Significance
Winter 1997						
One-year	7	191.47	315.38	0.6071	0.7501	NS
Two-year	7	36109.3	597.4	60.447	0.0000	***
Five-year †	3	12786.5	569.2	22.463	0.0000	***
15-year †	-	-	-	-	-	-
Spring 1997						
One-year	7	2355.24	916.27	2.57	0.0132	*
Two-year	7	189682	30472	6.225	0.0000	***
Five-year	7	1606582	60546	26.5348	0.0000	***
15-year †	3	300781	84086	3.5773	0.0163	*
Summer 1997						
One-year	7	1055.63	1137.97	0.9276	0.4871	NS
Two-year †	3	40407.2	350.78	11.5193	0.0000	***
Five-year	7	693135	27620	25.0955	0.0000	***
15-year	7	903972	44546	20.2932	0.0000	***
Autumn 1998						
One-year	7	894.719	136.789	6.5409	0.0000	***
Two-year	7	4889.23	610.95	8.0026	0.0000	***
Five-year †	-	-	-	-	-	-
15-year	7	23786.5	3122.2	7.6186	0.0000	***
Winter 1998						
One-year	7	36513	1302	28.0434	0.0000	***
Two-year	7	72611.9	873.4	83.1346	0.0000	***
Five-year	7	16385.2	590.3	27.7609	0.0000	***
15-year	7	8699.62	383.73	22.6715	0.0000	***

† indicates where data are absent or incomplete.

Table 6.3 - Tukey-Kramer Honestly Significant Difference (HSD) test for significant differences in the winter 1997 PAR data (only Two-year and Five-year had significant differences). Shaded headings indicate control transects, NS = not significant, “+” = significant.

Winter 1997									
Two-year									
	0	10	20	50	100	110	120	150	
0	NS								
10	+	NS							
20	+	NS	NS						
50	+	+	+	NS					
100	+	+	+	NS	NS				
110	+	+	+	NS	NS	NS			
120	+	+	+	NS	NS	NS	NS		
150	+	+	+	NS	NS	NS	NS	NS	
Five-year									
	0	10	20	50					
0	NS								
10	+	NS							
20	+	NS	NS						
50	+	NS	NS	NS					

In spite of being unlogged, there were significant differences at the One-year site in spring 1997, between 110 m ($31 \mu\text{mol m}^{-2} \text{s}^{-1}$) and the 10 and 150 m points (Table 6.2; Table 6.4), which suggests that significant differences in average hourly maximum PAR between distances need not necessarily be edge-related.

Table 6.4 - Tukey-Kramer HSD test for significant differences in the spring 1997 PAR data (all sites had significant differences). Shaded headings indicate control transects, NS = not significant, “+” = significant.

Spring 1997									
One-year									
	0	10	20	50	100	110	120	150	
0	NS								
10	NS	NS							
20	NS	NS	NS						
50	NS	NS	NS	NS					
100	NS	NS	NS	NS	NS				
110	NS	+	NS	NS	NS	NS			
120	NS	NS	NS	NS	NS	NS	NS	NS	
150	NS	NS	NS	NS	NS	+	NS	NS	NS
Two-year									
	0	10	20	50	100	110	120	150	
0	NS								
10	NS	NS							
20	+	NS	NS						
50	+	NS	NS	NS					
100	+	+	NS	NS	NS				
110	+	NS	NS	NS	NS	NS			
120	+	NS	NS	NS	NS	NS	NS	NS	
150	+	+	NS	NS	NS	NS	NS	NS	NS
Five-year									
	0	10	20	50	100	110	120	150	
0	NS								
10	+	NS							
20	+	NS	NS						
50	+	NS	NS	NS					
100	+	+	+	+	NS				
110	+	+	+	+	NS	NS			
120	+	+	+	+	NS	NS	NS	NS	
150	+	NS	+	+	NS	NS	NS	NS	NS
15-year									
	0	10	20	50					
0	NS								
10	NS	NS							
20	NS	NS	NS						
50	+	NS	NS	NS					

At the Two-year site, 0 m ($250 \mu\text{mol m}^{-2} \text{s}^{-1}$; Figure 6.2) was significantly different from all distances except 10 m ($166 \mu\text{mol m}^{-2} \text{s}^{-1}$), which was itself significantly different from 100 and 150 m (Table 6.2; Table 6.4). This may suggest an edge effect of less than 20 m. The 0 m point at the Five-year site ($331 \mu\text{mol m}^{-2} \text{s}^{-1}$; Figure 6.2) was significantly different from all other points and 10 m ($109 \mu\text{mol m}^{-2} \text{s}^{-1}$) was significantly different from all control distances except 150 m, while 20 and 50 m (121 and $123 \mu\text{mol m}^{-2} \text{s}^{-1}$) were also significantly different from controls

(Table 6.2; Table 6.4). The older Five-year site thus suggests a deeper penetration distance (~ 50 m). The 0 m point at the 15-year site ($288 \mu\text{mol m}^{-2} \text{s}^{-1}$; Figure 6.2), was significantly different from 50 m, but there was no control data and little inference can be made (Table 6.2; Table 6.4).

Summer 1997 average hourly maximum PAR measurements at the One-year site were similar to spring, but with no significant differences (Figure 6.2; Table 6.2). There was no control data at the Two-year site, but the 0 m distance ($142 \mu\text{mol m}^{-2} \text{s}^{-1}$; Figure 6.2), was significantly different from other impact points (Table 6.2; Table 6.5), which supports the trend observed in the preceding spring. At the Five-year site, average maximum PAR at 0 m ($199 \mu\text{mol m}^{-2} \text{s}^{-1}$) was significantly larger than all other distances while the 20 m point ($70 \mu\text{mol m}^{-2} \text{s}^{-1}$) was significant from all control distances, except 150 m (Table 6.2; Table 6.5).

Table 6.5 - Tukey-Kramer HSD test for significant differences in the summer 1997 PAR data (all sites except the One-year site had significant differences). Shaded headings indicate control transects, NS = not significant, “+” = significant.

Summer 1997									
Two-year									
	0	10	20	50					
0	NS								
10	+	NS							
20	+	NS	NS						
50	+	NS	NS	NS					
Five-year									
	0	10	20	50	100	110	120	150	
0	NS								
10	+	NS							
20	+	NS	NS						
50	+	NS	NS	NS					
100	+	NS	+	NS	NS				
110	+	NS	+	NS	NS	NS			
120	+	NS	+	NS	NS	NS	NS	NS	
150	+	NS	NS	NS	NS	NS	NS	NS	NS
15-year									
	0	10	20	50	100	110	120	150	
0	NS								
10	+	NS							
20	+	NS	NS						
50	+	+	NS	NS					
100	+	+	NS	NS	NS				
110	+	+	NS	NS	NS	NS			
120	+	+	NS	NS	NS	NS	NS	NS	
150	+	+	NS	NS	NS	NS	NS	NS	NS

Maximum PAR at 0 m for the 15-year site ($269 \mu\text{mol m}^{-2} \text{s}^{-1}$; Figure 6.2) was significantly different from all other distances while 10 m ($117 \mu\text{mol m}^{-2} \text{s}^{-1}$) was significantly different from 50 m and all control points (Table 6.2; Table 6.5). In spite of the lack of control data, the Two-year site still appeared to have the more

restricted edge effect relative to the older Five-year and 15-year sites, as points after 0 m were not significantly different.

Although logging at the One-year site was then complete in autumn 1998 (~3 months old), there was no obvious edge effect. The 10 m point recorded the highest average maximum PAR ($22 \mu\text{mol m}^{-2} \text{s}^{-1}$; Figure 6.4), which was significantly different from all distances except 120 m (Table 6.2; Table 6.6). Lack of a response was likely to be due to the time of year and the time required for canopy damage to take effect (see Chapter 4).

Table 6.6 - Tukey-Kramer HSD test for significant differences in the autumn 1998 PAR data (all sites except Five-year had significant differences). Shaded headings indicate control transects, NS = not significant, “+” = significant.

Autumn 1998									
One-year									
	0	10	20	50	100	110	120	150	
0	NS								
10	+	NS							
20	NS	+	NS						
50	NS	+	NS	NS					
100	NS	+	NS	NS	NS				
110	NS	+	NS	NS	NS	NS			
120	NS	NS	NS	NS	NS	NS	NS		
150	NS	+	NS	NS	NS	NS	NS	NS	NS
Two-year									
	0	10	20	50	100	110	120	150	
0	NS								
10	+	NS							
20	+	NS	NS						
50	+	NS	NS	NS					
100	+	NS	NS	NS	NS				
110	+	NS	NS	NS	NS	NS			
120	+	NS	NS	NS	NS	NS	NS		
150	+	NS	NS	NS	NS	NS	NS	NS	NS
15-year									
	0	10	20	50	100	110	120	150	
0	NS								
10	NS	NS							
20	NS	NS	NS						
50	NS	NS	NS	NS					
100	+	+	+	NS	NS				
110	+	+	+	NS	NS	NS			
120	+	+	+	NS	NS	NS	NS		
150	+	+	+	NS	NS	NS	NS	NS	NS

At the Two-year site, the autumn 1998 average hourly maximum PAR at 0 m ($61 \mu\text{mol m}^{-2} \text{s}^{-1}$; Figure 6.2) was significantly different from all other distances (Table 6.2; Table 6.6). There were no useful data from the Five-year site. At the 15-year site, there were significant differences between the 0, 10 and 20 m points ($35, 31$ and $40 \mu\text{mol m}^{-2} \text{s}^{-1}$) and all control distances (Table 6.2; Table 6.6), suggesting that impact transects at older sites are substantially different to controls. As with the

winter 1997 measurements, the edge effects were rather muted relative to the spring and summer, probably due to shorter days, more cloud and lower solar angle.

In winter 1998, there was a narrow edge effect apparent at all sites (Figure 6.2). At the One-year site, the 0 m point ($66 \mu\text{mol m}^{-2} \text{s}^{-1}$; Figure 6.2) was significantly different from all other distances (Table 6.2; Table 6.7). There was also a significant difference between 120 m and the 150 m distance (Table 6.2; Table 6.7), indicating that significant differences need not be edge related. At the Two-year site, the differences were more substantial, with 0 m ($96 \mu\text{mol m}^{-2} \text{s}^{-1}$) significantly different from all other distances, while the 10 m point ($18 \mu\text{mol m}^{-2} \text{s}^{-1}$) was significantly different from 100, 120 and 150 m. Finally, the 20 m point ($22 \mu\text{mol m}^{-2} \text{s}^{-1}$) was significantly different from 50, 100, 120 and 150 m (Table 6.2; Table 6.7). This is somewhat at odds with earlier trends, where this younger edge otherwise suggested a narrower penetration distance (< 20 m).

At the Five-year site, the 0 m point ($87 \mu\text{mol m}^{-2} \text{s}^{-1}$; Figure 6.2) was significant from all other distances (Table 6.2; Table 6.7), while the 20 m point ($27 \mu\text{mol m}^{-2} \text{s}^{-1}$; Figure 6.2) was significantly different from 100, 110 and 120 m (Table 6.2; Table 6.7). At the 15-year site, the 0 m point ($41 \mu\text{mol m}^{-2} \text{s}^{-1}$) was also significantly different from all other distances, and the 10 and 20 m points (20 and $17 \mu\text{mol m}^{-2} \text{s}^{-1}$; Figure 6.2) were significantly different from 50 m and all control points (Table 6.2; Table 6.7).

The notion of younger edges having a narrower PAR edge penetration distance is not supported in winter 1998 results, as the Two-year site indicates a larger PAR gradient than in other seasons. This may be due to an overall reduction in PAR variability within cooler seasons than a trend relative to the edge. It was also apparent that significant differences do not necessarily imply an edge effect (as they occurred at the One-year site before logging).

From the observations obtained at the One-year site (both here and in Chapter 4), it was apparent that the initial PAR edge effect was narrow (< 10 m) on an edge up to 1-year-old. At the Two-year site, this effect appears to be slightly larger (< 20 m) while the Five-year and 15-year sites suggested an edge effect in terms of PAR that can penetrate up to 50 m.

Table 6.7 - Tukey-Kramer HSD test for significant differences in the winter 1998 PAR data (all sites had significant differences). Shaded headings indicate control transects, NS = not significant, "+" = significant.

Winter 1998								
One-year								
	0	10	20	50	100	110	120	150
0	NS							
10	+	NS						
20	+	NS	NS					
50	+	NS	NS	NS				
100	+	NS	NS	NS	NS			
110	+	NS	NS	NS	NS	NS		
120	+	NS	NS	NS	NS	NS	NS	
150	+	NS	NS	NS	NS	NS	+	NS
Two-year								
	0	10	20	50	100	110	120	150
0	NS							
10	+	NS						
20	+	NS	NS					
50	+	NS	+	NS				
100	+	+	+	NS	NS			
110	+	NS	NS	NS	NS	NS		
120	+	+	+	NS	NS	NS	NS	
150	+	+	+	NS	NS	NS	NS	NS
Five-year								
	0	10	20	50	100	110	120	150
0	NS							
10	+	NS						
20	+	NS	NS					
50	+	NS	NS	NS				
100	+	NS	+	NS	NS			
110	+	NS	+	NS	NS	NS		
120	+	NS	+	NS	NS	NS	NS	
150	+	NS	NS	NS	NS	NS	NS	NS
15-year								
	0	10	20	50	100	110	120	150
0	NS							
10	+	NS						
20	+	NS	NS					
50	+	+	+	NS				
100	+	+	+	NS	NS			
110	+	+	+	NS	NS	NS		
120	+	+	+	NS	NS	NS	NS	
150	+	+	+	NS	NS	NS	NS	NS

6.3.2 Minimum temperature

Average daily minimum temperature was not a good indicator of edge effects, as differences observed between distances approach the level of accuracy achievable when comparing these dataloggers (see Appendix B; Figure 6.3) and hence any gradients observed within this factor are unreliable. In any case, gradients near edges were generally within the range of average daily minima that occurred at the corresponding controls (Figure 6.3).

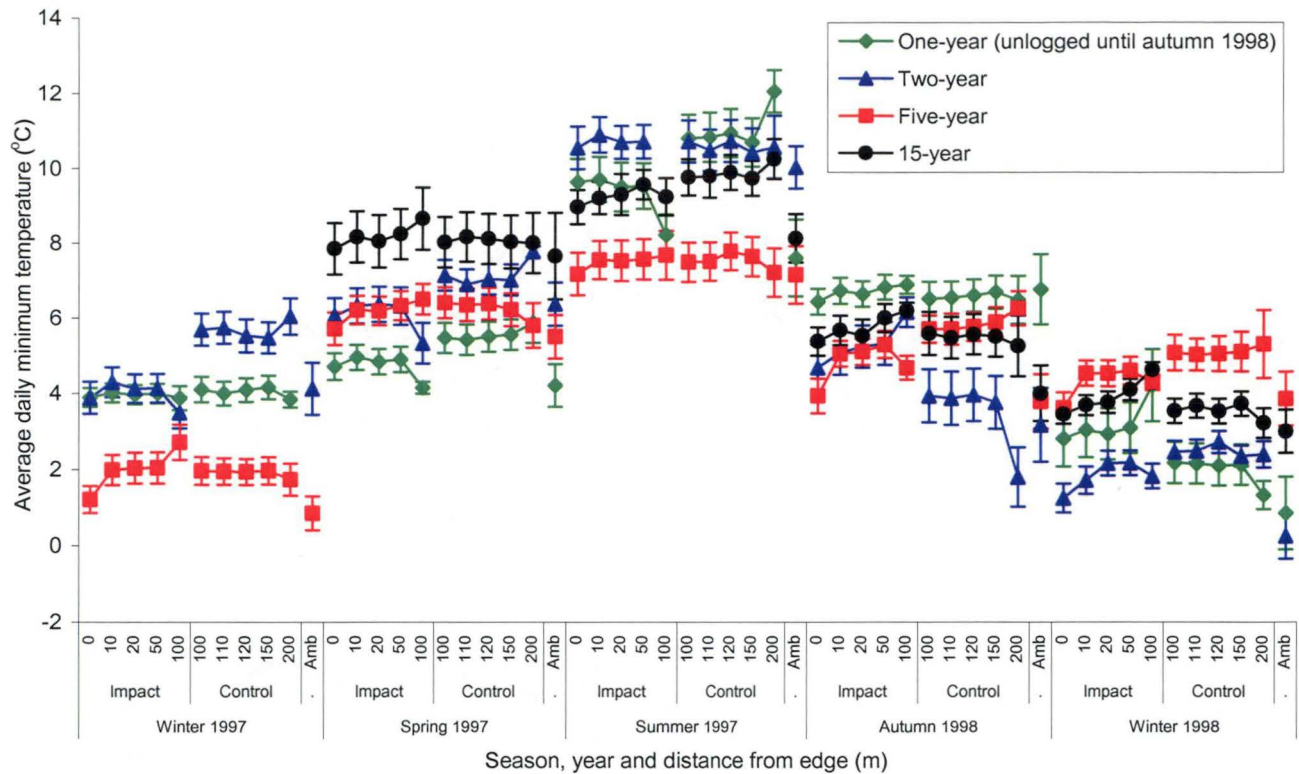


Figure 6.3 - Average daily minimum temperatures across five seasons (Winter 1997 – Winter 1998) at impact transects (0 – 100 m) and controls (100 – 200 m) at the One-year, Two-year, Five-year and 15-year sites. Bars are standard error.

There were only two instances of significant differences near edges (Five-year in autumn 1998; Table 6.8; Table 6.9, the Two-year site in winter 1998; Table 6.8; Table 6.9), both of which suggested that impact points close to 0 m were more similar to exposed average daily minima than to control levels. This supports the notion of a narrow edge effect. However, there were also significant changes between distances further from the edge (Two-year site in winter 1997; Table 6.8; Table 6.9; One-year in summer 1997; Table 6.8; Table 6.9: Two-year site in autumn 1998; Table 6.8; Table 6.9), suggesting that statistically significant differences need not be edge related. All significant differences may be a product of low variability rather than indications of substantial change. There was thus limited potential for identifying penetration distances within sites or seasons, let alone patterns with respect to edge age.

Table 6.8 - ANOVA results for average daily minimum temperature at each site within each season. NS = not significant, ** = very significant (P < 0.01), * = highly significant (P < 0.001).**

Season and site	DF	MS	MS Error	F Ratio	Prob.>F	Significance
Winter 1997						
One-year †	9	0.1643	1.3898	0.1183	0.9992	NS
Two-year	10	12.6984	3.0983	4.0985	0.0000	***
Five-year	10	2.6998	2.4575	1.0986	0.3659	NS
15-year †	-	-	-	-	-	-
Spring 1997						
One-year	10	4.3324	2.4888	1.7407	0.0754	NS
Two-year	10	5.8772	3.3683	1.7448	0.0745	NS
Five-year	10	1.3687	2.8315	0.4834	0.8989	NS
15-year	10	0.7989	8.7822	0.091	0.9999	NS
Summer 1997						
One-year	10	18.3156	5.9759	3.065	0.0015	**
Two-year †	9	0.7257	4.2939	0.169	0.9997	NS
Five-year	10	0.5528	4.2981	0.1286	0.9994	NS
15-year	10	3.5829	3.1071	1.1531	0.3285	NS
Autumn 1998						
One-year	10	0.2718	2.7476	0.0989	0.9998	NS
Two-year	10	19.9493	7.6421	2.6104	0.0055	**
Five-year	10	8.5071	2.5401	3.3491	0.0000	***
15-year	10	3.6197	3.7751	0.9588	0.4817	NS
Winter 1998						
One-year	10	8.7174	5.5709	1.5648	0.1233	NS
Two-year	10	7.6359	2.0881	3.6568	0.0002	***
Five-year	10	5.7707	4.1929	1.3763	0.1928	NS
15-year	10	2.0247	1.4191	1.4268	0.1745	NS

† indicates where data are absent or incomplete.

Table 6.9 - Tukey-Kramer HSD test for significant differences in average daily minimum temperature data for each season. Shaded headings indicate control transects, NS = not significant, “+” = significant.

Winter 1997												
Two-year												
	0	10	20	50	100	100	110	120	150	200	Exposed	
0	NS											
10	NS	NS										
20	NS	NS	NS									
50	NS	NS	NS	NS								
100	NS	NS	NS	NS	NS							
100	NS	NS	NS	NS	+	NS						
110	NS	NS	NS	NS	+	NS	NS					
120	NS	NS	NS	NS	NS	NS	NS	NS				
150	NS	NS	NS	NS	NS	NS	NS	NS	NS			
200	NS	NS	NS	NS	NS	+	NS	NS	NS	NS	NS	
Exposed	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
Summer 1997												
One-year												
	0	10	20	50	100	100	110	120	150	200	Exposed	
0	NS											
10	NS	NS										
20	NS	NS	NS									
50	NS	NS	NS	NS								
100	NS	NS	NS	NS	NS							
100	NS	NS	NS	NS	NS	NS						
110	NS	NS	NS	NS	NS	NS	NS					
120	NS	NS	NS	NS	NS	NS	NS	NS				
150	NS	NS	NS	NS	NS	NS	NS	NS	NS			
200	NS	NS	NS	NS	+	NS	NS	NS	NS	NS	NS	
Exposed	NS	NS	NS	NS	NS	NS	NS	+	NS	+	NS	NS

Table 6.9 - Continued

Autumn 1998												
Two-year												
	0	10	20	50	100	100	110	120	150	200	Exposed	
0	NS											
10	NS	NS										
20	NS	NS	NS									
50	NS	NS	NS	NS								
100	NS	NS	NS	NS	NS							
100	NS	NS	NS	NS	NS	NS						
110	NS	NS	NS	NS	NS	NS	NS					
120	NS	NS	NS	NS	NS	NS	NS	NS				
150	NS	NS	NS	NS	NS	NS	NS	NS	NS			
200	NS	NS	NS	+	+	NS	NS	NS	NS	NS		
Exposed	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	
Five-year												
	0	10	20	50	100	100	110	120	150	200	Exposed	
0	NS											
10	NS	NS										
20	NS	NS	NS									
50	NS	NS	NS	NS								
100	NS	NS	NS	NS	NS							
100	NS	NS	NS	NS	NS	NS						
110	NS	NS	NS	NS	NS	NS	NS					
120	+	NS	NS	NS	NS	NS	NS	NS				
150	+	NS	NS	NS	NS	NS	NS	NS	NS			
200	+	NS	NS	NS	NS	NS	NS	NS	NS	NS		
Exposed	NS	NS	NS	NS	NS	NS	NS	NS	+	+	NS	
Winter 1998												
Two-year												
	0	10	20	50	100	100	110	120	150	200	Exposed	
0	NS											
10	NS	NS										
20	NS	NS	NS									
50	NS	NS	NS	NS								
100	NS	NS	NS	NS	NS							
100	NS	NS	NS	NS	NS	NS						
110	NS	NS	NS	NS	NS	NS	NS					
120	NS	NS	NS	NS	NS	NS	NS	NS				
150	NS	NS	NS	NS	NS	NS	NS	NS	NS			
200	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS		
Exposed	NS	NS	+	+	NS	+	+	+	+	+	NS	

6.3.3 Maximum temperature

In the winter 1997, the only significant differences in average daily maximum temperature occurred at the Two-year site, with the 0 m point (7.4 °C; Figure 6.4) significantly higher than the impact 100 m value. The 20, 50 and 100 m impact distances (6.1, 6.2 and 5.9 °C) were significantly lower than the control 100 and 110 m points, and the exposed average (9.2 °C) was significantly higher than all impact distances and the 120 and 150 m points (Table 6.10; Table 6.11).

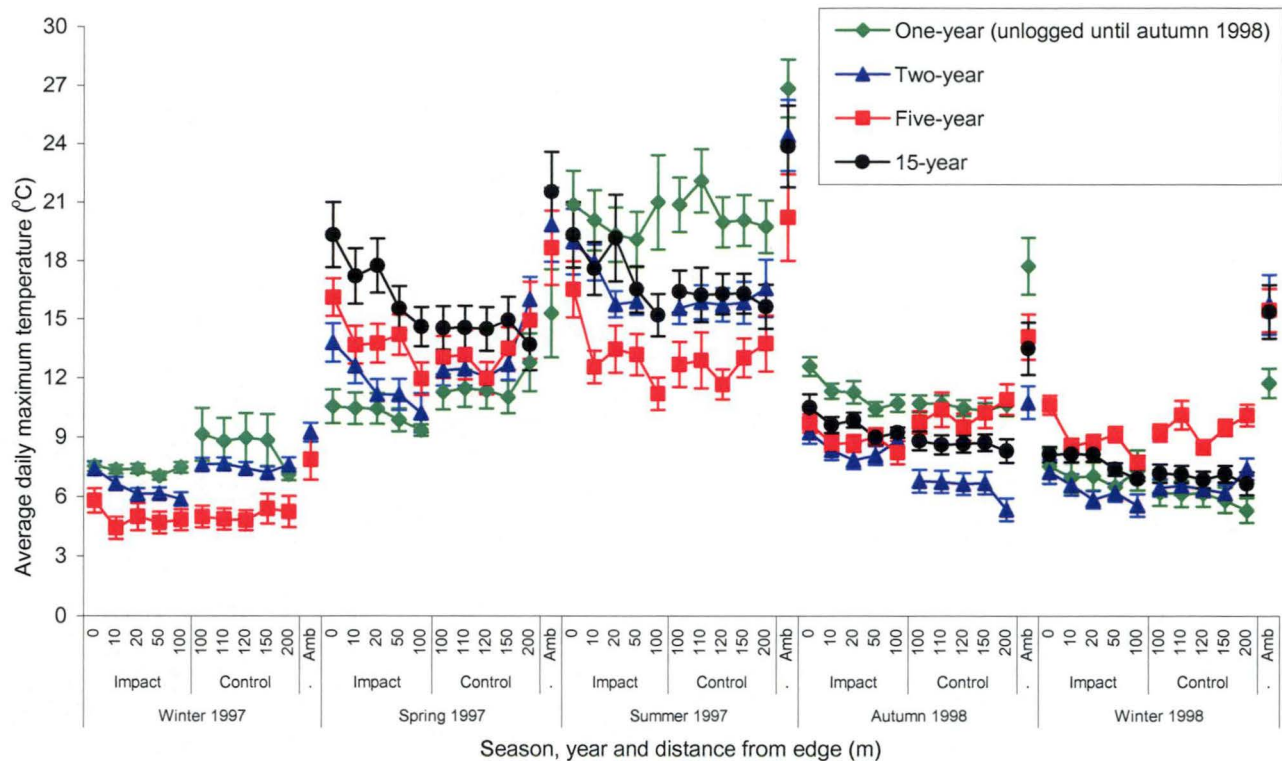


Figure 6.4 - Average daily maximum temperature across five seasons (Winter 1997 – Winter 1998) at impact transects (0 – 100 m) and controls (100 – 200 m) at the One-year, Two-year, Five-year and 15-year sites. Bars are standard error.

Table 6.10 - ANOVA results for average daily maximum temperature at each site within each season. NS = not significant, * = significant ($P < 0.05$), ** = very significant ($P < 0.01$), *** = highly significant ($P < 0.001$).

Season and site	DF	MS	MS Error	F Ratio	Prob.>F	Significance
Winter 1997						
One-year †	9	12.0728	11.5109	1.0488	0.4039	NS
Two-year	10	12.9507	1.7485	7.0467	0.0000	***
Five-year	10	11.4548	6.9612	1.6455	0.0977	NS
15-year †	-	-	-	-	-	-
Spring 1997						
One-year	10	33.4753	15.7356	2.1274	0.0248	*
Two-year	10	92.7351	14.6934	6.3113	0.0000	***
Five-year	10	46.9434	19.3193	2.4299	0.0103	*
15-year	10	86.9756	29.2839	2.9701	0.0018	**
Summer 1997						
One-year	10	50.6955	32.8171	1.5448	0.1298	NS
Two-year †	9	86.8131	13.9352	6.2298	0.0000	***
Five-year	10	72.2366	20.3743	3.5455	0.0003	***
15-year	10	66.0732	24.8016	2.6641	0.0054	**
Autumn 1998						
One-year	10	48.834	4.0033	12.1985	0.0000	***
Two-year	10	32.6475	5.3682	6.0817	0.0000	***
Five-year	10	30.8731	6.288	4.9099	0.0000	***
15-year	10	25.6086	4.4003	5.8197	0.0000	***
Winter 1998						
One-year	10	31.7081	7.0823	4.4771	0.0000	***
Two-year	10	109.417	6.097	17.9457	0.0000	***
Five-year	10	68.824	5.2781	13.0394	0.0000	***
15-year	10	63.3769	3.4049	18.6132	0.0000	***

† indicates where data are absent or incomplete.

These differences suggest a high degree of variation in maximum temperature between distances at this site, and that, as with PAR and minimum temperatures, significant differences are not necessarily edge related. Average maximum temperature at other locations otherwise appeared to be relatively stable, although data were incomplete for the One-year and 15-year sites (Figure 6.4).

Table 6.11 - Tukey-Kramer HSD test for significant differences in the winter 1997 average daily maximum temperatures (only the Two-year site had significant differences). Shaded headings indicate control transects, NS = not significant, “+” = significant.

Winter 1997												
Two-year	0	10	20	50	100	100	110	120	150	200	Exposed	
0	NS											
10	NS	NS										
20	NS	NS	NS									
50	NS	NS	NS	NS								
100	+	NS	NS	NS	NS							
100	NS	NS	+	+	+	NS						
110	NS	NS	+	+	+	NS	NS					
120	NS	NS	NS	NS	NS	NS	NS	NS				
150	NS	NS	NS	NS	NS	NS	NS	NS	NS			
200	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS		
Exposed	+	+	+	+	+	NS	NS	+	+	NS	NS	NS

In the spring 1997 deployments, there was little change with distance at the unlogged One-year site, but the exposed average maximum temperature (15.3 °C; Figure 6.4) was significantly different from all impact distances except 0 m (Table 6.10; Table 6.12), again indicating high levels of variability in maximum temperature in undisturbed forest associated with differences in the degree of canopy buffering and that significant differences need not be edge related. At the logged sites there was an indication of edge effects with decreases in average daily maximum temperature across all impact transects, but there was considerable variation within and between distances on controls (Figure 6.4).

At the Two-year site, the 200 m point (16 °C; Figure 6.4) was significantly different from the 20, 50 and 100 m points and the exposed average (19.8 °C) was significantly warmer than all distances except 200 m (Table 6.10; Table 6.12). At the Five-year site, the exposed (18.6 °C) was significantly different from the impact 100 m point and 120 m (Table 6.10; Table 6.12). The 15-year site exposed average (21.5 °C; Figure 6.4) was significantly different from all control distances (Table 6.10; Table 6.12), which, unlike previous significant results, suggests that impact transect maxima were more similar to external exposed levels, indicating an edge effect.

Table 6.12 - Tukey-Kramer HSD test for significant differences in the spring 1997 average daily maximum temperatures (all sites had significant differences). Shaded headings indicate control transects, NS = not significant, “+” = significant.

Spring 1997												
One-year												
	0	10	20	50	100	100	110	120	150	200	Exposed	
0	NS											
10	NS	NS										
20	NS	NS	NS									
50	NS	NS	NS	NS								
100	NS	NS	NS	NS	NS							
100	NS	NS	NS	NS	NS	NS						
110	NS	NS	NS	NS	NS	NS	NS					
120	NS	NS	NS	NS	NS	NS	NS	NS				
150	NS	NS	NS	NS	NS	NS	NS	NS	NS			
200	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS		
Exposed	NS	+	+	+	+	NS	NS	NS	NS	NS	NS	NS
Two-year												
	0	10	20	50	100	100	110	120	150	200	Exposed	
0	NS											
10	NS	NS										
20	NS	NS	NS									
50	NS	NS	NS	NS								
100	NS	NS	NS	NS	NS							
100	NS	NS	NS	NS	NS	NS						
110	NS	NS	NS	NS	NS	NS	NS					
120	NS	NS	NS	NS	NS	NS	NS	NS				
150	NS	NS	NS	NS	NS	NS	NS	NS	NS			
200	NS	NS	+	+	+	NS	NS	NS	NS	NS		
Exposed	+	+	+	+	+	+	+	+	+	NS	NS	NS
Five-year												
	0	10	20	50	100	100	110	120	150	200	Exposed	
0	NS											
10	NS	NS										
20	NS	NS	NS									
50	NS	NS	NS	NS								
100	NS	NS	NS	NS	NS							
100	NS	NS	NS	NS	NS	NS						
110	NS	NS	NS	NS	NS	NS	NS					
120	NS	NS	NS	NS	NS	NS	NS	NS				
150	NS	NS	NS	NS	NS	NS	NS	NS	NS			
200	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS		
Exposed	NS	NS	NS	NS	+	NS	NS	+	NS	NS	NS	NS
15-year												
	0	10	20	50	100	100	110	120	150	200	Exposed	
0	NS											
10	NS	NS										
20	NS	NS	NS									
50	NS	NS	NS	NS								
100	NS	NS	NS	NS	NS							
100	NS	NS	NS	NS	NS	NS						
110	NS	NS	NS	NS	NS	NS	NS					
120	NS	NS	NS	NS	NS	NS	NS	NS				
150	NS	NS	NS	NS	NS	NS	NS	NS	NS			
200	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS		
Exposed	NS	NS	NS	NS	NS	+	+	+	+	+	NS	NS

The effect of high exposed temperatures on undisturbed forest was readily apparent at the unlogged One-year site in the summer 1997, which had the highest average daily exposed temperature (26.8 °C). The corresponding transect maxima were higher than all other sites (Figure 6.4), although there were no significant differences between distances (Table 6.10). At the Two-year site, the average daily maximum

temperature decreased with distance from the edge and the exposed point (24.4 °C; Figure 6.4) was significantly different from all other distances except 0 m (Table 6.10; Table 6.13). This is a strong indication of canopy buffering, suggesting that maximum temperatures near the edge are more similar to the exposed zones than undisturbed forest.

Table 6.13 - Tukey-Kramer HSD test for significant differences in the summer 1997 average daily maximum temperatures (all sites except One-year had significant differences). Shaded headings indicate control transects, NS = not significant, “+” = significant.

Summer 1997											
Two-year											
	0	10	20	50	100	110	120	150	200	Exposed	
0	NS										
10	NS	NS									
20	NS	NS	NS								
50	NS	NS	NS	NS							
100	NS	NS	NS	NS	NS						
110	NS	NS	NS	NS	NS	NS					
120	NS	NS	NS	NS	NS	NS	NS				
150	NS	NS	NS	NS	NS	NS	NS	NS			
200	NS	NS	NS	NS	NS	NS	NS	NS	NS		
Exposed	NS	+	+	+	+	+	+	+	+	+	NS
Five-year											
	0	10	20	50	100	100	110	120	150	200	Exposed
0	NS										
10	NS	NS									
20	NS	NS	NS								
50	NS	NS	NS	NS							
100	NS	NS	NS	NS	NS						
100	NS	NS	NS	NS	NS	NS					
110	NS	NS	NS	NS	NS	NS	NS				
120	NS	NS	NS	NS	NS	NS	NS	NS			
150	NS	NS	NS	NS	NS	NS	NS	NS	NS		
200	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	
Exposed	NS	+	+	+	+	+	+	+	+	+	NS
15-year											
	0	10	20	50	100	100	110	120	150	200	Exposed
0	NS										
10	NS	NS									
20	NS	NS	NS								
50	NS	NS	NS	NS							
100	NS	NS	NS	NS	NS						
100	NS	NS	NS	NS	NS	NS					
110	NS	NS	NS	NS	NS	NS	NS				
120	NS	NS	NS	NS	NS	NS	NS	NS			
150	NS	NS	NS	NS	NS	NS	NS	NS	NS		
200	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	
Exposed	NS	NS	NS	+	+	+	+	+	+	+	NS

At the Five-year site, the average daily maximum generally decreased on the impact transects, but increased on the controls (Figure 6.4). The exposed average (20.2 °C) was significantly different from all other distances except 0 and 200 m (Table 6.10; Table 6.13), suggesting a possible edge effect similar to that recorded at the Two-year site, but also that undisturbed forest average maximum temperatures can be highly varied. At the 15-year site, the average daily maximum temperature also

generally decreased on the impact transects, while the controls were relatively stable (Figure 6.4). The exposed maximum (23.9 °C) was significantly different from 50 and 100 m on the impact transects and all control points (Table 6.10; Table 6.13), implying that distances near the edge were similar to exposed conditions.

In autumn 1998 at the then logged One-year site, there is some suggestion of an edge gradient, with a decrease across the impact transects relative to stable controls. The exposed average (17.7 °C; Figure 6.4) was significantly different from all other points (Table 6.10; Table 6.14) and hence did not suggest an edge effect. At the Two-year site, the 0 m point (9.2 °C; Figure 6.4) was significantly different from all control distances while the 200 m point (5.3 °C) was also different to the 10 m and 100 m impact distances. The exposed (10.7 °C) was significantly different from all controls, and 20 and 50 m on the impact transects (Table 6.10; Table 6.14). Significant differences relative to the 0 m and exposed points are indicative of an edge effect, while other differences suggest that the 200 m point for this site was rather different to other control distances.

The Five-year site maximum temperatures decreased across impact transects, while controls were generally warmer (Figure 6.4). The exposed (14.1 °C) was significantly different from all other points except 200 m (Table 6.10; Table 6.14), suggesting that, like the Two-year site, this distance is not typical of the rest of the site. At the 15-year site, the average daily maximum temperature decreased across the impact transects and was generally stable across the controls (Figure 6.4). The exposed (13.5 °C) was significantly different from all other distances (Table 6.10;) and is thus counter to the notion of an edge effect.

In winter 1998 at the One-year site, the average daily maximum temperature generally decreased on both impact and control transects (Figure 6.4), while the exposed (11.7 °C; Figure 6.4) was significantly different from all other distances (Table 6.10; Table 6.15). Average maxima at the Two-year site decreased with distance from the edge relative to controls that were generally stable (Figure 6.4). The exposed (15.7 °C) was significantly different from all other distances (Table 6.10; Table 6.15). The Five-year site was the warmest site in this season, with a decrease in maximum temperature across most impact points, while controls were more variable (Figure 6.4). The 100 m impact distance (7.7 °C) was significantly different from 0 and 110 m, while the exposed (15.4 °C) was significantly different

from all other points (Table 6.10; Table 6.15). The 15-year site site temperature maxima generally decreased with distance from the edge across both impact and control transects (Figure 6.4), while the exposed (15.4 °C) was again significantly different from all other distances (Table 6.10; Table 6.15).

Table 6.14 - Tukey-Kramer HSD test for significant differences in the autumn 1998 average daily maximum temperatures (all sites had significant differences). Shaded headings indicate control transects, NS = not significant, "+" = significant.

[illegible]

Average daily maximum temperatures at 0 m points from all sites appears to track with their respective average hourly maximum PAR measurements (Figure 6.2; Figure 6.4), most probably through a loss of canopy buffering at logged edges such that it receives direct sun exposure. However, unlike the light regime, increasing penetration distances with age of the edge were not detected.

As in the BACI study (Chapter 4), the degree of edge effect appears to depend on exposed conditions, with more pronounced edge effects in warmer seasons regardless of the age of the edge. However, significant differences indicative of an edge effect in terms of impact distances being similar to exposed levels, were observed at only one site in spring 1997 (15-year; Table 6.12), once in summer 1997 (15-year; Table 6.13) and once in autumn 1998 (Two-year; Table 6.14). Significant differences between 0 m points and other distances were also rare, occurring only in winter 1997 and autumn 1998 (both Two-year; Table 6.11; Table 6.14).

Gradients in average daily maximum temperature relative to the edge were common at all logged sites, making this a better indicator of edge effects than minimum temperatures, but the identification of penetration distances is problematic owing to substantial levels of variability within and between control distances (Figure 6.4), particularly at the Two-year and Five-year sites. This was supported by significant observations between distances at the Two-year site (winter 1997; Table 6.11, spring 1997; Table 6.12, autumn 1998; Table 6.14) and the Five-year site (spring 1997; Table 6.12, summer 1997; Table 6.13, autumn 1998; Table 6.14, winter 1998; Table 6.15).

As with minimum temperatures, seasonal differences were obvious at all sites and support the notion of substantial canopy buffering at this scale (i.e. days), with the most common significant differences occurring between nearly all distances at a site and their respective exposed points. This was noted in spring 1997 (unlogged One-year site – not 0 m, the Two-year and 15-year; Table 6.12), summer 1997, (Two-year; Table 6.13), autumn 1998 (Five-year – not 200 m and 15-year; Table 6.14) and winter 1998 (all sites; Table 6.15). These results are counter to the detection of edge effects, as they imply that the impact transects are not as close to exposed levels as they are to undisturbed forest.

Table 6.15 - Tukey-Kramer HSD test for significant differences in the winter 1998 average daily maximum temperatures (all sites had significant differences). Shaded headings indicate control transects, NS = not significant, “+” = significant.

Winter 1998												
One-year												
	0	10	20	50	100	100	110	120	150	200	Exposed	
0	NS											
10	NS	NS										
20	NS	NS	NS									
50	NS	NS	NS	NS								
100	NS	NS	NS	NS	NS							
100	NS	NS	NS	NS	NS	NS						
110	NS	NS	NS	NS	NS	NS	NS					
120	NS	NS	NS	NS	NS	NS	NS	NS				
150	NS	NS	NS	NS	NS	NS	NS	NS	NS			
200	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS		
Exposed	+	+	+	+	+	+	+	+	+	+	+	NS
Two-year												
	0	10	20	50	100	100	110	120	150	200	Exposed	
0	NS											
10	NS	NS										
20	NS	NS	NS									
50	NS	NS	NS	NS								
100	NS	NS	NS	NS	NS							
100	NS	NS	NS	NS	NS	NS						
110	NS	NS	NS	NS	NS	NS	NS					
120	NS	NS	NS	NS	NS	NS	NS	NS				
150	NS	NS	NS	NS	NS	NS	NS	NS	NS			
200	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS		
Exposed	+	+	+	+	+	+	+	+	+	+	+	NS
Five-year												
	0	10	20	50	100	100	110	120	150	200	Exposed	
0	NS											
10	NS	NS										
20	NS	NS	NS									
50	NS	NS	NS	NS								
100	+	NS	NS	NS	NS							
100	NS	NS	NS	NS	NS	NS						
110	NS	NS	NS	NS	NS	+	NS					
120	NS	NS	NS	NS	NS	NS	NS	NS				
150	NS	NS	NS	NS	NS	NS	NS	NS	NS			
200	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS		
Exposed	+	+	+	+	+	+	+	+	+	+	+	NS
15-year												
	0	10	20	50	100	100	110	120	150	200	Exposed	
0	NS											
10	NS	NS										
20	NS	NS	NS									
50	NS	NS	NS	NS								
100	NS	NS	NS	NS	NS							
100	NS	NS	NS	NS	NS	NS						
110	NS	NS	NS	NS	NS	NS	NS					
120	NS	NS	NS	NS	NS	NS	NS	NS				
150	NS	NS	NS	NS	NS	NS	NS	NS	NS			
200	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS		
Exposed	+	+	+	+	+	+	+	+	+	+	+	NS

The average of the slope of temperature changes with distance across all sites for the impact and control transects in each season (Figure 6.5) gives a strong indication of the behaviour of maximum temperatures on average. However, as it ignores

substantial levels of variability that occurred within distances, univariate analysis of this parameter was considered inappropriate.

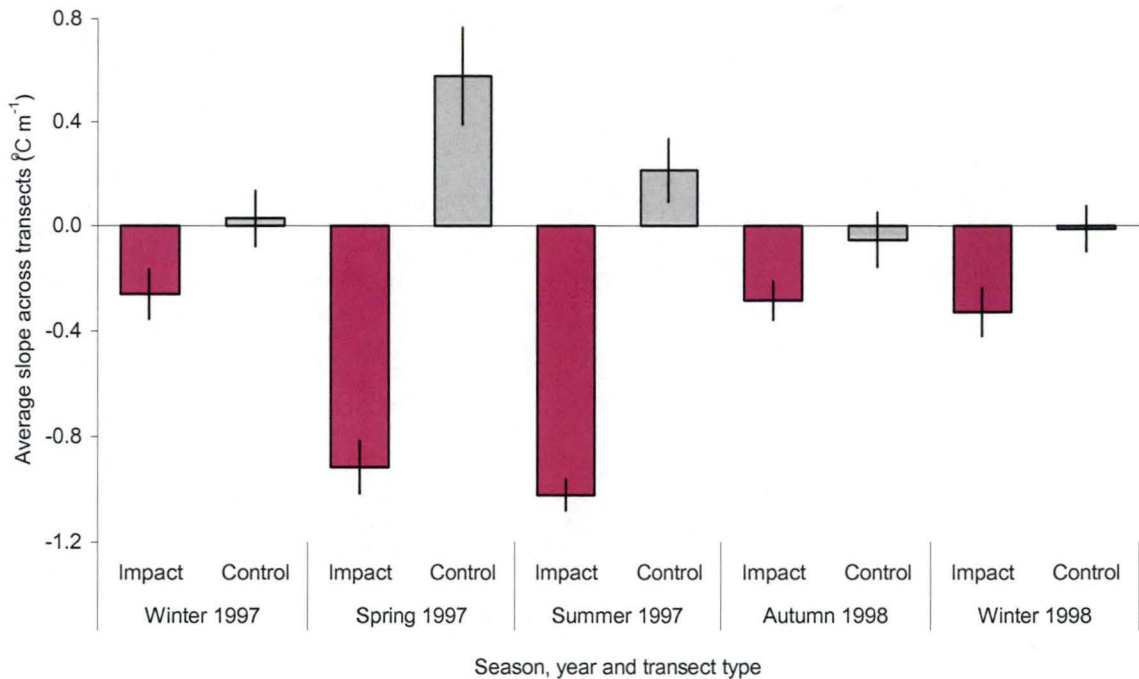


Figure 6.5 - Average across sites of the slope of maximum temperature differences across distances across transects within each season. Bars are standard error.

Control average slopes were either positive in warmer seasons (spring and summer 1997) or close to zero in cooler periods (winter 1997, autumn 1998 and winter 1998 respectively; Figure 6.5). Impact transects always maintained a negative slope and indicated a marked seasonal response, with substantially more negative average slopes in warmer seasons (Figure 6.5). While warmer temperatures promote larger edge effects, there appears to be little variation between sites in terms of slope on either impact or control transects (i.e. standard errors are narrow; Figure 6.5). If edge age differences were reflected in these results, the variability in average slope should be larger on impact transects, but these were either the same or smaller than on controls (Figure 6.5), suggesting that there are no major differences with the age of the edge in terms of daily maximum temperature.

6.3.4 Maximum vapour pressure deficit

There were no immediately apparent gradients in average daily maximum vapour pressure deficit (VPD) relative to edges in the winter 1997 deployments (Figure 6.6). At the One-year site, there were no exposed data and no significant differences Table 6.16). At the Two-year site, the exposed average maximum VPD (0.05 kPa) was

significantly different from 20, 50 and 100 m on the impact transects, and 100 m on the control, 20 m (0.03 kPa) was significantly lower than 0 and 110 m, and finally 50 m (0.01 kPa; Figure 6.6) was significantly lower than 0, 10, 110, 120 and 200 m (Table 6.16; Table 6.17). At the Five-year site, the exposed and 0 m points (0.04 and 0.05 kPa) were significantly different to the 50 and 150 m distances while 150 m (0.02 kPa) was also different to the 100, 120 and 200 m points on the controls (Table 6.16; Table 6.17). No data were obtained from the 15-year site.

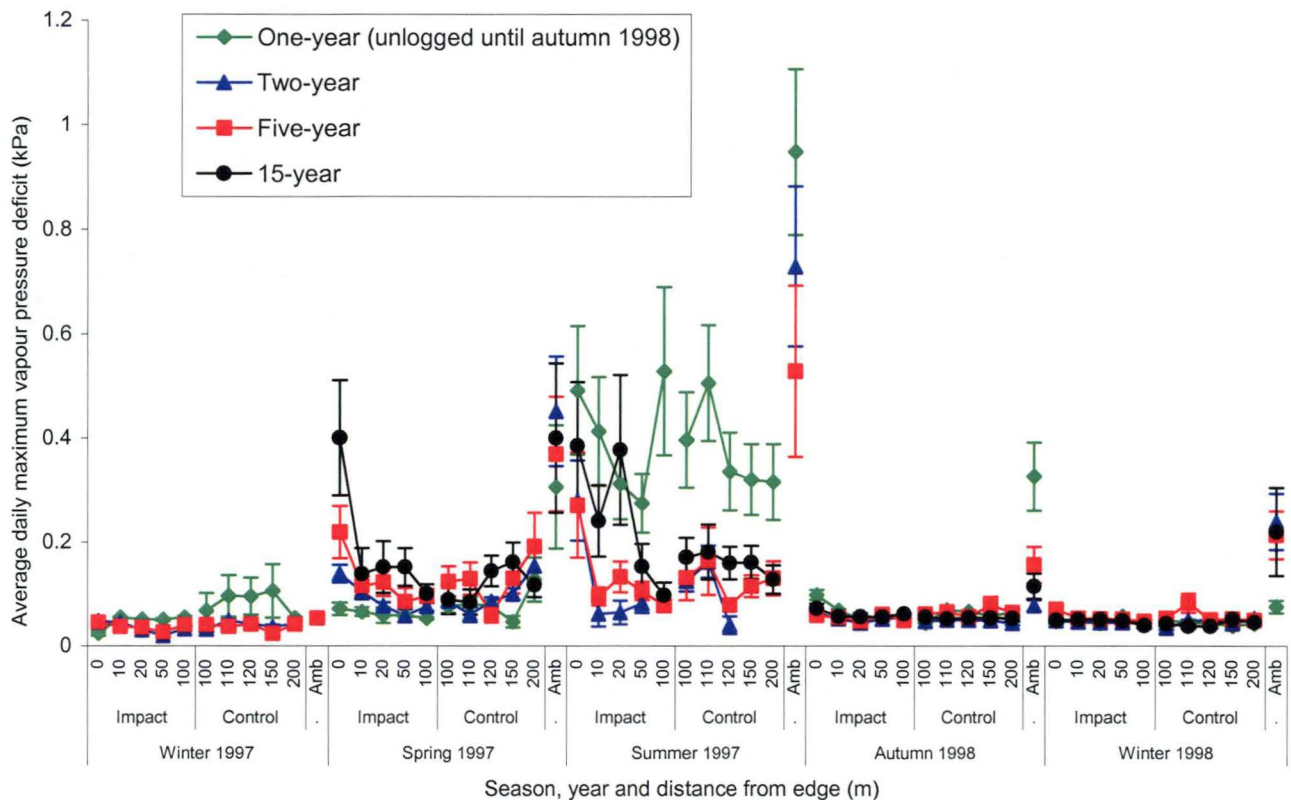


Figure 6.6 - Average daily maximum vapour pressure deficit across five seasons (Winter 1997 – Winter 1998) at impact transects (0 – 100 m) and controls (100 – 200 m) at the One-year, Two-year, Five-year and 15-year sites. Bars are standard error.

Apart from indicating that significant differences in average daily maximum VPD need not occur near an edge, these differences and their general lack of pattern reflect the low variation within distances under wet conditions and supports the notion of minimal edge effects in terms of VPD in cooler weather. Under these circumstances, very small differences between points can become statistically significant, but are unlikely to have any detectable biological consequences at this scale.

Table 6.16 - ANOVA results for average daily maximum VPD at each site within each season.NS = not significant, ** = very significant ($P < 0.01$), *** = highly significant ($P < 0.001$).

Season and site	DF	MS	MS Error	F Ratio	Prob.>F	Significance
Winter 1997						
One-year †	9	0.0116	0.0115	1.0087	0.4354	NS
Two-year	10	0.0017	0.0002	6.8228	0.0000	***
Five-year	10	0.0011	0.0002	4.3337	0.0000	***
15-year †	-	-	-	-	-	-
Spring 1997						
One-year	10	0.0683	0.0143	4.7702	0.0000	***
Two-year	10	0.1579	0.0116	13.6132	0.0000	***
Five-year	10	0.0909	0.0234	3.8815	0.0001	***
15-year	10	0.1974	0.0568	3.4732	0.0004	***
Summer 1997						
One-year	10	0.3955	0.1347	2.936	0.0023	**
Two-year †	8	0.5672	0.0324	17.4913	0.0000	***
Five-year	10	0.1887	0.0459	4.0945	0.0001	***
15-year †	9	0.1226	0.0625	1.6927	0.0495	NS ††
Autumn 1998						
One-year	10	0.0669	0.0034	19.944	0.0000	***
Two-year	10	0.0014	0.0002	6.3569	0.0000	***
Five-year	10	0.0106	0.0017	6.1757	0.0000	***
15-year	10	0.0039	0.0007	5.4825	0.0000	***
Winter 1998						
One-year	10	0.0011	0.0003	4.3633	0.0000	***
Two-year	10	0.0454	0.0026	17.5103	0.0000	***
Five-year	10	0.0368	0.0031	11.8878	0.0000	***
15-year	10	0.0286	0.0052	5.5314	0.0000	***

† indicates where data are absent or incomplete.

†† although this is (just) significant at the 0.05 level, the associated Tukey-Kramer HSD test indicated no differences.

Table 6.17 - Tukey-Kramer HSD test for significant differences in the winter 1997 average daily maximum VPD data (Two-year and Five-year sites had significant differences). Shaded headings indicate control transects, NS = not significant, "+" = significant.

Winter 1997												
Two-year												
	0	10	20	50	100	100	110	120	150	200	Exposed	
0	NS											
10	NS	NS										
20	+	NS	NS									
50	+	+	NS	NS								
100	NS	NS	NS	NS	NS							
100	NS	NS	NS	NS	NS	NS						
110	NS	NS	+	+	NS	NS	NS					
120	NS	NS	NS	+	NS	NS	NS	NS				
150	NS	NS	NS	NS	NS	NS	NS	NS	NS			
200	NS	NS	NS	+	NS	NS	NS	NS	NS	NS		
Exposed	NS	NS	+	+	+	+	NS	NS	NS	NS	NS	NS
Five-year												
	0	10	20	50	100	100	110	120	150	200	Exposed	
0	NS											
10	NS	NS										
20	NS	NS	NS									
50	+	NS	NS	NS								
100	NS	NS	NS	NS	NS							
100	NS	NS	NS	NS	NS	NS						
110	NS	NS	NS	NS	NS	NS	NS					
120	NS	NS	NS	NS	NS	NS	NS	NS				
150	+	NS	NS	NS	+	NS	NS	+	NS			
200	NS	NS	NS	NS	NS	NS	NS	NS	+	NS		
Exposed	NS	NS	NS	+	NS	NS	NS	NS	+	NS	NS	NS

The spring 1997 deployment at the One-year site was similar to the previous season with the exposed (0.3 kPa; Figure 6.6) significantly different from all other distances (Table 6.16; Table 6.18). At the Two-year site, the average daily maximum VPD was also low, although there was a gradient of decreasing maxima with distance from the edge (Figure 6.6) that was matched by an increase across the controls (Figure 6.6). The exposed (0.45 kPa) was significantly different from all other distances (Table 6.16; Table 6.18), which is counter to the notion of edge effects, as it suggests substantial canopy buffering at all distances. At the Five-year site, the pattern was similar (Figure 6.6). The exposed (0.37 kPa) was significantly different from all other distances except 0 and 200 m (Table 6.16; Table 6.18), which may suggest an edge effect at 0 m, but also suggests that the 200 m point at the Five-year site is not typical of other control distances. This was also observed for average maximum temperatures.

At the 15-year site, the average daily maximum VPD decreased sharply after 0 m (0.4 kPa; Figure 6.6) and was significantly higher than 10 and 100 m on the impact transects and 100 and 110 m on the controls (Table 6.16; Table 6.18), possibly indicating an edge effect. The exposed was identical to the 0 m value (i.e. 0.4 kPa), but was only significantly different from 100 and 110 m on the controls (Table 6.16; Table 6.18), supporting both the notion of an edge effect as well as substantial variability in VPD maxima in undisturbed forests.

In summer 1997, there is further evidence of the effect of exposed conditions on undisturbed forest microclimates, with the pattern of response for average daily maximum VPD at the One-year site being very similar to that found for maximum temperature in the same season (Figure 6.4; Figure 6.6). This might be anticipated as these data are not independent. In spite of large changes in average daily maximum VPD between distances at the One-year site, the only significant differences indicated canopy buffering between the exposed point (0.95) and all other points except the 0, impact 100 and 110 m points (Table 6.16; Table 6.19). Such changes in VPD within an undisturbed forest are likely to be in response to differences in slope and canopy architecture, and suggest that natural gradients and variability in forest VPD maxima can be considerable. This supports the notion that edge gradients were likely to be influential on the vegetation only under extreme conditions.

Table 6.18 - Tukey-Kramer HSD test for significant differences in the spring 1997 average daily maximum VPD data (all sites had significant differences). Shaded headings indicate control transects, NS = not significant, "+" = significant.

Spring 1997												
One-year												
	0	10	20	50	100	100	110	120	150	200	Exposed	
0	NS											
10	NS	NS										
20	NS	NS	NS									
50	NS	NS	NS	NS								
100	NS	NS	NS	NS	NS							
100	NS	NS	NS	NS	NS	NS						
110	NS	NS	NS	NS	NS	NS	NS					
120	NS	NS	NS	NS	NS	NS	NS	NS				
150	NS	NS	NS	NS	NS	NS	NS	NS	NS			
200	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS		
Exposed	+	+	+	+	+	+	+	+	+	+	+	NS
Two-year												
	0	10	20	50	100	100	110	120	150	200	Exposed	
0	NS											
10	NS	NS										
20	NS	NS	NS									
50	NS	NS	NS	NS								
100	NS	NS	NS	NS	NS							
100	NS	NS	NS	NS	NS	NS						
110	NS	NS	NS	NS	NS	NS	NS					
120	NS	NS	NS	NS	NS	NS	NS	NS				
150	NS	NS	NS	NS	NS	NS	NS	NS	NS			
200	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS		
Exposed	+	+	+	+	+	+	+	+	+	+	+	NS
Five-year												
	0	10	20	50	100	100	110	120	150	200	Exposed	
0	NS											
10	NS	NS										
20	NS	NS	NS									
50	NS	NS	NS	NS								
100	NS	NS	NS	NS	NS							
100	NS	NS	NS	NS	NS	NS						
110	NS	NS	NS	NS	NS	NS	NS					
120	NS	NS	NS	NS	NS	NS	NS	NS				
150	NS	NS	NS	NS	NS	NS	NS	NS	NS			
200	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS		
Exposed	NS	+	+	+	+	+	+	+	+	+	NS	NS
15-year												
	0	10	20	50	100	100	110	120	150	200	Exposed	
0	NS											
10	+	NS										
20	NS	NS	NS									
50	NS	NS	NS	NS								
100	+	NS	NS	NS	NS							
100	+	NS	NS	NS	NS	NS						
110	+	NS	NS	NS	NS	NS	NS					
120	NS	NS	NS	NS	NS	NS	NS	NS				
150	NS	NS	NS	NS	NS	NS	NS	NS	NS			
200	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS		
Exposed	NS	NS	NS	NS	NS	+	+	NS	NS	NS	NS	NS

Table 6.19 - Tukey-Kramer HSD test for significant differences in the summer 1997 average daily maximum VPD data (all sites except the 15-year had significant differences). Shaded headings indicate control transects, NS = not significant, “+” = significant.

Summer 1997												
One-year												
	0	10	20	50	100	100	110	120	150	200	Exposed	
0	NS											
10	NS	NS										
20	NS	NS	NS									
50	NS	NS	NS	NS								
100	NS	NS	NS	NS	NS							
100	NS	NS	NS	NS	NS	NS						
110	NS	NS	NS	NS	NS	NS	NS					
120	NS	NS	NS	NS	NS	NS	NS	NS				
150	NS	NS	NS	NS	NS	NS	NS	NS	NS			
200	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS		
Exposed	NS	+	+	+	NS	+	NS	+	+	+	+	NS
Two-year												
	0	10	20	50	100	110	120	Exposed				
0	NS											
10	NS	NS										
20	NS	NS	NS									
50	NS	NS	NS	NS								
100	NS	NS	NS	NS	NS							
110	NS	NS	NS	NS	NS	NS						
120	NS	NS	NS	NS	NS	NS	NS					
Exposed	+	+	+	+	+	+	+	+	NS			
Five-year												
	0	10	20	50	100	100	110	120	150	200	Exposed	
0	NS											
10	NS	NS										
20	NS	NS	NS									
50	NS	NS	NS	NS								
100	NS	NS	NS	NS	NS							
100	NS	NS	NS	NS	NS	NS						
110	NS	NS	NS	NS	NS	NS	NS					
120	NS	NS	NS	NS	NS	NS	NS	NS				
150	NS	NS	NS	NS	NS	NS	NS	NS	NS			
200	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS		
Exposed	NS	+	+	+	+	+	+	+	+	+	+	NS

At the Two-year site in summer 1997, the average maximum VPD decreased sharply after 0 m, but was otherwise relatively stable (Figure 6.6). The exposed value (0.73 kPa) was significantly different from all other distances (Table 6.16; Table 6.19) and thus did not indicate an edge effect. At the Five-year site, the average daily maximum VPD also decreased after 0 m (Figure 6.6), but the exposed (0.53 kPa) was significantly different from all distances except 0 m (Table 6.16; Table 6.19) and, unlike the Two-year site, supports the notion of a narrow edge effect (< 10 m). At the 15-year site, the average daily maximum VPD was higher and more variable across the early portion of the impact transects relative to more stable controls (Figure 6.6). There were no exposed data and no significant differences (Table 6.16), but an edge effect of at least 20 m can be identified on the impact transects relative to the low levels observed on the controls. There was, however a substantial

level of variability at these distances relative to other points, indicating that this effect was not uniformly distributed across this edge.

As with the winter 1997 deployments, there was little response in average daily maximum VPD in either the autumn or winter of 1998, suggesting that edge effects in cooler/wetter seasons will be insubstantial and unlikely to be biologically important. The effect of the forest on maintaining wet conditions is well demonstrated with exposed positions often significantly drier than transect points. Any age patterns in maximum VPD (if they exist) are thus likely to be restricted to warmer seasons and may be influential only after a substantial dry period.

At the One-year site in autumn 1998, the exposed (0.33 kPa) was significantly different from all other distances (Table 6.16; Table 6.20), but there may have been a slightly higher VPD maxima at 0 m to suggest a narrow edge effect (Figure 6.6). At the Two-year site, the 0 m point (0.06 kPa) was significantly different from 20 m, and the 100 and 200 m points on the controls, and may suggest an edge effect, particularly as the exposed (0.08 kPa; Figure 6.6) was significantly different from all distances except 0 m (Table 6.16; Table 6.20). At the Five-year site, the average daily maximum VPD was relatively stable (Figure 6.6). The exposed (0.16 kPa) was significantly different from all other distances (Table 6.16; Table 6.20). At the 15-year site, the pattern was similar, with the exposed (0.11 kPa) also significantly different from all other distances (Table 6.16; Table 6.20).

The winter 1998 deployments were very similar to autumn (Figure 6.6). At the One-year site, the average daily maximum VPD was low and stable across both transect types, while the exposed (0.07 kPa) was significantly different from all other points except 50 m (Table 6.16; Table 6.21). The VPD regime at the Two-year site was similar, but with a higher exposed (0.24 kPa; Figure 6.6) that was also significantly different from all points (Table 6.16; Table 6.21). The Five-year site VPD maxima suggested a very small gradient at 0 m (Figure 6.6), while the exposed (0.21 kPa) was also significantly different from all other points (Table 6.16; Table 6.21). The 15-year site was also similar to the One-year and the Two-year site (Figure 6.6), with an exposed (0.22 kPa) that was again significantly different from all other points (Table 6.16; Table 6.21).

Unlike temperature, VPD is a bounded parameter so that, once saturated by rain, a patch of forest will register close to zero in terms of VPD regardless of changes in other microclimate parameters until the system begins to dry out. This was particularly evident in the number of significant differences between exposed points and all other distances within their respective site, with two sites in spring 1997 (the Two-year site and the unlogged One-year site; Table 6.18), one site in summer 1997 (Two-year again; Table 6.19), three sites in autumn 1998 (One-year – then logged, Five-year and 15-year; Table 6.20) and at all four sites in winter 1998 (Table 6.21). This suggests a high level of canopy buffering for this parameter regardless of distance, which is counter to detecting an edge effect.

Substantial patterns in maximum VPD emerged during spring and summer, which generally tracked with changes in average hourly maximum PAR and/or average daily maximum temperature (Figure 6.2; Figure 6.4). Seasonal responses thus appear to be the dominant influence, although cool season VPD measurements on transects (note not exposed points) approached the level of accuracy of the temperature dataloggers (Appendix B). Cool season VPD results thus need to be considered with caution, despite some significant differences in cooler season results (Two-year and Five-year in winter 1997; Table 6.17). Instances where significant differences could actually be related to an edge effect were rare, with the Five-year and 15-year sites in spring 1997 (Table 6.18), the Five-year site in summer 1998 (although the data for the Two-year and 15-year sites were incomplete; Table 6.19) and possibly the Two-year site in autumn 1998 (Table 6.20), all of which suggested a narrow edge effect of less than 10 m.

Gradients with respect to the edge were common, but these generally also indicated a narrow penetration distance (< 10 m) after accounting for changes on the controls. Results from the One-year site in the spring and summer of 1999 also suggest a narrow gradient (< 10 m again; see Chapter 4). Incomplete 15-year site observations in summer 1997 suggested an edge effect of 20 to 50 m, but otherwise differences with age were not observed.

Table 6.21 - Tukey-Kramer HSD test for significant differences in the winter 1998 average daily maximum VPD data (all sites had significant differences). Shaded headings indicate control transects, NS = not significant, “+” = significant.

Winter 1998												
One-year												
	0	10	20	50	100	100	110	120	150	200	Exposed	
0	NS											
10	NS	NS										
20	NS	NS	NS									
50	NS	NS	NS	NS								
100	NS	NS	NS	NS	NS							
100	NS	NS	NS	NS	NS	NS						
110	NS	NS	NS	NS	NS	NS	NS					
120	NS	NS	NS	NS	NS	NS	NS	NS				
150	NS	NS	NS	NS	NS	NS	NS	NS	NS			
200	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS		
Exposed	+	+	+	NS	+	+	+	+	+	+	+	NS
Two-year												
	0	10	20	50	100	100	110	120	150	200	Exposed	
0	NS											
10	NS	NS										
20	NS	NS	NS									
50	NS	NS	NS	NS								
100	NS	NS	NS	NS	NS							
100	NS	NS	NS	NS	NS	NS						
110	NS	NS	NS	NS	NS	NS	NS					
120	NS	NS	NS	NS	NS	NS	NS	NS				
150	NS	NS	NS	NS	NS	NS	NS	NS	NS			
200	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS		
Exposed	+	+	+	+	+	+	+	+	+	+	+	NS
Five-year												
	0	10	20	50	100	100	110	120	150	200	Exposed	
0	NS											
10	NS	NS										
20	NS	NS	NS									
50	NS	NS	NS	NS								
100	NS	NS	NS	NS	NS							
100	NS	NS	NS	NS	NS	NS						
110	NS	NS	NS	NS	NS	NS	NS					
120	NS	NS	NS	NS	NS	NS	NS	NS				
150	NS	NS	NS	NS	NS	NS	NS	NS	NS			
200	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS		
Exposed	+	+	+	+	+	+	+	+	+	+	+	NS
15-year												
	0	10	20	50	100	100	110	120	150	200	Exposed	
0	NS											
10	NS	NS										
20	NS	NS	NS									
50	NS	NS	NS	NS								
100	NS	NS	NS	NS	NS							
100	NS	NS	NS	NS	NS	NS						
110	NS	NS	NS	NS	NS	NS	NS					
120	NS	NS	NS	NS	NS	NS	NS	NS				
150	NS	NS	NS	NS	NS	NS	NS	NS	NS			
200	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS		
Exposed	+	+	+	+	+	+	+	+	+	+	+	NS

The average slope of the maximum daily VPD regressed against transect distances across locations per season confirmed a marked seasonal response (Figure 6.7), although, as with the maximum temperature summary, this interpretation ignores a considerable amount of variation within distances. Winter 1997 and autumn and

winter 1998 had relatively shallow slopes compared to spring and summer 1997 regardless of the transect type, while controls were close to zero (Figure 6.7). Controls had larger and more variable slopes in spring and summer (Figure 6.7), which suggests that VPD responses in undisturbed forest are difficult to predict. This might be anticipated as this parameter, which even more than temperature, is strongly influenced by conditions at each site prior to each deployment. There were strong indications of an edge effect in spring and summer in terms of the slope of the response, but, as with maximum temperatures (Figure 6.5), the penetration distance would appear to be reliant on the exposed conditions rather than differences in the age of the edge.

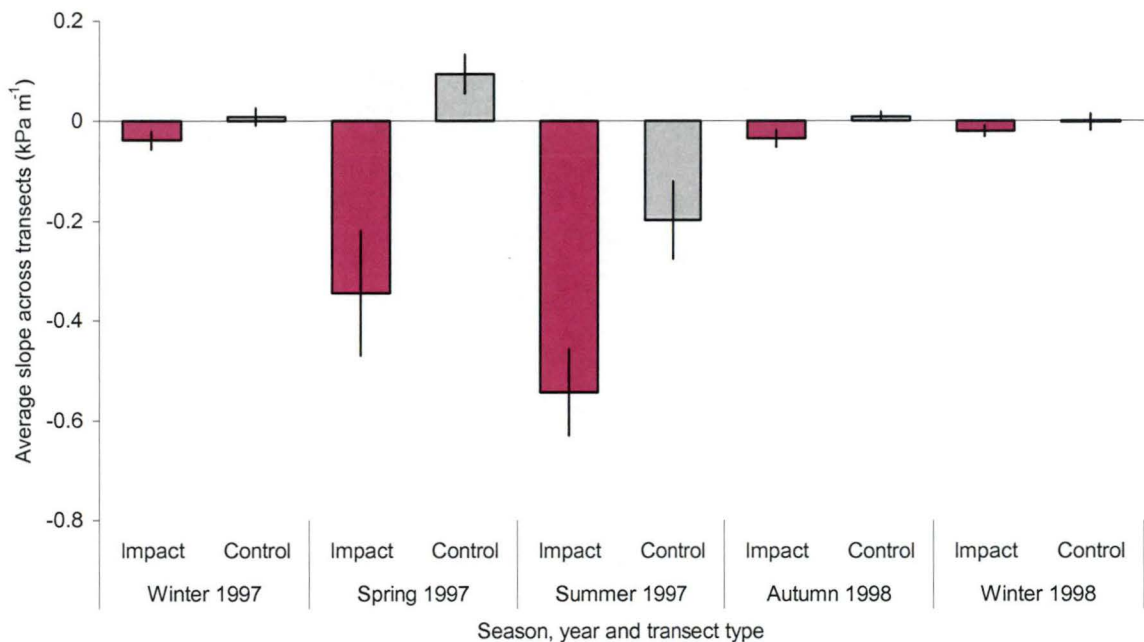


Figure 6.7 - Average across sites of the slope of maximum VPD differences across distances along transects within each season. Bars are standard error.

6.4 Discussion

6.4.1 Age responses in microclimate parameters

Microclimate varied across edges of different ages in southern Tasmanian forests, but did not conform to a simple gradient model. Average hourly maximum (daytime) photosynthetically active radiation (PAR) varied with edge age, with a response of less than 10 m at the youngest edge (One-year; < 1 year), 20 m at the 2-year-old site (Two-year) and up to 50 m at the 5 and 15 year-old edges (Five-year and 15-year). Increased light penetration with age is likely to be the effect of

ongoing canopy disturbance in the border vegetation that started with collateral damage associated with the felling of adjacent trees (*sensu* Chen *et al.* 1995). This continued deeper into the edge under the influence of a gradient of wind exposure (*sensu* Lovejoy *et al.* 1986, Laurance 1991, Fraver 1994, Laurance 1997), which may itself respond to age of the edge. Gradients of wind-induced damage have been noted elsewhere (Laurance 1991, Fraver 1994, Laurance 1997), but only Lovejoy *et al.* (1986) and Fraver (1994) suggests any relationship to the age of the edge.

This suggests that edge effects cannot be described in terms of microclimate or physical disturbance in isolation, but are the product of the interaction of both gradients. Patterns with respect to edge age are thus difficult to identify, particularly when different sites have been used as surrogates for temporal change, as the physical disturbance/microclimate gradient is likely to be influenced by differences in forest composition, slope, aspect and degree of wind exposure (e.g. Laurance 1991, Matlack 1993, 1994, Laurance *et al.* 1998, Mesquita *et al.* 1999, Gascon *et al.* 2000) which may vary substantially between locations. The lack of concurrent data between sites also makes interpretation of microclimate differences problematic owing to differences in weather between sampling periods. However, if forest microclimates were as stable as much of the literature would have us believe, the confounding influence of changes in conditions outside the forest should be limited.

Although it was apparent in the vegetation survey at the border of the One-year coupe that a single fallen tree at the edge can easily penetrate a considerable distance, there was no response in the associated microclimate (Chapters 4 & 5), which is counter to the notion of a linkage between mechanical damage and microclimate. In contrast, Laurance (1991) found substantial changes in light, humidity and temperature responses to wind-induced damage in tropical Queensland forest edges and noted that differences in forest architecture between systems may play an important role in determining the degree of wind disturbance. In Queensland forests, woody lianas entangled within the vegetation may result in widespread damage from a single fallen tree (Laurance 1991). The less entwined temperate forests in southern Tasmania may be less damage-prone and have a corresponding reduced microclimate response. In the absence of more information on vegetation disturbance regimes at forest edges, the notion of age-related gradients of mechanical damage remains open to question.

Age responses in average hourly maximum PAR were not translated into differences in either average daily minimum/maximum temperatures or vapour pressure deficit (VPD). Maximum temperature and VPD indicated an edge effect of less than 10 m, irrespective of the age of the edge, which may be a response to the zone of direct and prolonged sun exposure. Increased light further from the edges of older sites appears to be more unevenly distributed which is in line with a mechanical disturbance gradient, as wind induced canopy damage is patchy (Laurance 1991). Higher PAR levels at these distances thus comprised, varying degrees of sun fleck and more diffuse backscattered light from the surrounding vegetation (*sensu* Hutchison and Matt 1977, Oke 1978, Kira and Yoda 1989, Shuttleworth 1989). Although the light regime may be generally increased, the effect on maximum temperature and VPD is limited, as sun flecks are transitory and backscattered light is spectrally less energetic (Hutchison and Matt 1977, Oke 1978).

Maximum temperature was probably the best indicator of the edge effect as the method employed for estimating VPD in this study (Appendix A) makes no allowance for differences in air currents between distances, and these results thus represent an integration of both the dryness of the air and the degree of air movement. Large differences in VPD relative to the edge are thus not entirely the product of drier conditions, but also suggest increased wind exposure, which may vary substantially between locations, although the southerly aspect of most sites faced prevailing winds. Minimum temperature showed little response to the presence of an edge and nothing by way of differences with age.

Many studies of forest edges indicate that the penetration distance of a microclimate effect varies with the factor under observation. Cadenasso *et al.* (1997) reported that light penetrated further than maximum temperature or VPD, but this was interpreted as being the exclusion of gradients in the latter by side canopy at the edge, rather than a relationship to wind damage. Other studies have found that humidity and temperature gradients were larger than light responses (Young and Mitchell 1994, Chen *et al.* 1995, Parry 1997, Gehlhausen *et al.* 2000). Fraver (1994) and Gehlhausen *et al.* (2000) considered that increased wind exposure at the edge might push changes in factors such as relative humidity beyond the distance of the light gradient. Although neither study measured wind exposure across edges, their inference was supported by Chen *et al.* (1995), who found elevated wind exposure to

a distance of up to 240 m in forests in the northwest of the USA, and Laurance (1991, 1997), who suggested that wind induced changes may be larger in spatial extent than microclimate changes. In spite of wind exposure being widely acknowledged as being important in the dynamics of edges (e.g. Ranney *et al.* 1981, Laurance 1991, Chen *et al.* 1992, Fraver 1994, Young and Mitchell 1994, Camargo and Kapos 1995, Chen *et al.* 1995, Brosofske *et al.* 1997, Laurance 1997, Laurance *et al.* 1998, Gascon *et al.* 2000, Gehlhausen *et al.* 2000), few studies attempt to quantitatively assess this factor (although see Chen *et al.* 1995, Brosofske *et al.* 1997).

The overall impression from other age-related microclimate research in edges is that of a reduced edge effect with time (Williams-Linera 1990, Matlack 1993, Kapos *et al.* 1997). This is in contrast to this study that has indicated either an increase in terms of PAR or no change with respect to maximum temperature or VPD. Vegetation research considering temporal changes in edges (Ranney *et al.* 1981, Matlack 1994, Laurance *et al.* 1998) has found little evidence of age-related gradients of canopy damage. Laurance *et al.* (1998) found no age trend in death or damage rates in Brazilian forest edges, which runs counter to the model proposed in this study, although Williams-Linera (1990) suggested that the development of side canopy, which may take as little as 5 years in the tropics, might act as a windbreak. Conversely, Lovejoy *et al.* (1986) and Fraver (1994) suggested that there is a high level of turbulence when strong winds strike an abrupt edge, a major reason for high rates of disturbance in these zones. The best interpretation of the available research is perhaps that the relationship between forest edges and wind exposure is likely to be highly variable and thus difficult to predict.

If the PAR gradient is an indication of canopy damage, the similar penetration distances at the Five-year (5 years) and 15-year sites (15 years) suggests that these edges achieved a degree of stability within about five years of edge creation. Strong microclimate responses at the 15-year site also suggest that there has been little side canopy growth, which has been found to take around 20 years in other temperate regions (Williams-Linera 1990). Lack of development of side canopy at older sites in this study may be due to high levels of disturbance in the edge and/or possibly inhibition (in form of shading) from the adjacent regeneration. However, Mesquita *et al.* (1999) found a reduction of the edge effect in response to increased crown density within the adjacent vegetation: the 15-year site could thus have shown a reduced

microclimatic edge effect even with limited side canopy development. The canopy within the adjacent coupe was, however, primarily comprised of young eucalypts from 10 – 14 m tall (Pers. Obs.), the foliage density of which was relatively low compared to other tree species of a similar height. The influence of the regeneration on the adjacent coupe at the 15-year site may thus remain limited until slower growing, but otherwise more dense adjacent foliage, develops.

Apart from Chen *et al.* (1995) and Parry (1997), this study is one of the few to consider edges that are not maintained. Many other edge studies thus appear to be actually observing the dynamics of side canopy over prolonged periods, rather than exposure to un-buffered microclimate in an exposed edge, as is the case in this study. Chen *et al.* (1995) was concerned with edges adjacent to 10 – 15 year-old regenerating clearcuts in oldgrowth Douglas-Fir forests in the northwest of the USA, while Parry (1997) focussed on 4-year-old edges on coupes in the Victorian Central Highlands, Australia. These authors found edge effects from 30 to 240 and 68 to 118 m respectively, larger than the maximum observed in this study (i.e. less than 50 m at the Five-year and 15-year sites in terms of PAR), but neither makes any inference on the role of the edge age or succession.

6.4.2 Seasonal differences within sites

Seasonal differences in the undisturbed forest were more pronounced than edge effects in all parameters other than PAR. Regardless of the site, there was a difference of more than 10 °C in minimum temperatures between warmer and cooler seasons on control transects, while a difference of ~17 °C was observed for temperature maxima (Figure 6.3; Figure 6.4) and VPD differed by as much as 0.47 kPa (Figure 6.6). These large seasonal changes suggest that the notion of canopy buffering within southern Tasmanian forests should not be overestimated. Within edge research, canopy buffering appears to have been often interpreted to result in stable forest climates (e.g. Lovejoy *et al.* 1986, Franklin *et al.* 1991, Murcia 1995, Luczaj and Sadowska 1997, Cadenasso *et al.* 1997), which may explain the tendency for low levels of control in many studies.

While the notion of climatic stability certainly applies, it does so for only small temporal scales (perhaps only days), as a forest microclimate will shift toward the average exposed situation if the latter is maintained for a long enough period (weeks -

months). This situation might be unique (or enhanced) in southern temperate broadleaf evergreen rainforests, as northern temperate forests are often deciduous (canopy buffering is not thus maintained) and tropical rainforests have less seasonal variability closer to the equator. This aside, edge effects in all microclimate parameters, other than minimum temperature, were profoundly influenced by exposed conditions, rather than the age of the edge which was most apparent in maximum temperature and VPD differences in spring and summer.

All microclimate parameters exhibit significant differences not related to an edge effect, indicating high levels of variability within sites, probably relating to changes in forest architecture, slope, aspect and the vagaries of the exposed weather situation prior to deployments at each site. Although edge effects have been difficult to identify, this points to the advantage of control transects at the same scale as impact measurements, in the absence of which gradients observed in microclimate parameters lack an appropriate context.

High variability on the controls and at the One-year site prior to logging (in particular the summer 1997) and large seasonal differences, suggest that southern Tasmanian forests must tolerate a large range of temperature extremes. Hence, while an edge induced change in microclimate may be detected a substantial distance into unlogged forest, its biological relevance to surrounding vegetation may be limited, as it appears that the flora can already tolerate degree of climatic change. This also suggests that any microclimatic damage to flora in the edge will occur only on days with extreme exposed conditions.

6.5 Conclusions

Microclimate changes in southern Tasmanian temperate broadleaf forest edges are more complex than a simple gradient model, with considerable difference between PAR, maximum temperature and maximum VPD responses. However, edge effects in all three parameters were best observed in warmer seasons (spring and summer) but with no pattern relative to edge age. Cooler season edge effects were negligible across all sites regardless of age.

The PAR gradient in edges had a penetration distance that appeared to increase with edge age, to ~ 50 m within 5 years of logging and burning. This was assumed to be a response to mechanical disturbance gradients developing as a result of increased wind

exposure, which also increased with the age of the edge. The PAR gradient was still apparent at the oldest site (15 years), which suggests that the influence of the adjacent regeneration on edge effects is limited and that the edge effect in these forests, although narrow, persists for a prolonged period.

Maximum temperature and VPD exhibited no age response, but were reliant on exposed conditions and maintained a consistently narrow edge effect (< 10 m). With a lack of age responses in microclimate parameters other than PAR, the detection of age related trends in epiflora is considered unlikely, although there may be a response within 10 m of the edge, in line with maximum temperature and VPD responses. Within larger vegetation, there may be some evidence of an age gradient related to progressive canopy damage.

7 Gradients in vegetation in forest edges of different ages

7.1 Introduction

Within age-related vegetation edge research there is substantial variability in the range of ages considered, as well as measurement criteria and the penetration distances detected. Ranney *et al.* (1981) observed edges in ranges of ages from 10 – 20 years, up to more than 70 years old in Wisconsin, USA, for which penetration distances from 10 – 15 m (but up to 30 m) were detected, with a peak occurring at around 20 years. This took the form of increased basal area and stem density relative to forest interiors, with several tree species favoured by their proximity to the edge. Ranney *et al.* (1981) found five factors to be important in the dynamics of edges, the relative influences of which are unknown and thought likely to alter with age. These include:

- Regional vegetation type
- Successional stage of the forest at the time of edge creation
- Edge aspect
- Herbivore activity (Harper 1970 in Ranney *et al.* 1981)
- Manner in which the edge is maintained

Williams-Linera (1990) also found increased stem density and basal area in edges to a depth of 10 – 15 m, in addition to higher mortality in established trees. While the peak in microclimate changes was observed in the youngest edge (reaching from 2.5 – 15 m into an edge < 1-year-old), the floristic changes were maintained across all edges greater than 5 years old.

Matlack (1994) considered forest herbs, shrubs and seedlings within forest edges in Pennsylvania and Delaware, USA, in three different age classes based on the architecture of the edge (see Matlack 1993 in Chapter 6). The largest edge effects (up to 40 m) in terms of species abundances occurred at younger edges and support the notion that increased recruitment is a common result of edge effects. Matlack (1994) went on to describe a three-stage model for vegetation succession in edges:

- 1) *Pattern formation* - Creation of a steep microclimate gradient with associated improved recruitment of opportunistic trees and shrubs, so that the distribution of species becomes edge-oriented. A stem density gradient forms and the established trees and shrubs in the edge acquire more foliage, resulting in a closed vertical wall of vegetation across the exposed face of an edge or “side canopy” within 10 – 30 years.
- 2) *Re-assortment of physical gradients* - Closure of the side canopy relaxes light related physical gradients (temperature increases, vapour pressure deficit changes, litter moisture, etc). The forest dynamics within the edge thus become less edge-oriented and influenced by smaller scale forest disturbances. Some species are removed, while others persist and reflect the historical edge environment.
- 3) *Pattern relaxation* - Residual edge pattern is diminished, although the temporal inertia behind the side canopy can continue for decades, owing to the longevity of forest plants at the species or clone level, or dormant as soil-stored seed (Canham 1985, Matlack and Good 1990).

Esseen and Renhorn (1998) investigated the influence of edge effects on trees and epiphytic lichens in young (0.5 - 2.5 years old) and old (8 – 16 years old) forest fragments in northwestern Sweden. They found that lichens were significantly affected by creation of the edge, with a penetration distance of 25 – 50 m depending on the degree of exposure. At older edges, there was some recovery within 20 – 30 m of the edge, probably as a result of increased light availability. Esseen and Renhorn (1998) thus regarded edge effects to be temporally dynamic under the combined influence of several factors including microclimate changes (e.g. Matlack 1993, Chen *et al.* 1995, Parry 1997), wind and snow exposure (Ranney *et al.* 1981, Laurance *et al.* 1998) and altered nutrient regimes (Weathers *et al.* 1995). There is considerable capacity for variation in edge responses relative to any or all these

factors, and thus temporal patterns of change in edges at the scale of a few years are difficult to detect. The use of longer time frames in edge research (i.e. tens of years; Ranney *et al.* 1981, Matlack 1994) is more likely to elucidate changes, but indicates nothing about small-scale temporal differences. The static view of edges, as is favoured by many studies (Murcia 1995), is also uninformative.

Laurance *et al.* (1998) found increased tree mortality, damage rates and turnover within 60 m of edges in the Brazilian Amazon. However, only turnover increased with age, probably as a result of higher recruitment. Laurance *et al.* (1998) regarded the edges in that study to be in a prolonged state of flux, similar to Ranney *et al.* (1981), who was of the opinion that:

“...edges appear to be a good example of Clement’s (1916) disclimax where edge maintenance acts much in the same way as a perpetual disturbance of forest interiors. No edges examined were of sufficient age, composition and structure to verify edge equilibrium and the character of a “climax edge””.

This assumes that the edge in question is maintained. Edges of coupes that are not a “perpetual disturbance” may have entirely different dynamics, particularly at large temporal scales.

Current insights on the temporal dynamics of edges have thus been obtained through research on edges, which has been established against an open matrix of pasture or crops for decades or even hundreds of years (e.g. 300 years; Wales 1972). The bulk of vegetation research in edges (~ 70 % of reviewed literature) is focussed on those that were greater than 10 years old (40 % were 40 or more years old). Research conducted at younger edges, where the influence of microclimate is likely to be strongest owing to a lack of side canopy, appears to be lacking. There is also little information on edges that are not maintained, such as the borders of coupes (~ 3 % of research), and few studies have specifically considered the role of edge age in terms of vegetation (~ 3 %).

Studies of edges of different ages in terms of microclimate (Chapter 6) indicated a mixed response, with an age-related photosynthetically active radiation (PAR) gradient of up to 50 m in edges more than five years old. Increased canopy disturbance at older sites was thought to be the source of this response. Conversely, maximum temperature and vapour pressure deficit (VPD) indicated no age response,

with a penetration distance of less than 10 m across all sites. This was thought to be in response to the limits of direct sun exposure as apposed to a more diffuse light regime at greater distances. Results from the before and after, control and impact (BACI) study of vegetation changes (Chapter 5) suggested a number of potential edge effect indicators in terms of both epiflora composition and specific taxa, but with only a single site, the usefulness of these indicators is open to question.

This chapter determines whether changes in vascular plants and epiflora can be correlated with microclimatic responses to edge age (Chapter 6) and tests the veracity of edge indicators across a number of sites (Chapter 5). The aims were:

1. To determine the width of the forest edge effect as measured by the cover of vascular plants and whether this corresponds to PAR gradients. Does the width of the edge effect decline with age?
2. To determine the width of the forest edge as measured by changes in epiflora, to see if this was affected by age of the edge, and whether this agreed with microclimate measurements (particularly maximum temperature and VPD).
3. To see if a distinctive “edge flora” develops within forest edges in southern Tasmania.
4. To establish if the three temporal phases of edge dynamics described by Matlack (1994) can be applied to Tasmanian forest edges.

7.2 Methods

Data were collected from the same coupes used in the microclimate study of edges of different ages (Chapter 6) and thus comprised Small (One-year), Manuka (Two-year), Isabella (Five-year) and Glover (15-year; Chapter 1). Vegetation surveys at each site were conducted the same as the approach described in the before and after study of vegetation changes (Chapter 5), but without the benefit of surveys prior to edge creation. Only the data collected from the One-year site after logging were considered. Surveys were conducted from January to November 1998.

Large-scale vegetation characteristics were identified using TASFORHAB surveys (Peters 1984; Appendix C). These data were used to determine the general forest composition and structure of each site, based on Kirkpatrick *et al.* (1988) and Jarman *et al.* (1994) forest classifications (Chapter 1). The arrangement of quadrats and

subplots (including extra randomly placed plots around 50, 100, 150 and 200 m) was the same as in the BACI study (Chapter 5), except that impact and control transects were continuous the Two-year and 15-year sites. Vascular data included the number, diameter at breast height (DBH) and Braun-Blanquet cover of all taxa within each subplot. Taxonomic resolution was the same as the BACI study.

In the before and after study (Chapter 5), each 2×2 m subplot was divided into four 1×1 m units, which were further divided into 0.5×0.5 m sub-units, making sixteen sampling areas in each subplot and a total of eighty per quadrat (Chapter 5). In this study, the subplot was divided only once, resulting in four sampling units per subplot and twenty within each quadrat (Figure 7.1). This was done because the BACI study aimed at identifying changes within the same points before and after disturbance. A reduced sampling intensity was considered reasonable when comparing between different sites, as observations were not repeated. Epiflora data from the BACI study at the One-year site were amalgamated at this scale for comparison purposes.

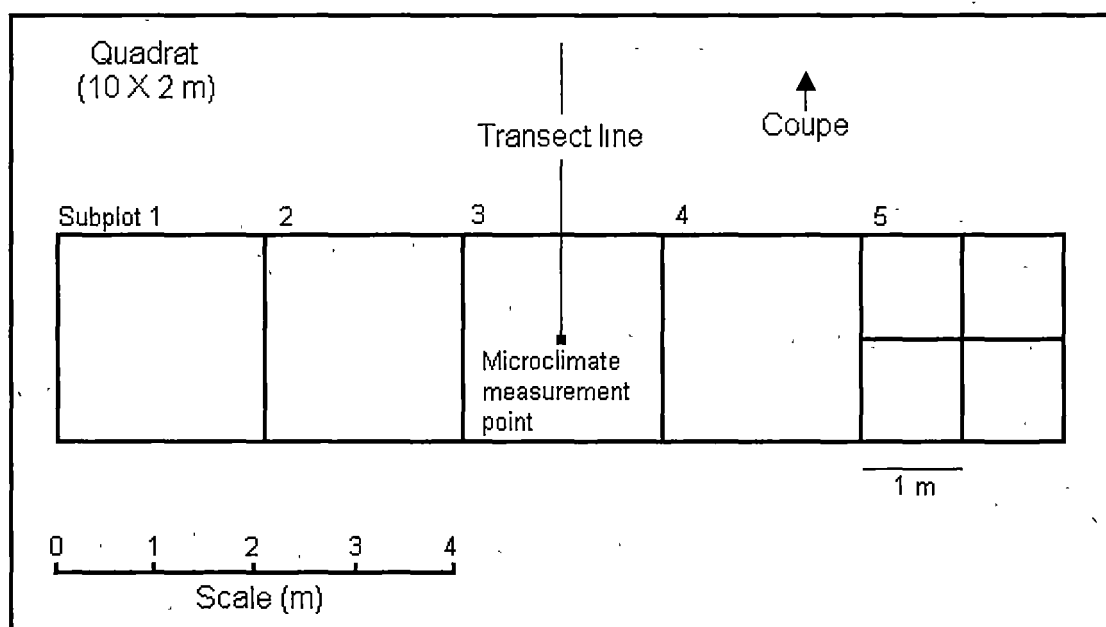


Figure 7.1 - Detailed view of a quadrat indicating the five subplots from which vascular data were collected. Each of these was further divided form twenty epiflora sampling units.

Within each unit, epiflora taxa (comprising all moss, liverwort and epiphytic vascular species) were considered for their presence below ~ 1.3 m above ground (breast height) on any of up to five substrates: Ground, Rocks, Logs, Trees and Manferns, although the number of substrates considered in analyses was reduced. Taxonomic resolution was the same as the BACI study (Chapter 5), but this was also modified for analyses. Ferns and flowering plants included in the epiflora were the

Asteraceae, Blechnaceae, Dennstaedtiaceae, Dicksoniaceae, Dryopteridaceae, Gleicheniaceae, Grammitidaceae, Hymenophyllaceae, Orchidaceae, Polypodiaceae and Psilotaceae (Table 7.1). Members of the Blechnaceae, Dicksoniaceae, Dennstaedtiaceae and Dryopteridaceae were included in vascular plant analyses (although at the species level), as they occurred as both seedlings and adults.

7.2.1 Data summaries and analysis

Multivariate analyses employed the PC-ORD Analysis Package (Version 4.0 MjM Software Design © 1995 - 1999; McCune and Mefford 1999), while univariate statistics were calculated using the JMP software (Version 3.1.2, Sas Institute Inc. © 1989 - 1995). Analyses of large vascular vegetation were similar to the BACI study (Chapter 5) and thus based on the average cover of all taxa within each quadrat. The average relative canopy cover and seedling density, across all species, were also considered within each distance.

Table 7.1 - List of families observed in the epiflora surveys. Shading indicates potential indicators groups that were identified in the BACI study.

ANALYSIS_ID (Family)	Species	ANALYSIS_ID (Family)	Species
Acrobolbaceae	<i>Marsupidium</i> spp.	Hypnaceae	<i>Hypnum</i> spp.
Acrobolbaceae	<i>Tylimanthus</i> spp.	Hypnodendraceae	<i>Hypnodendron comosum</i>
Aneuraceae	<i>Riccardia</i> spp.	Hypopterygiaceae	<i>Cyathophorum bulbosum</i>
Asteraceae	<i>Senecio</i> sp.	Hypopterygiaceae	<i>Hypopterygium rotulatum</i>
Aulacomniaceae	<i>Leptotheca gaudichaudii</i>	Hypopterygiaceae	<i>Lopidium concinnum</i>
Blechnaceae	<i>Blechnum wattsii</i>	Jungermanniaceae	<i>Chandonanthus squarrosus</i>
Bryaceae	<i>Bryum</i> sp.	Lepidolaenaceae	<i>Gackstroemia weindorferi</i>
Dawsoniaceae	<i>Dawsonia longiseta</i>	Lepidoziaceae	<i>Bazzania</i> spp.
Dennstaedtiaceae	<i>Histiopteris incisa</i>	Lepidoziaceae	<i>Acromastigum colensoanum</i>
Dennstaedtiaceae	<i>Pteridium esculentum</i>	Lepidoziaceae	<i>Lepidozia</i> spp.
Dicksoniaceae	<i>Dicksonia antarctica</i>	Lepidoziaceae	<i>Telaranea</i> sp.
Dicranaceae	<i>Campylopus</i> spp.	Leucobryaceae	<i>Leucobrium candidum</i>
Dicranaceae	<i>Dicranoloma</i> spp.	Meteoriaceae	<i>Weymouthia</i> spp.
Dicranaceae	<i>Holomitrium</i> sp.	Orchidaceae	<i>Chiloglottis</i> sp.
Dicranaceae	<i>Trematodon</i> sp.	Orchidaceae	<i>Pterostylis</i> sp.
Ditrichaceae	<i>Ditrichum difficile</i>	Orthotrichaceae	<i>Macromitrium</i> sp.
Dryopteridaceae	<i>Polystichum proliferum</i>	Orthotrichaceae	<i>Zygodon</i> sp.
Dryopteridaceae	<i>Rumohra adiantiformis</i>	Plagiochilaceae	<i>Plagiochila</i> spp.
Geocalycaceae	<i>Chiloscyphus argatus</i>	Polypodiaceae	<i>Phymatosaurus pustulatus</i>
Geocalycaceae	<i>Heteroscyphus decipiens</i>	Polytrichaceae	<i>Polytrichum</i> sp.
Gleicheniaceae	<i>Sticherus</i> sp.	Psilotaceae	<i>Tmesipteris billardieri</i>
Grammitidaceae	<i>Ctenopteris heterophylla</i>	Ptychomniaceae	<i>Glyphothecium sciuroides</i>
Grammitidaceae	<i>Grammitis</i> spp.	Ptychomniaceae	<i>Ptychomnium aciculare</i>
Grimmiaceae	<i>Grimmia pulvinata</i>	Rhizogoniaceae	<i>Rhizogonium novae-hollandiae</i>
Hookeriaceae	<i>Distichophyllum</i> sp.	Rhizogoniaceae	<i>Rhizogonium pennatum</i>
Hymenophyllaceae	<i>Hymenophyllum australe</i>	Scapaniaceae	<i>Blepharidophyllum vertebrale</i>
Hymenophyllaceae	<i>Hymenophyllum flabellatum</i>	Schistochilaceae	<i>Paraschistochila tuloides</i>
Hymenophyllaceae	<i>Hymenophyllum marginatum</i>	Schistochilaceae	<i>Schistochila</i> spp.
Hymenophyllaceae	<i>Hymenophyllum rarum</i>	Sematophyllaceae	<i>Sematophyllum</i> spp.
Hymenophyllaceae	<i>Hymenophyllum cupressiforme</i>	Sematophyllaceae	<i>Wijkia extenuata</i>
Hymenophyllaceae	<i>Hymenophyllum peltatum</i>	Splachnaceae	<i>Tayloria gunnii</i>
Hymenophyllaceae	<i>Polyphlebium venosum</i>	Trichocoleaceae	<i>Trichocolea mollissima</i>
Hymenophytaceae	<i>Hymenophyton flabellatum</i>		

The best indicators of edge effects in the BACI study were the changes in epiflora composition observed on Log and Stem substrates and Across substrates (Chapter 5). There was also little apparent loss of information in analysis of the epiflora at the family level, which, apart from increasing the accuracy of ordination analyses, was a useful way of accommodating some of the compositional variation between sites without compromising information on edges. The epiflora composition was considered on these substrates using the frequency of each family within each quadrat after allowing for differences in the availability of substrates (Chapter 5).

Specific indicators comprised the liverwort families Acrobolbaceae, Scapaniaceae, Lepidoziaceae and Schistochilaceae, mosses in the Sematophyllaceae and Dicranaceae, and ferns in the Blechnaceae, Grammitidaceae and Hymenophyllaceae (Chapter 5; Table 7.1). These were compared in terms of their average frequency within each distance from the edge, ignoring substrates (i.e. Across substrates). This accounted for the any different substrate preferences that taxa may exhibit between sites. Univariate statistical analysis of indicator families was thought unlikely to produce reliable results, owing to substantial variability.

In the absence of *a priori* data, interpretation of non-metric multidimensional scaling analyses (MDS - see Chapter 3 for a description of this technique) focussed on the edge effect in terms of the dispersal of quadrats from near the edge in each ordination relative to that of other distances. This was assisted by the consideration of the average Euclidean distance from the position of each point (quadrat) to that of the ordination centroid (average of all points). As with the similar approach used in the BACI study, this entails some distortion depending on the degree to which a two-dimensional MDS result represents multidimensional space. For this reason, distances were calculated using the separate MDS analyses for each site. Statistical differences could not be calculated owing to a lack of independence.

7.3 Results

7.3.1 Stem epiflora compositional differences with edge age

MDS ordination of the Stem-based epiflora indicated that sites were more influential than distance from edge. The Two-year site formed a more or less discrete group (axes 1&3 and 2&3; Figure 7.2), while the One-year and Five-year sites formed large overlapping groups from which a number of outliers were apparent, indicating

similar, but varied, compositions at both sites (axes 1&2, 1&3 and 2&3; Figure 7.2). The 15-year site also overlapped the One-year and Five-year sites, but was somewhat less varied (axes 1&2, 1&3 and 2&3; Figure 7.2).

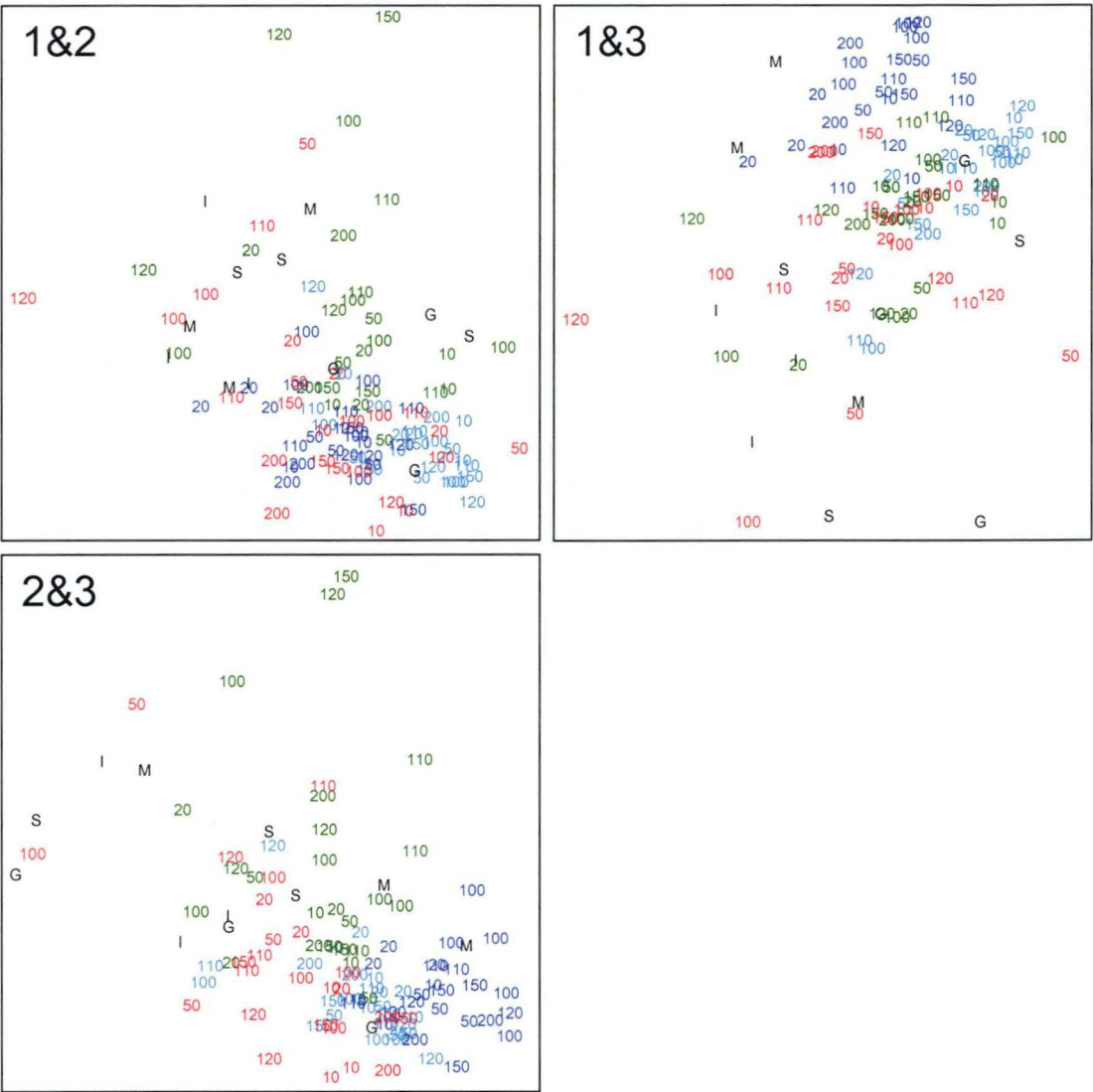


Figure 7.2 - MDS ordination in three dimensions of the epiflora composition on Stems across all sites. Numbers indicate distances from the edge with green = One-year, dark blue = Two-year, red = Five-year and light blue = 15-year. Letters (“S”, “M”, “I” and “G”) = 0 m points for each site. 1&2, 1&3 and 2&3 refer to the axes on the ordination.

No distance trends were observed within or between sites, although the combining of data from all locations within a single ordination may distort or smother such trends. The 0 m points for each site were widely dispersed (axes 1&2, 1&3 and 2&3; Figure 7.2), implying that there was no development of a specific edge adapted epiflora at older borders (at least on Stems), but also that the epiflora community at these points was not typical of their respective site compositions. That 0 m points should become outliers in response to the edge cannot be conclusively proved, due to the lack of *a priori* data and the presence of a substantial number of more profound outliers,

particularly from the One-year and Five-year sites (axes 1&2, 1&3 and 2&3; Figure 7.2). This does, however, support the notion of a narrow edge effect (< 10 m) in line with the major microclimate gradient (Chapter 6).

To determine if there were any distance relationships within locations and to confirm that 0 m points generally occurred as outliers, each site was ordinated separately (Figure 7.3). This allows for a clearer observation of distance trends within each site, but there is no way to directly compare between ordinations owing to differences in scale. Any age trends across these analyses must thus be treated with caution.

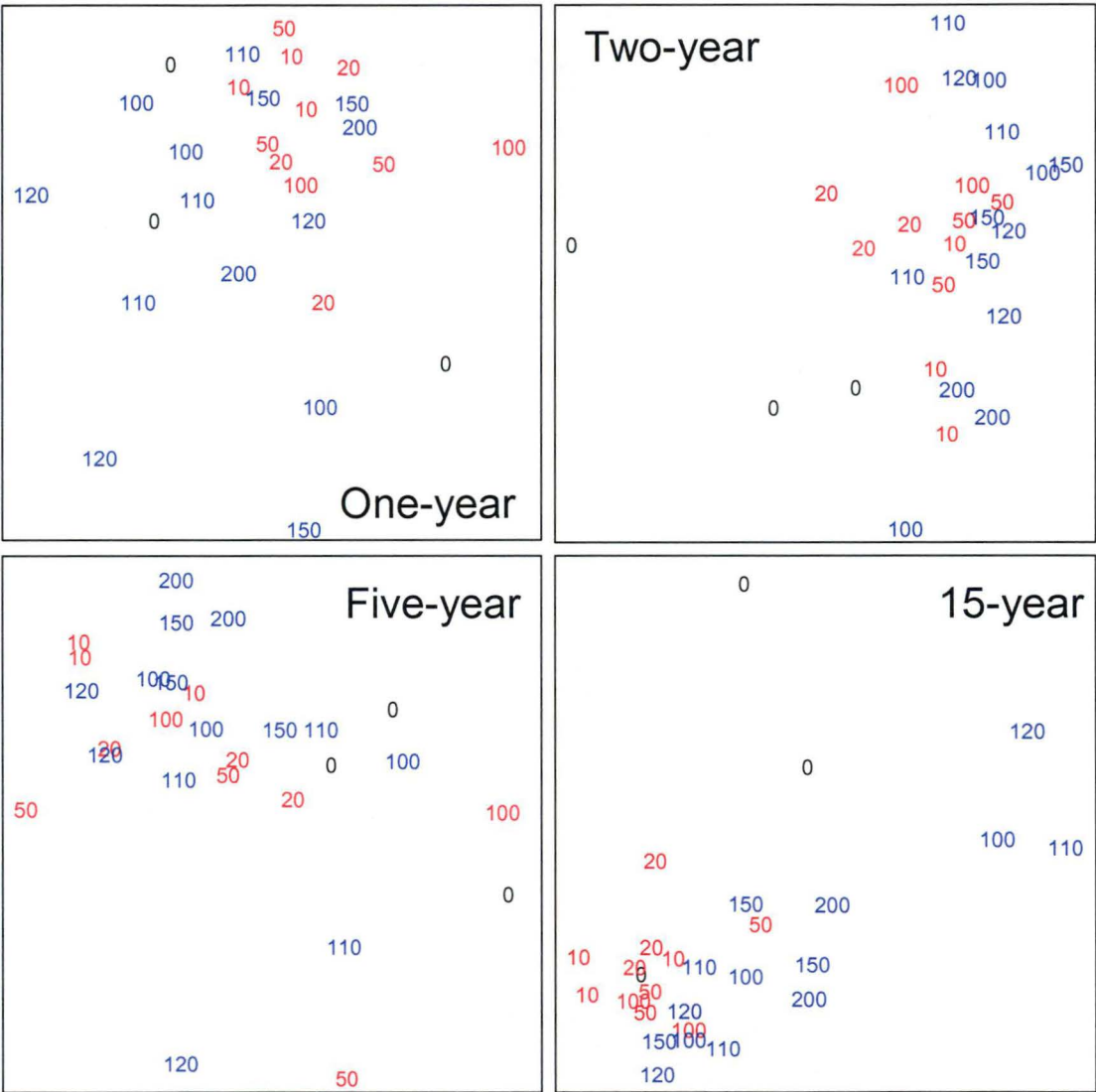


Figure 7.3 - Four *separate* MDS ordinations in two dimensions of the epiflora composition on Stems for each site. Red numbers = impact transects, blue = controls while black = 0 m points.

Within site, differences between control and impact transects were readily apparent, particularly at the 15-year site and, to a lesser degree, at the One-year and Two-year sites (Figure 7.3). This was also observed in the BACI study and considered to be in response to variation in large vascular plant composition within the site. While there

was otherwise some grouping of individual distances (e.g. 10 m points at the One-year and 15-year sites, 20 m points at the Two-year site), there were no apparent gradients relative to the edge regardless of site (Figure 7.3). The 0 m points remained outliers as before, particularly at the Two-year site and two of the three points at the 15-year site while the One-year and Five-year sites were less pronounced in this respect. Both sites have already been shown to maintain a relatively diverse Stem-based epiflora (Figure 7.3), which could absorb the influence of the edge. This suggests that edge effects on Stem-based epiflora are likely to be unevenly distributed between sites, but with no pattern relative to edge age.

In terms of average Euclidean distances, large differences at 0 m were confirmed for the Two-year and 15-year sites (Figure 7.4). Variability in dispersion distance was also largest at 0 m for these sites (Figure 7.4), suggesting that the edge effect was not evenly expressed.

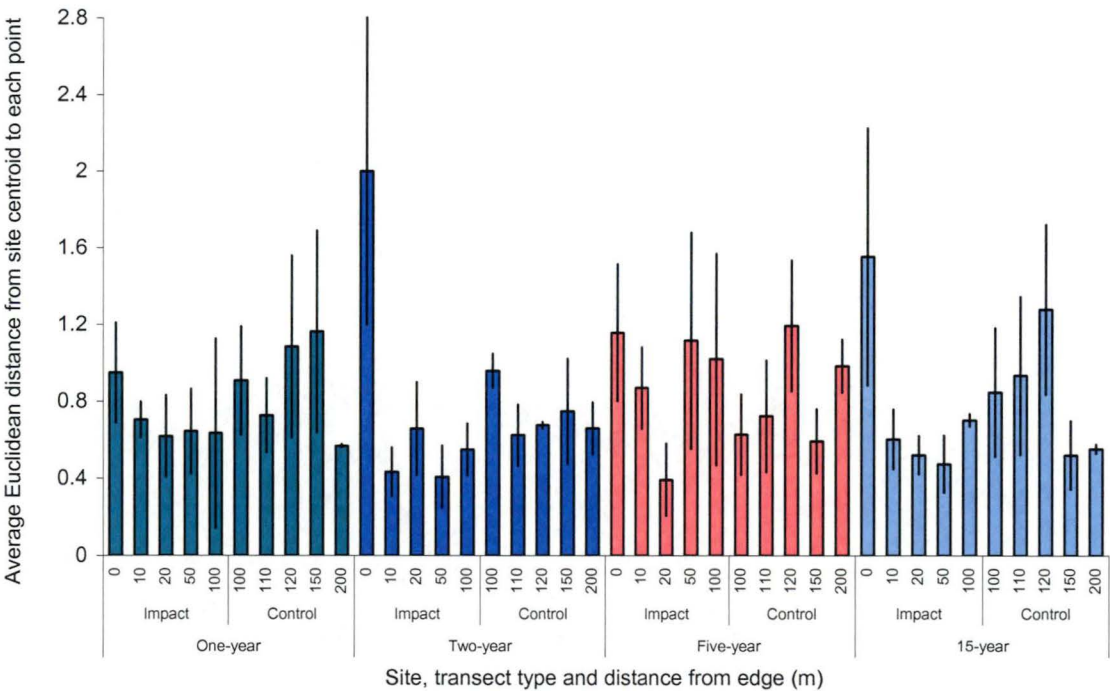


Figure 7.4 - Average Euclidean distance from each MDS point to the ordination centroid for each site based on Stems (Figure 7.3). Bars are standard error.

Within the One-year and Five-year sites, the dispersal of 0 m points was within the range of values at other distances on both impact and control transects (Figure 7.4), although they did appear to be amongst other outliers. Where they can be identified, edge effects in terms of epiflora composition on Stems would appear to be restricted to less than 10 m, but there were no patterns with age of the edge.

7.3.2 Log epiflora differences with edge age

The epiflora composition on Logs across all sites indicated that location differences still dominate (Figure 7.5) with the Two-year site relatively less distinct from other sites (axes 1&2, 1&3 and 2&3; Figure 7.5). The One-year site was more uniform, but interspersed with the Five-year and 15-year sites (axes 1&2, 1&3 and 2&3; Figure 7.5), the 15-year site indicated a relatively more varied composition than that occurring on Stems, while the Five-year site was unchanged (axes 1&2 and 2&3; Figure 7.5). There was less obvious dispersion of 0 m points relative to that observed on Stems, with no suggestion of any age related trends in either the degree of dispersal of 0 m points or their positioning (axes 1&2, 1&3 and 2&3; Figure 7.5).

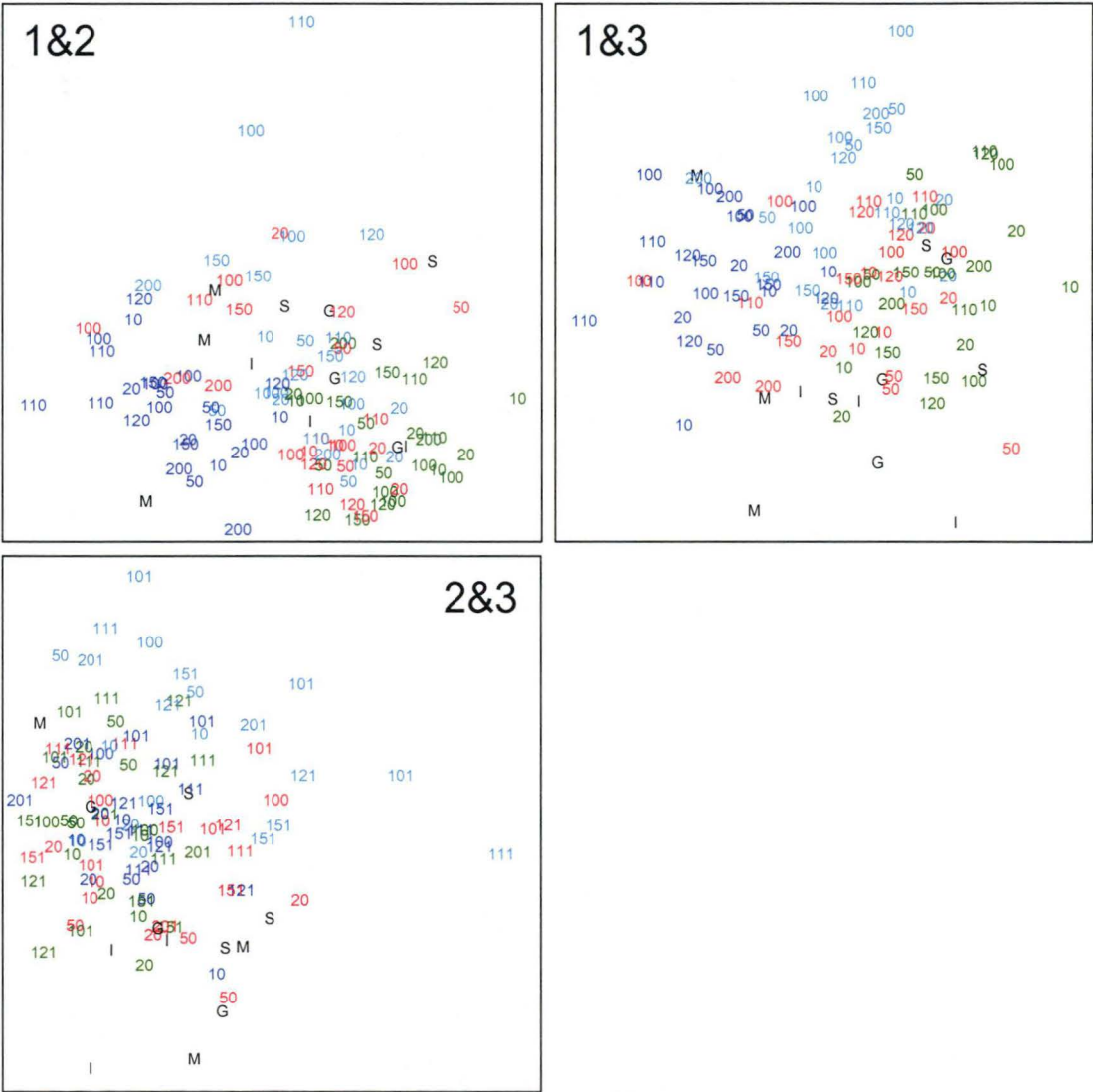


Figure 7.5 - MDS ordination in three dimensions of the epiflora composition on Logs across all sites. Numbers indicate distances from the edge with green = One-year, dark blue = Two-years, red = Five-year and light blue = 15-years. Letters (“S”, “M”, “I” and “G”) = 0 m points for each site. 1&2, 1&3 and 2&3 refer to the axes on the ordination.

Consideration of site-specific differences revealed little segregation of control and impact transects, apart from a suggestion at the 15-year site (Figure 7.6). This contrasts to the observations on Stems, which suggests that differences both within and between sites probably relate more to variation in forest structural complexity than composition.

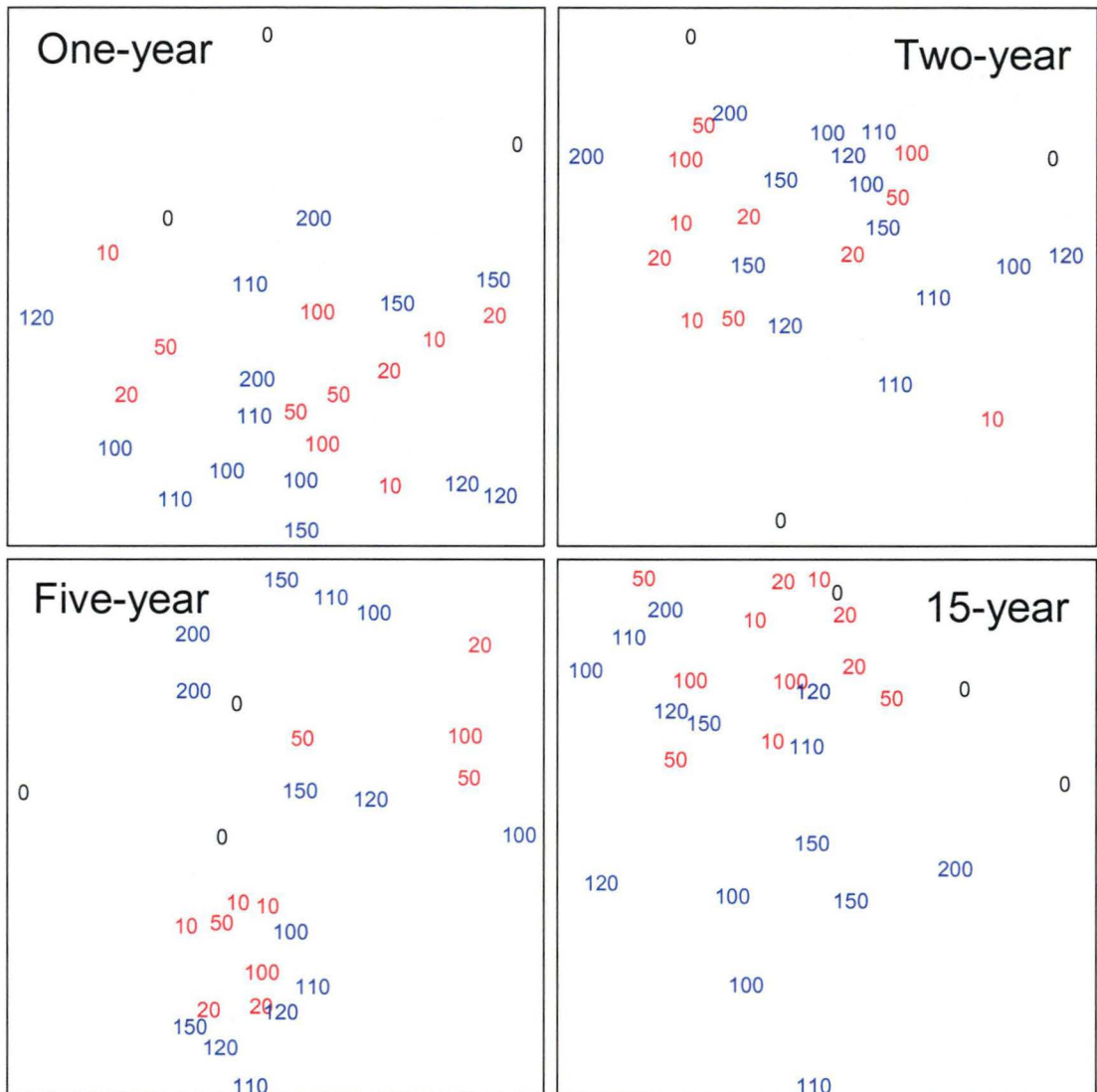


Figure 7.6 - Four *separate* MDS ordinations in two dimensions of the epiflora composition on Logs for each site. Red numbers = impact transects, blue = controls while black = 0 m points.

The One-year and Two-year sites indicate highly dispersed 0 m points, while the older Five-year and 15-year sites appeared to be relatively less varied at their edges (Figure 7.6). There was little, if any, pattern across distances within any site (Figure 7.6).

Euclidean dispersal distances suggest a penetration distance of up to 50 m for the One-year and Two-year sites (Figure 7.7). However, at both sites, the dispersion of points after and including 10 m were within natural levels. The *effective edge*

influence would thus appear to be substantially less than this distance and more in line with the major microclimate response (< 10 m; Chapter 6). At the Five-year and 15-year sites, there is no discernable effect (Figure 7.7). While this trend might be age-related, the available evidence suggests that the older sites were inherently more variable (Figure 7.5) which decreases the influence of the edge.

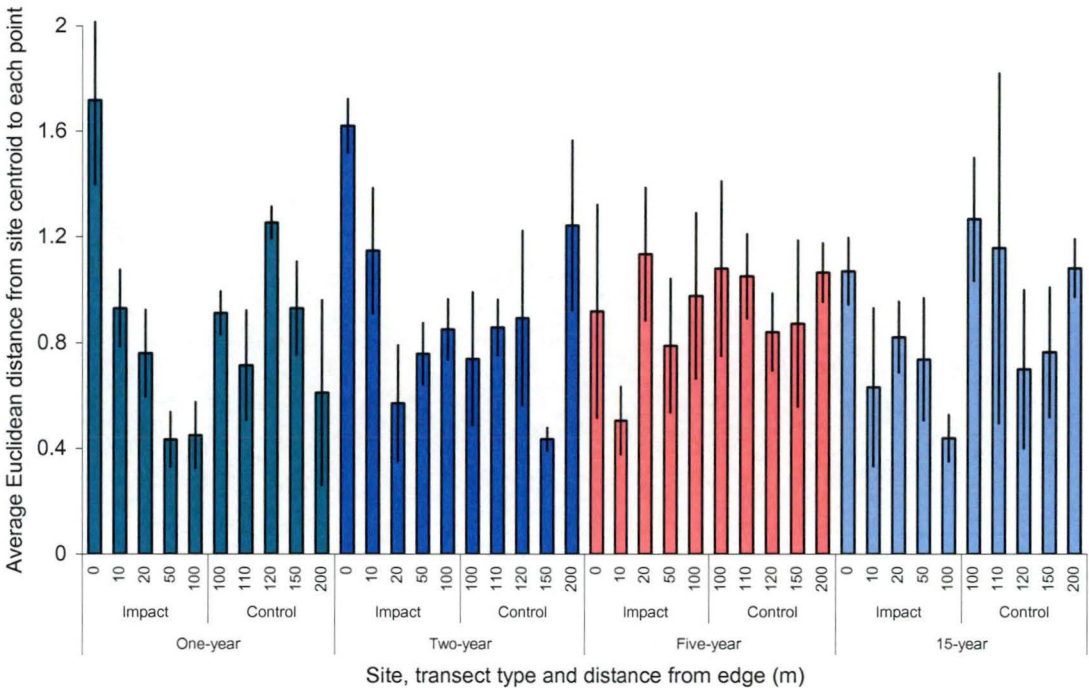


Figure 7.7 - Average Euclidean distance from each MDS point to the ordination centroid for each site based on Logs (Figure 7.6). Bars are standard error.

7.3.3 Across-substrate epiflora differences with age

With data combined Across substrates, the influence of site was still the most apparent factor. The Two-year and 15-year site compositions were relatively uniform and largely discrete (axes 1&2 and 2&3; Figure 7.8). The One-year site was more diverse, but also more discrete (axes 1&3) and tended to oppose other sites, especially the Two-year and 15-year sites (axes 1&3 and 2&3; Figure 7.8). The Five-year site was the most diverse, with elements in common to all other locations (axes 1&2, 1&3 and 2&3; Figure 7.8). The 0 m points were outliers as before, but generally occurred opposite the One-year site (axes 1&3 and 2&3; Figure 7.8).

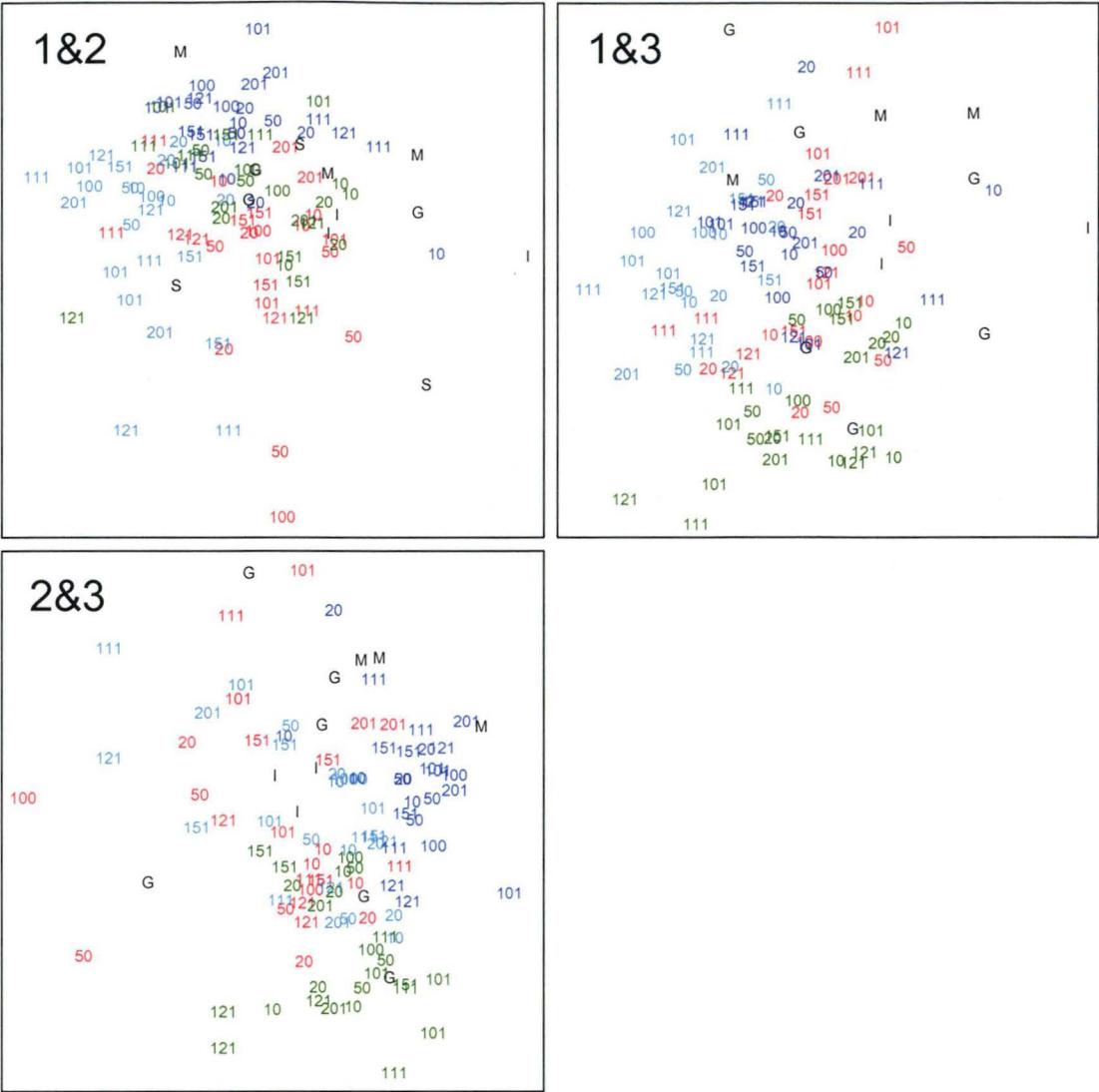


Figure 7.8 - MDS ordination in three dimensions of the epiflora composition irrespective of substrate across all sites. Numbers indicate distances from the edge with green = One-year, dark blue = Two-years, red = Five-year and light blue = 15-years. Letters ("S", "M", "I" and "G") = 0 m points for each site. 1&2, 1&3 and 2&3 refer to the axes on the ordination.

Within site analyses indicated differences between control and impact transects at all sites except the Five-year site (Figure 7.9). There were no apparent distance trends at any site, with highly dispersed 0 m points at the One-year and Two-year sites, but less profound differences at the Five-year and 15-year sites (Figure 7.9). This is similar to the pattern observed on Logs, where it is suggested that highly diverse epiflora compositions at the older sites might smother or distort any influence of the edge.

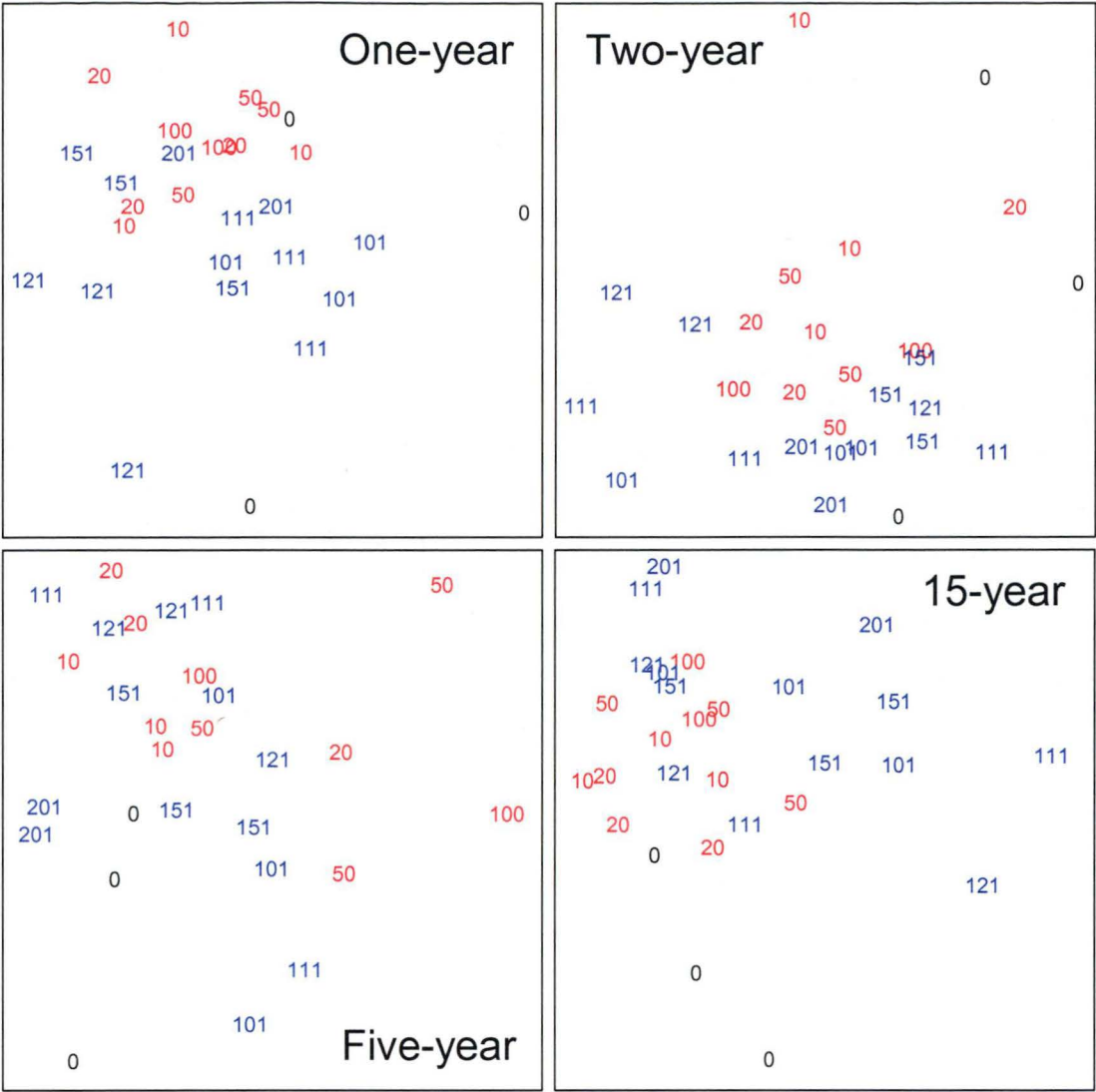


Figure 7.9 - Four *separate* MDS ordinations in two dimensions of the epiflora composition Across substrates for each site. Red numbers = impact transects, blue = controls while black = 0 m points.

Average Euclidean distances from the ordination centroids supported this view, with an edge effect apparent at both the One-year and Two-year sites, but no clear indication at either the Five-year or 15-year sites (Figure 7.10). Gradients in terms of Euclidean dispersion distances at the edge of both the One-year and Two-year sites were within the range of controls for all distances after and including 10 m. Again, the degree of background diversity appeared to be the defining factor at all sites.

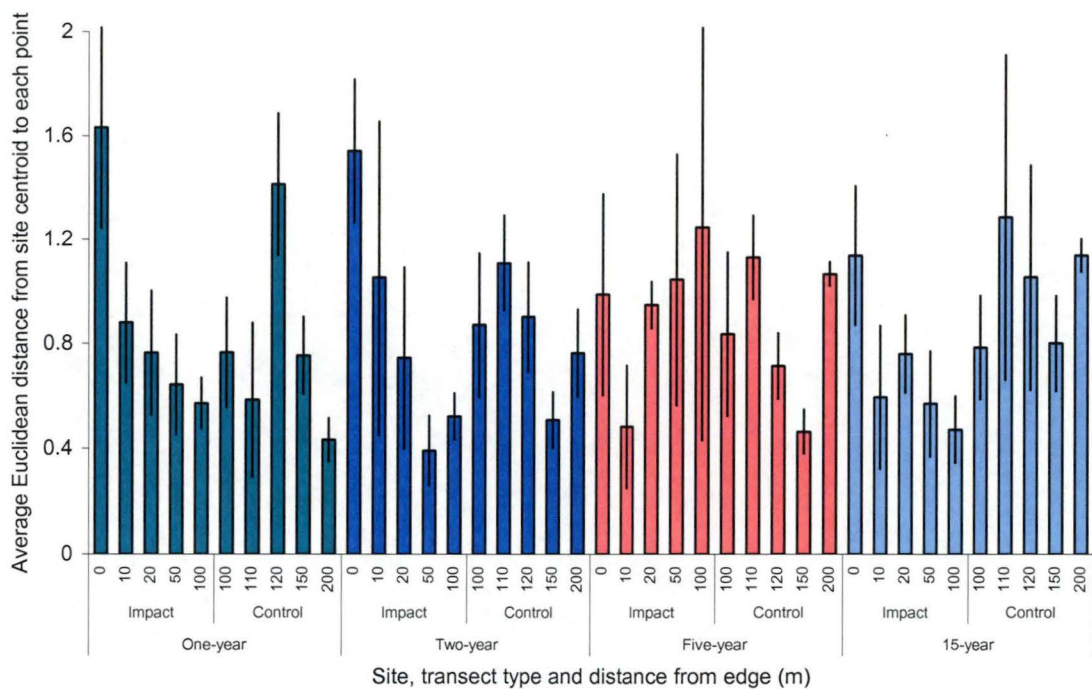


Figure 7.10 - Average Euclidean distance from each MDS point to the ordination centroid for each site based on epiflora compositions Across substrates (Figure 7.9). Bars are standard error.

7.3.4 Indicator families

Within the Acrobolbaceae at the One-year site, the gradient of increasing average frequency from 0 to 100 m (Figure 7.11) was the product of a pre-logging trend (see Chapter 5) and not indicative of an edge effect. Average frequencies across the controls for this site were generally lower than that observed at impact points (particularly 20 – 100 m levels; Figure 7.11), which supports the notion that the impact gradient was not edge-related. The Two-year and Five-year sites may indicate a narrow edge effect (< 10 m), while there is limited response at the 15-year site. This may suggest a level of recovery.

The Lepidoziaceae occurred at high frequency at all sites, with saturation of all subplots (i.e. average frequency = 1) for over half of the distances considered (Figure 7.12). At the One-year site, there was a gradient in average frequency up to 50 m. This may not have been edge-related, as there was a similar gradient on the controls (Figure 7.12). At the Two-year and Five-year sites, there were edge gradients to 50 m and 20 m respectively, while all other distances, apart from 50 m at the Five-year site, were close to saturation (Figure 7.12). The 15-year site had a slightly lower average frequency at 0 m, but was saturated at nearly all other distances (Figure 7.12). There may thus be an age-related decline in the edge effect with a

penetration distance of up to 50 m at the One-year and Two-year sites, 20 m at the Five-year site and 10 m at the 15-year site.

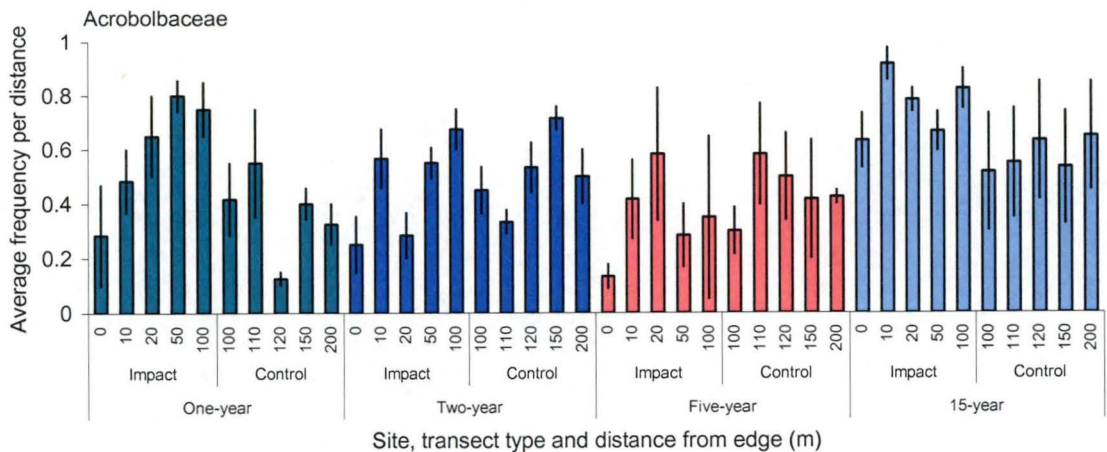


Figure 7.11 - Average frequency of the Acrobolbaceae within each distance across sites irrespective of the substrate. Bars are standard error.

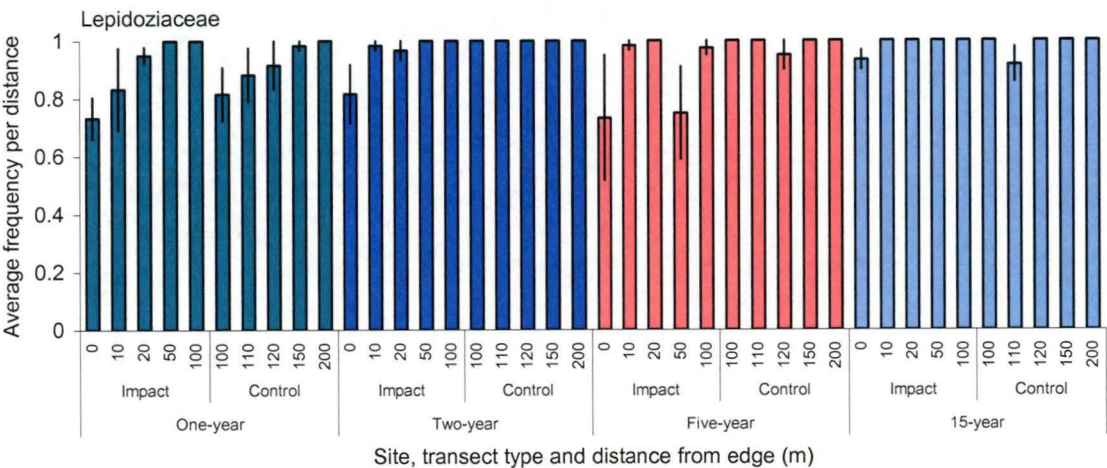


Figure 7.12 - Average frequency of the Lepidoziaceae within each distance across sites irrespective of the substrate. Bars are standard error.

The Scapaniaceae might suggest an edge effect at the Two-year and Five-year sites (< 10 m), but this family was poorly represented at some distances (note lack of error bars at many site/distance combinations) and trends relative to edges are thus unreliable, with considerable variation (particularly at the One-year site; Figure 7.13). Similarly, the Blechnaceae was also unevenly distributed within and between sites (Figure 7.14). The effective use of either group as an indicator of edges is doubtful.

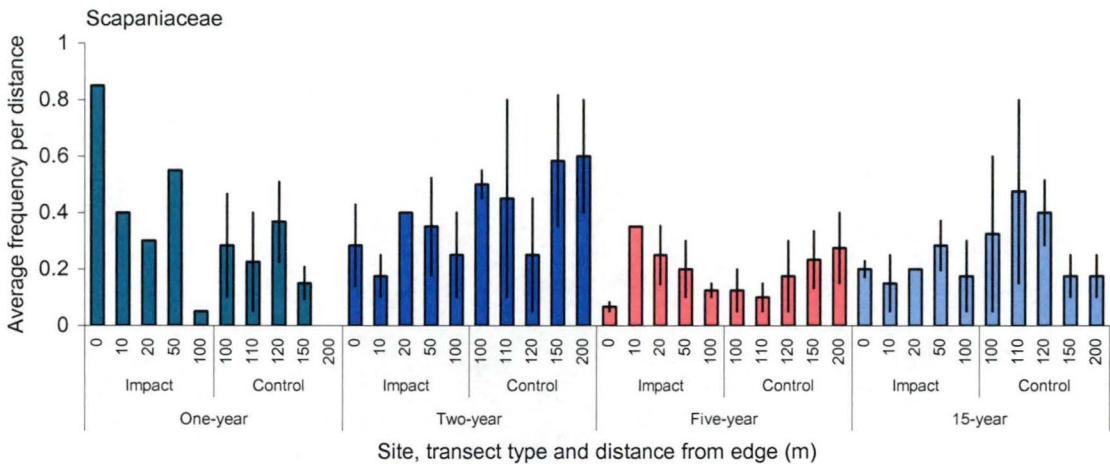


Figure 7.13 - Average frequency of the Scapaniaceae within each distance across sites irrespective of the substrate. Bars are standard error.

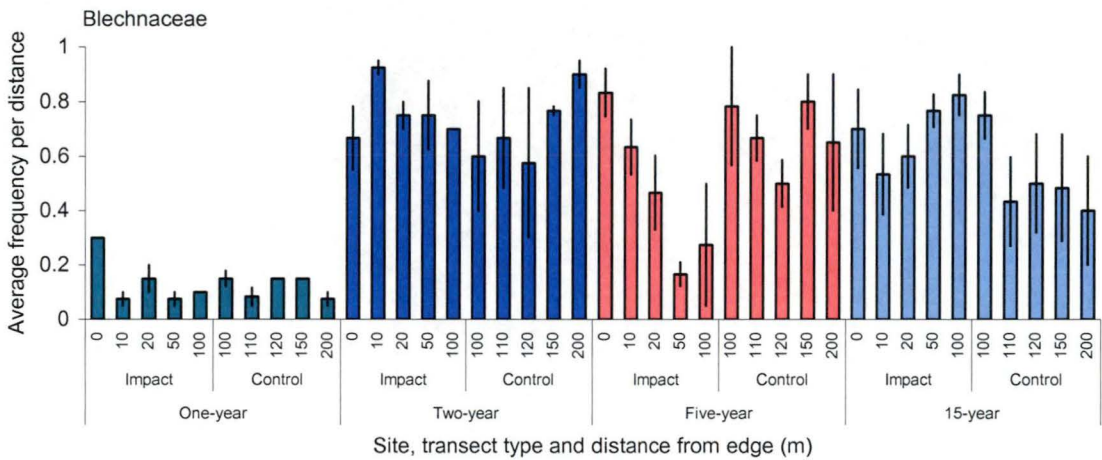


Figure 7.14 - Average frequency of the Blechnaceae within each distance across sites irrespective of the substrate. Bars are standard error.

There also appears to be little consistency in edge response in the Schistochilaceae and Dicranaceae (Figure 7.15; Figure 7.16), and any edge-related trends would appear to be site specific. There is a considerable degree of ecological diversity encompassed within both families (Jarman and Fuhrer 1995) and thus it may be that these groups are less suitable as edge indicators, particularly when comparing sites. This group possibly represents an instance where analysis at higher taxonomic level was not appropriate.

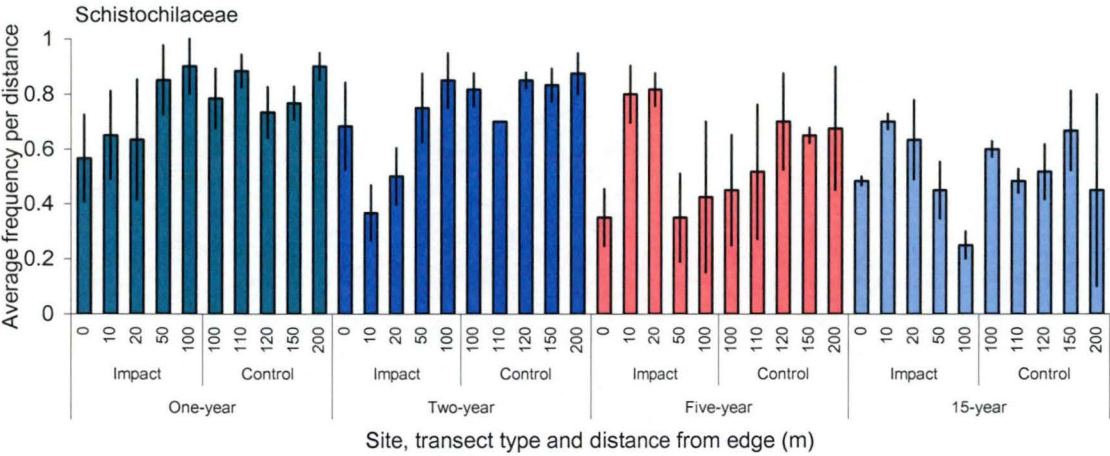


Figure 7.15 - Average frequency of the Schistochilaceae within each distance across sites irrespective of the substrate. Bars are standard error.

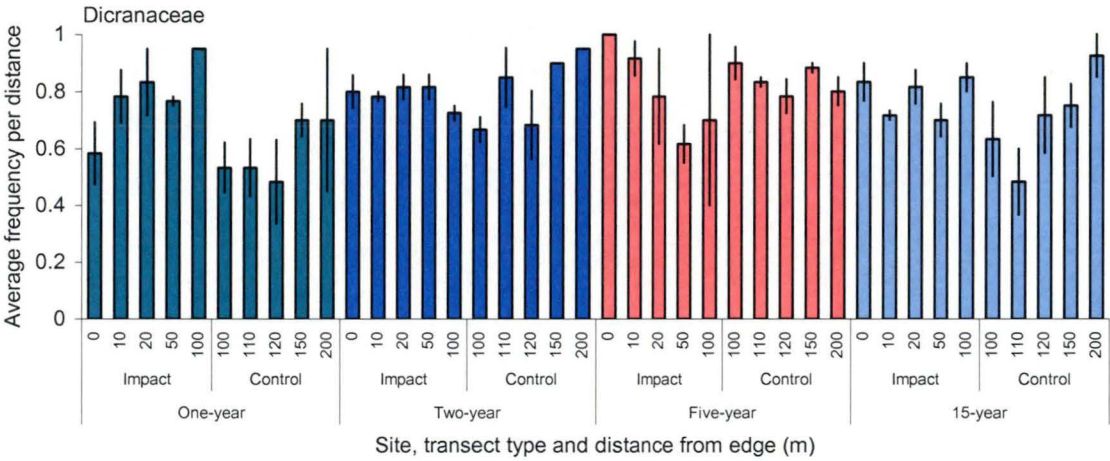


Figure 7.16 - Average frequency of the Dicranaceae within each distance across sites irrespective of the substrate. Bars are standard error.

At the One-year site, the average frequency of the Sematophyllaceae was lowest at 0 m (Figure 7.17). At the Two-year site, the average frequency at 0 m was roughly intermediate compared to other distances (Figure 7.17). At the Five-year site, the average frequency at 0 m was highest for the site, but the other impact distances were also higher than controls. At the 15-year site, this pattern was repeated, although not as strongly (Figure 7.17). Estimating the edge penetration distance for this family is difficult in the face of an apparently variable response, but there would appear to be a decline at 0 m points at the One-year site, no response at the Two-year site (possibly indicating recovery) and increases at the edge of both the Five-year site and at the 15-year site. However, the latter trends are not strong and this group is thus also thought to be unreliable as an indicator.

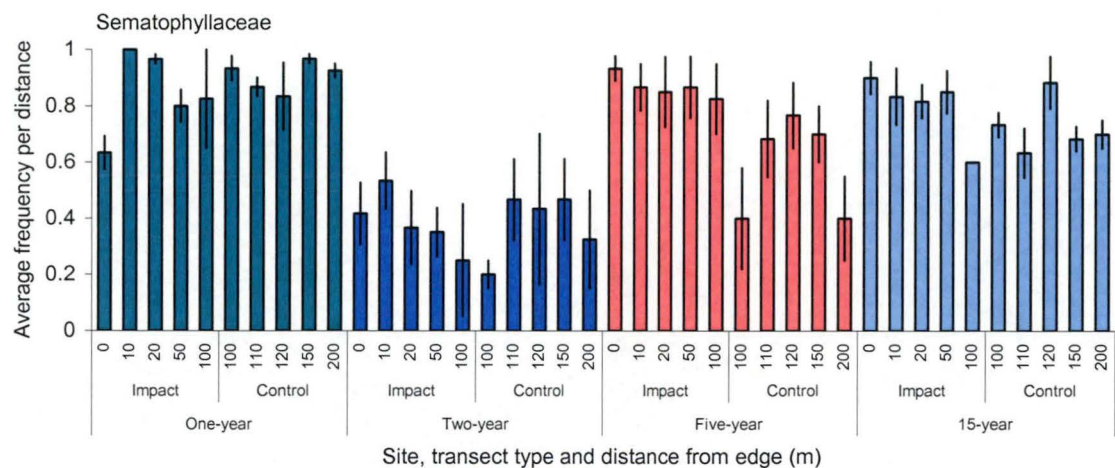


Figure 7.17 - Average frequency of the Sematophyllaceae within each distance across sites irrespective of the substrate. Bars are standard error.

The Grammitidaceae was comprised mostly of *Grammitis billardierei*. At the One-year site, the 0 m point average frequency was lower than all other distances with a similar response occur at the Two-year site (Figure 7.18). The Five-year site was more variable, with the 0 m point intermediate relative to the range across other distances, but at the 15-year site, the 0 m point was again lower than other distances (Figure 7.18). Similarly, the Hymenophyllaceae also suggested an effective penetration distance of less than 10 m regardless of the age of the site, as gradients relative to the edge at the Two-year, Five-year and 15-year sites that may be edge-related are within the range of controls (Figure 7.19). Thus both families generally appeared to be responsive to edge effects to a depth of less than 10 m, but with no pattern relative to the age of each site.

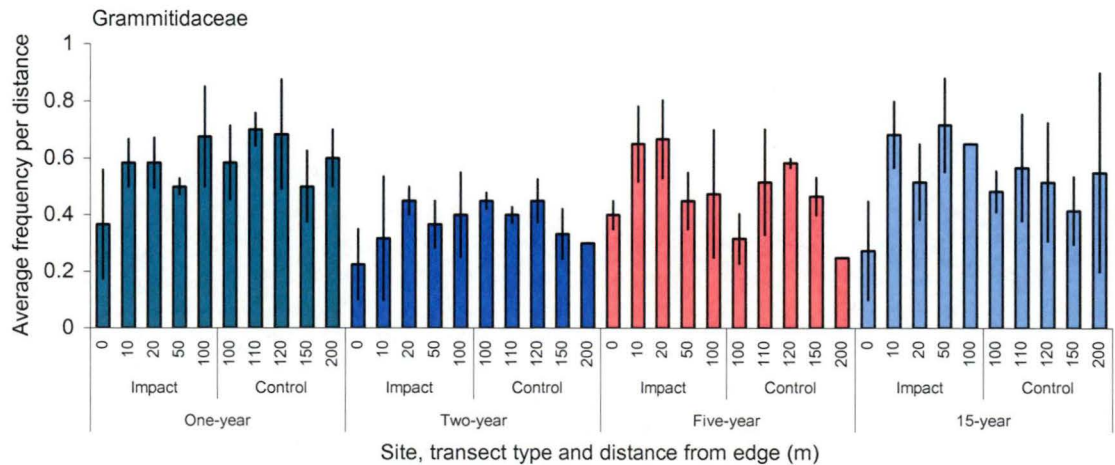


Figure 7.18 - Average frequency of the Grammitidaceae within each distance across sites irrespective of the substrate. Bars are standard error.

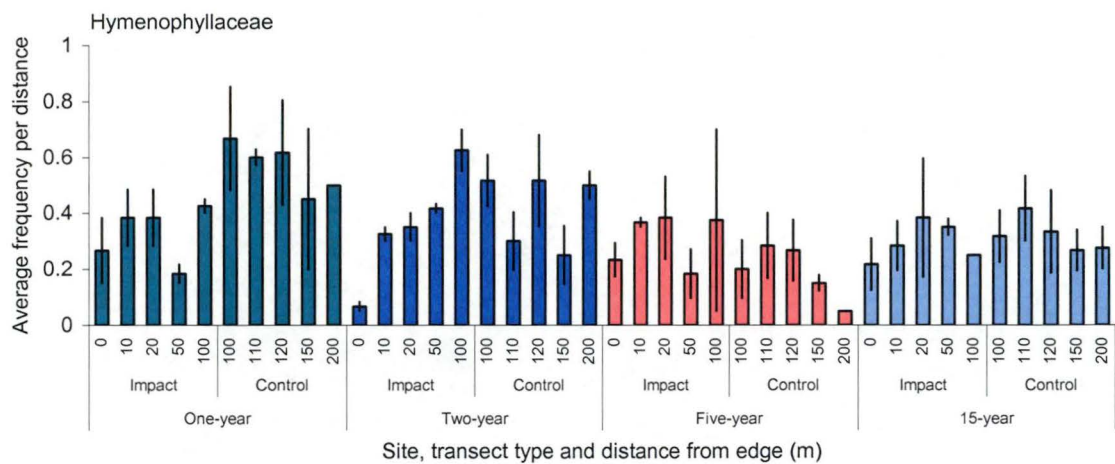


Figure 7.19 - Average frequency of the Hymenophyllaceae within each distance across sites irrespective of the substrate. Bars are standard error.

7.3.5 Vascular taxa responses at edges of different ages

Nearly all sites within the survey were *Eucalyptus obliqua* mixed forests from five different Kirkpatrick *et al.* (1988) forest classifications and one rainforest type (Jarman *et al.* 1994; Chapter 1; Table 7.2), and thus comprised varying combinations of understorey rainforest species. In terms of large-scale complexity, the One-year and Five-year sites are the most diverse, with four and three different forest types respectively, while the Two-year and 15-year sites comprised only two forest types within each site (Table 7.2). However, diversity at the quadrat level was high, regardless of the broader forest framework (Figure 7.20).

Table 7.2 - List of forest types occurring at each site based on Kirkpatrick *et al.* (1988) and Jarman *et al.* (1994) forest classifications.

Site	Transect type	Forest types
One-year	Impact	OB1100, OB1110, OB1001
	Control	OB1100, OB1110, OB1001, OB101
Two-year	Impact	OB1100, OB1110
	Control	OB1100
Five-year	Impact	Thamnic 1.1, OB1100
	Control	OB1100, OB1110
15-year	Impact	OB1100
	Control	OB1100, OB11010

MDS ordination of all quadrats within each site indicated that the Two-year site was distinct from other sites and more uniform in composition (axes 1&2 and 2&3; Figure 7.20). The 15-year site was also relatively less diverse, but had a similar composition to components of the One-year and Five-year sites (axes 1&3 and 2&3; Figure 7.20), both of which otherwise formed large overlapping clusters. The Five-year and 15-year sites tended to oppose the Two-year site (axes 1&2 and 2&3) while

the One-year site appeared to form two dispersed clusters (axes 1&3 and 2&3; Figure 7.20) that are each largely comprised of impact or control distances. This suggests considerable differences in the vascular composition, as evidenced in the diversity of Kirkpatrick *et al.* (1988) forest classes at this site (Table 7.2). The 0 m points were dispersed toward the fringes of the ordination (axes 1&3 and 1&3; Figure 7.20), although the specifics of each site's distance trends are best observed within the separate analysis. There were, however, no indications of any trends relative to edge age.

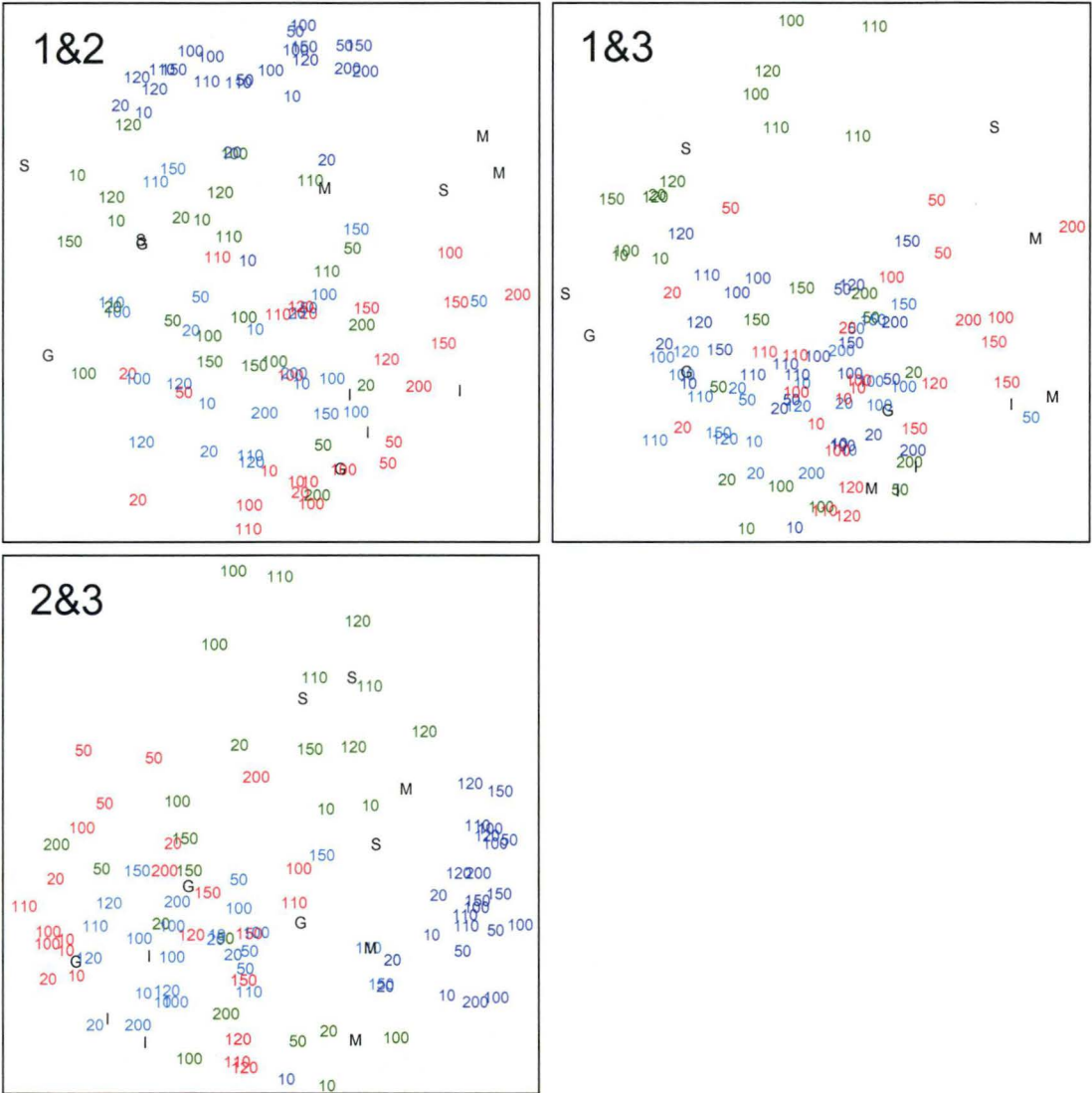


Figure 7.20 - MDS ordination in three dimensions of the average percent cover of large vascular plants in each quadrat at each site. Numbers indicate distances from the edge with green = One-year, dark blue = Two-years, red = Five-year and light blue = 15-years. Letters (“S”, “M”, “I” and “G”) = 0 m points for each site. 1&2, 1&3 and 2&3 refer to the axes on the ordination.

Within sites, control and impact transect differences were confirmed for the One-year site, while other locations suggested little segregation based on transect type (Figure 7.21). Only one 0 m point at the One-year site could be described as an

outlier relative to other distances, as apposed to the Two-year site where all three points were widely dispersed relative to the main group. This suggests an edge effect of less than 10 m at the Two-year site. The 15-year site 0 m points were well dispersed, but less remote from the general site composition, while the Five-year site indicated a relatively close association of edge points (Figure 7.21). Trends for 0 m points within sites were thus highly varied, with only the Two-year and possibly the 15-year sites indicating a narrow edge effect (< 10 m). There is no suggestion of any response at the One-year or Five-year sites and no hint of any age trends.

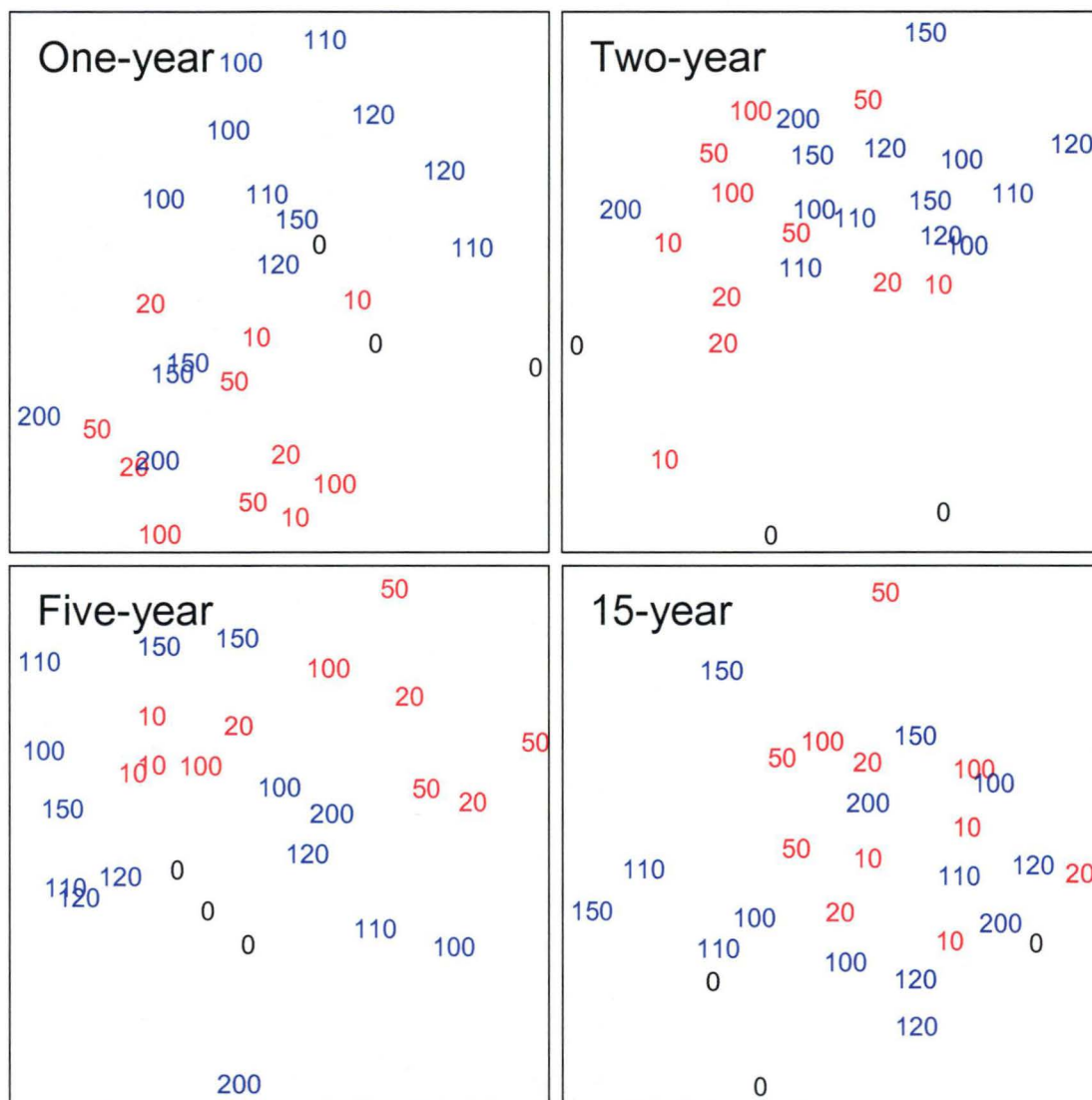


Figure 7.21 - Four *separate* MDS ordinations in two dimensions of large vascular composition at each site. Red numbers = impact transects, blue = controls while black = 0 m points.

Euclidean distances confirmed that the edge of the Two-year site was distinctive (Figure 7.22). There was no difference at the One-year and Five-year sites, while the edge effect at the 15-year site was within the range of controls, but generally distinct from other distances (Figure 7.22).

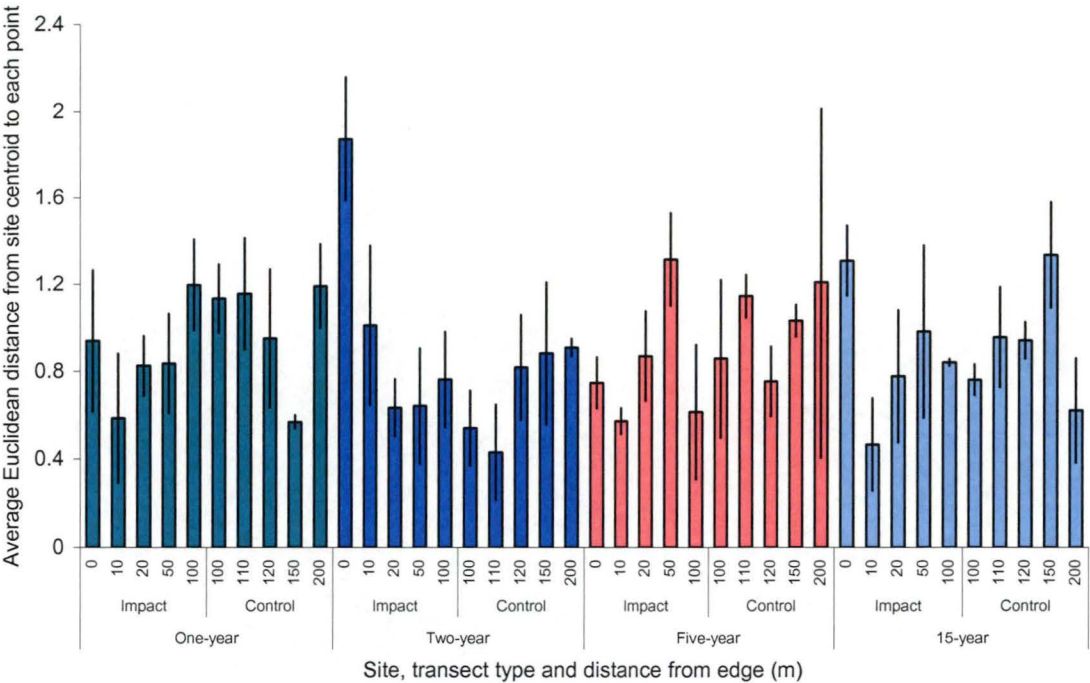


Figure 7.22 - Average Euclidean distance from each MDS point to the ordination centroid for each site based on large vascular taxa (Figure 7.21). Bars are standard error.

In terms of cover, the One-year site indicated a loss to a depth of less than 10 m, while the Two-year site indicated a gradient near the edge up to 20 m (Figure 7.23). The Five-year and 15-year sites were more variable, but also suggested a loss of canopy near the edge, yet largely within the range of other distances (Figure 7.23). There were thus no apparent age gradients in canopy loss near edges, even though all sites indicate a degree of loss. There were no significant differences in terms of the average relative cover between distances within any site (Table 7.3).

Seedling and sapling density varied substantially between sites, but with low recruitment across all distances at the One-year site (Figure 7.24). Otherwise, it would appear that seedling density is suppressed at the edge of other sites to a depth of less than 50 m at the Two-year site (Figure 7.24), while the Five-year and 15-year sites were more variable, with edge values encompassed within control variability (Figure 7.24). The only significant difference occurred at the Five-year site and was not edge related (Table 7.3; Table 7.4). In any case, there was certainly no evidence of increased recruitment at any site and no apparent age trends.

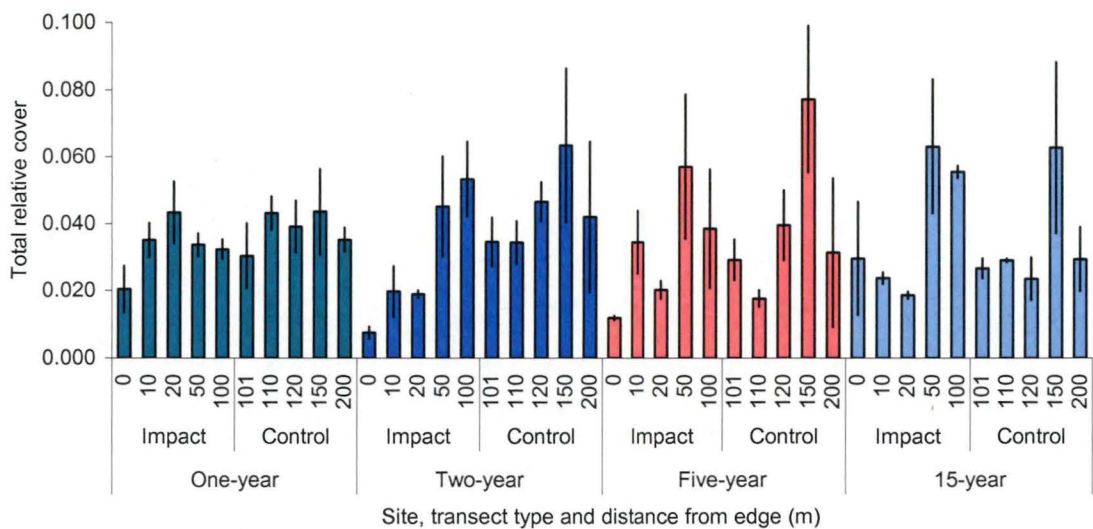


Figure 7.23 - Average total relative cover of canopy species for each distance across sites. Bars are standard error.

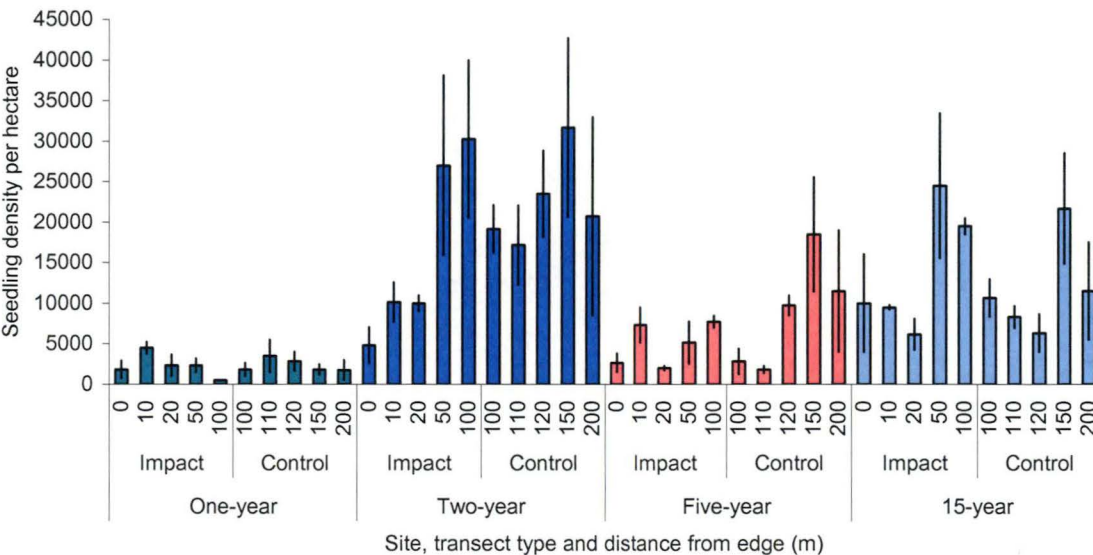


Figure 7.24 - Average seedling / sapling density of all tree species per hectare within distances across sites. Bars are standard error.

Table 7.3 – ANOVA of the relative cover and seedling density of tree taxa within each quadrat across distance. NS = Not significant, * = significant (0.05).

Relative cover	DF	MS	MS Error	F Ratio	Prob.>F	Significance
One-year	9	0.0002	0.0002	0.8193	0.6063	NS
Two-year	9	0.0009	0.0004	2.1438	0.0806	NS
Five-year	9	0.0011	0.0005	2.3561	0.0582	NS
15-year	9	0.0008	0.0005	1.7367	0.1524	NS
Seedling density						
One-year	9	3155754	3840278	0.8218	0.6044	NS
Two-year	9	2.31E+08	1.34E+08	1.7319	0.1536	NS
Five-year	9	80412551	30122549	2.6695	0.0389	*
15-year	9	1.25E+08	64157407	1.95	0.1089	NS

Table 7.4 - Tukey-Kramer HSD test for significant differences in tree seedling density (only the Five-year site had significant differences). Shading indicates control transects, NS = not significant, "+" = significant.

Five-year	0	10	20	50	100	100	110	120	150	200
0	NS									
10	NS	NS								
20	NS	NS	NS							
50	NS	NS	NS	NS						
100	NS	NS	NS	NS	NS					
100	NS	NS	NS	NS	NS	NS				
110	NS	NS	NS	NS	NS	NS	NS			
120	NS	NS	NS	NS	NS	NS	NS	NS		
150	NS	NS	+	NS	NS	NS	+	NS	NS	
200	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS

7.4 Discussion

7.4.1 Epiflora composition and indicator taxa responses to edge age

There was no apparent age trend in the epiflora composition on edges up to 15 years after their creation, with high levels of variability in composition being observed between and within sites. The notion that older edges may develop a distinctive "edge flora" comprising taxa with a better capacity to accommodate microclimate changes was not supported. Bryophyte community composition depends on a range of factors including altitude, drainage, exposure (Jarman and Fuhrer 1995) substrate age (Söderström 1988, Jarman and Kantvilas 1995), corrugation, pH, inclination, stability, (Fensham and Streimann 1997, Frisvoll and Presto 1997), nutrient and chemical composition (Kantvilas and Minchin 1989). The highly variable vascular composition and architecture of the host forest thus plays an important role in determining the make up of the corresponding epiflora community (e.g. Chapters 3 & 5; McCune and Antos 1981, 1982, Kantvilas and Minchin 1989, Jarman and Fuhrer 1995, Fensham and Streimann 1997, Frisvoll and Presto 1997).

Hence, while epiflora compositional gradients of up to 50 m were apparent at all edges irrespective of the strata (i.e. Stems, Logs and Across substrates), differences in undisturbed forest encapsulated most of these gradients after and including 10 m at the One-year and Two-year sites, while variability in controls at the Five-year and 15-year sites generally accounted for all impact changes. The *effective* edge effect for epiflora is thus less than 10 m at some sites, which is in line with the major microclimate regime, in particular the light regime (Chapter 6). Other, more variable sites have no edge effect in terms of epiflora composition. These results once again

confirm the importance of undisturbed controls in defining the appropriate context for impact changes in edges.

Similar penetration distances were observed in the epiflora community in the BACI study (Chapter 5) and the edge effect was found to be in response to an accumulation of large numbers of small differences within taxa at the 0 m points relative to other distances, rather than large differences within a few species.

Potential indicator taxa identified within the BACI varied in their edge response across sites. Most were actually poor indicators of edge effects, because either their response was specific to the One-year site (Dicranaceae), the taxa was highly unevenly distributed within and between sites (Scapaniaceae and Blechnaceae) or the response was inconsistent between sites (Schistochilaceae and Sematophyllaceae) possibly reflecting gradients other than age of the edge. Other indicator families suggested an edge effect, but varied substantially in terms of both the penetration distance and potential responses to age. The Acrobolbaceae and Lepidoziaceae suggested an edge effect that may have declined with age, although the former suggested only a narrow effect (< 10 m) when placed in context with controls. The Lepidoziaceae penetration distance declined from 50 m at edges up to 2 years old, to be less than 10 m by 15 years. The edge effect for the Lepidoziaceae at the younger sites was thus larger than the observed microclimate gradient (Chapter 6), indicating that this group is sensitive to edge creation, but responded to factors not considered in this study. These might be abiotic factors such as soil/substrate temperature and moisture content and/or biotic factors such as increased predation and/or loss of dispersal vectors (e.g. McDonnell and Stiles 1983, Burkey 1993, Kollman and Schneider 1997, Ostfeld *et al.* 1997, Restrepo and Gomez 1998).

Recovery of the Acrobolbaceae and Lepidoziaceae at the older sites may be through the expansion of those species within each family which are more tolerant to edge effects and/or that species undergo a degree of hardening, such that they are more capable of coping with more exposed conditions, albeit at some metabolic cost (Salisbury and Ross 1985). Hardening has been documented for bryophytes elsewhere, in terms of light (Harley *et al.* 1989), cold/frost (Rütten and Santarius 1992) and heat (Hearnshaw and Proctor 1982, Weis *et al.* 1986), but has generally pertained to differences between artificially supported (i.e. shade-house grown) and natural specimens. The epiflora within a closed forest may thus be relatively

unhardened within the blunted forest microclimate, with responses to edge effects dependant on the degree to which species can adjust (or harden) to the harsher conditions. Liverworts appear to generally lack strong hardening capabilities (Weis *et al.* 1986, Rütten and Santarius 1992), which may explain the higher sensitivity to environmental stresses created by logging observed elsewhere for this group (e.g. Söderström 1988, Kantvilas and Jarman 1993, Pharo and Beattie 1997).

The Hymenophyllaceae and Grammitidaceae indicated a narrow edge effect (< 10 m) across all sites irrespective of age. Given that the microclimate regime was also unaltered with age, the Hymenophyllaceae and Grammitidaceae appear to be the most appropriate indicators of climate change in forest edges.

That the Hymenophyllaceae should be a good indicator of edge effects would supports the observations of Peacock (1994) who found a decline in the health of filmy ferns within 0 – 3 m of callidendrous forest edges in the Florentine valley in central Tasmania, but estimated at total effect distance of 20 m. The narrower edge effect observed in this study may be due to the more sheltered southern aspects and the thamnisc understorey at most sites (see Chapter 5). Neyland and Brown (1994), in a study of disturbance in rainforests in eastern Tasmania, found a strong correlation between the health of trees, manferns and epiphytic ferns. Although there is some evidence that species richness of filmy ferns on coupes can recover after a prolonged period (50 years; Peacock and Duncan 1994), the general lack of recruitment of this group on regenerating coupes (Hickey 1994) make its survival in retained forest patches, and hence its sensitivity to edge effects, more important.

The Grammitidaceae (finger ferns) may also be a good indicator of edge effects, particularly as they comprise small plants with distinctive pale green fronds that are easily observed. The frequency measure was thus well suited to detect changes in this group, whereas other taxa often required a substantial loss of cover before they were lost from a sampling unit.

In terms of epiflora composition, the edge effect generally appears to correlate with the microclimate regime, but only after accounting for considerable variability in the undisturbed forest. The epiflora composition on all three of the strata (Stems, Logs and Across substrates) were useful indicators of edge effects, although the Across substrate summary is probably the best, as there is no reliance on availability of

substrates within sites and different substrate preferences that taxa may exhibit between sites. While the Lepidoziaceae appeared to be highly sensitive to environmental change, it did not correlate with the microclimate gradient unlike the Hymenophyllaceae and Grammitidaceae. The latter are thus also considered good indicators of microclimate gradients in edges, although more focused research is required with respect to edge effects including (amongst others) survival, recruitment and physiological tolerances.

7.4.2 Large vascular flora responses to edge age

Large vascular plant composition suggested a narrow (< 10 m) edge effect at some sites, but there was no pattern in terms of age with the effect largely restricted by high levels of background variability. Neither was there any age trend in terms of relative cover across sites. The notion of an age-related gradient of canopy disturbance as suggested to explain PAR gradients in the microclimate study across these sites (Chapter 6) was thus not supported.

Although there was no suggestion of a vascular edge effect at the One-year site in the current research, the BACI study indicated a 100 m penetration distance for this site. However, this was only apparent through a comparison of the vascular community structure before and after edge creation, with a large fallen tree considered responsible. There was no apparent change in microclimate (in particular PAR; Chapter 5), which adds credence to the notion that mechanical damage does not necessarily result in microclimatic changes.

While disturbance gradients in canopies relative to edges have been observed (Laurance 1991, 1997) and related to the age of the edge in some instances (Lovejoy *et al.* 1986, Fraver 1994), they do not necessarily occur everywhere (Williams-Linera 1990, Turton and Freiburger 1997). Mechanical disturbance is determined by the degree of exposure to prevailing winds and topography (Brosofske *et al.* 1997), but the associated damage is not readily predicted (Laurance 1991). Aspect has been widely regarded as important to edge effects (Laurance and Yensen 1991, Matlack 1993, Fraver 1994, Young and Mitchell 1994, Parry 1997) and its consideration within this study was thought unlikely to yield any new information. For this reason sites with similar aspects were selected (southerly) except for the One-year site (northwest). Southerly aspects are the most sheltered in terms of sun exposure in

Tasmania, but may be more exposed to prevailing winds (west – south). The microclimate penetration estimate is thus likely to be conservative, although rates of wind exposure may have been higher.

Increased stem density near edges, due to higher recruitment of shade intolerant species, has frequently been observed elsewhere (e.g. Wales 1972, Ranney *et al.* 1981, Whitney and Runkle 1981, Brothers 1993, Sizer and Tanner 1999, Oosterhoorn and Kappelle 2000), although Williams-Linera (1990) noted an overall increase in edge recruitment without any relationship to composition. While Turton and Freiburger (1997) found limited seedling germination in older edges on the Atherton Tablelands in Queensland, the major recruitment may have occurred before the study took place, with light restrictions imposed by side canopy closure limiting any further seedling establishment. There was a lack of differentiation between shade-tolerant/intolerant seedling taxa in this study, but there was no evidence of any increase in recruitment. This may partly explain the lack of side canopy formation at older sites and the maintenance of the microclimate gradient to less than 10 m across all ages. Elsewhere, the flush of recruitment might alleviate microclimate changes near ground level and ultimately assist in the sealing of the edge (e.g. Ranney *et al.* 1981, Williams-Linera 1990, Matlack 1994, Kapos *et al.* 1997).

Lack of recruitment may be in response to high stress levels in border vegetation, due to damage and/or microclimate changes, or the pollinators and seed vectors may be discouraged by proximity to the edge, resulting in low fertilization and/or dispersal (McDonnell and Stiles 1983, Burkey 1993, Kollman and Schneider 1997, Ostfeld *et al.* 1997, Restrepo and Gomez 1998, Restrepo and Vargas 1999). There may be a failure in survivorship for recruits in the harsher edge microclimate, particularly with the intrusion of soil and woody debris from firebreak construction. The need for wildfire to promote successful recruitment of many species within Tasmanian mixed forests, in particular the dominant eucalypts (Hickey 1994), suggests that microclimate changes are unlikely to be an influential factor, as the climatic regime of these systems after wildfire is probably be considerably harsher than an edge environment. Rather, it would appear that the relaxation of light limitations in the edge is not sufficient to promote recruitment in southern Tasmanian forests which otherwise require the removal of all competitors and a supply of a nutrients from the

ash left by the wildfire (Felton 1976, Duncan 1985, Hickey 1993, Wells and Hickey 1999).

Esseen and Renhorn (1998), in a study of lichen losses in edges, suggested that the biggest effect should be in the first year after creation. Their results were similar to those of this study, with no apparent increase in tree recruitment or responses to edge ages. Development of side canopy within the Swedish forest may be similarly slow to develop, possibly due to low growth rates in northern temperate coniferous forests. Restrepo and Vargas (1999) reported that seedling recruitment was influenced more by habitat type than distance from edge, which may be in line with epiflora changes that are intimately linked to substrate types.

The lack of large vascular recruits at all sites makes comparison with forest edges elsewhere difficult. Southern Tasmanian wet forests may be unique in this respect. It does, however suggest that there is a degree of stability, such that the narrow microclimate gradient remains extant for a prolonged period.

7.4.3 Edge effects at production forest coupes

This study is one of few to consider edge effects at borders that are not to be maintained and may be the only one to make temporal comparisons. Comparisons with other edges, particularly older sites, are thus confounded by the changes occurring within the exposed matrix which are thought to ameliorate edge effects (Mesquita *et al.* 1999) in a manner that may be very similar to the development of side canopy.

Of the research on edges of regenerating coupes or edges that have been overgrown by secondary forest, both Chen *et al.* (1992) and Renhorn *et al.* (1997) considered a narrow range of edge ages (10 – 15 years and 15 years respectively), while Matlack (1994) used overgrown borders that encompassed a range of ages from 44 – 114 years old. Mesquita *et al.* (1999) studied the edge effect relative to two different forms of adjacent regrowth in Amazon rainforest.

Chen *et al.* (1992) investigated coupe edges in Douglas-fir forests in the Pacific north western USA for which trees on the coupe were 2.5 m tall at the time of the study, as apposed to the surrounding canopy that was from 50 – 60 m tall. Chen *et al.* (1992) found reduced stem density, basal area, increased growth and mortality, as well as

higher numbers of seedlings and saplings within an edge effect that varied from 16 – 137 m, but the effect of the vegetation on the coupe was not considered.

Renhorn *et al.* (1997) transplanted two different species of foliose lichen into the 15-year-old edge of an oldgrowth forest in northeastern Sweden. Increased growth in both species occurred within 12 m of the forest edge. Although different in terms of measurements, the results of the Renhorn *et al.* (1997) study correlate with those in the Warra, in that they both imply a narrow response to microclimate changes (and/or physical disturbance). There was no apparent response to vegetation on the coupe, which was up to 4 m tall but mostly less than 1.5 m, at the time of the study.

Matlack (1994) considered “Embedded” edges (44 – 114 years) that had been overgrown by secondary forest wherein microclimate differences were no longer prevalent. There was still vegetative evidence of the original border, owing to the ability of species to persist as long-lived trees or clones or as dormant seed. This was described as *Pattern relaxation* (Matlack 1994), where the edge effect is slowly absorbed into more typical forest through the action of smaller scale disturbances and the eventual death of trees in the former edge zone. With the lack of a vascular plant response *Pattern relaxation* in southern Tasmanian wet forests may not apply, although there may be some relevance for epiflora changes, particularly as the microclimate evidence suggests a prolonged exposure. The preceding phase (*Re-assortment*), which Matlack (1994) proposed for the period after side canopy closure may still be applicable, but could be delayed until the regeneration on the adjacent coupe is of sufficient age/height to re-assert canopy buffering and thus restrict or alleviate microclimate changes. The dynamics of southern Tasmanian forest edges thus do not support the Matlack (1994) model.

While the edge effects on coupes should be gradually ameliorated by the adjacent regrowth, there is little evidence from Chen *et al.* (1992) or Renhorn *et al.* (1997) or, indeed, from any of the coupes in this study, particularly in light of the unaltered microclimate regime. Mesquita *et al.* (1999) found tree mortality was reduced in edges adjacent to two different forms of regrowth, with differences in response attributed to the dominant growth habit within each regeneration type such that denser vegetation had more influence even though it was considerably shorter. The open crowns of eucalypt regeneration on Tasmanian coupes may thus have less influence on adjacent edge effects than the slower growing understorey.

The structure of the forest may thus carry traces of the edge for a substantial period (Matlack 1994), but there was little evidence of changes in the large vascular flora except at the 0 m points at some sites. These edges appear to remain exposed for a prolonged period. If forest composition and architecture play an important role in the distribution of its epiflora, as is the indication in this study, then the residual edge effect in epiflora (although narrow) may persist for a long period, particularly with the prolonged microclimate exposure. None of the edges in this research was of sufficient age to prove or refute this notion, although Neyland and Brown (1994), in a study of disturbance to the edge of rainforest patches in eastern Tasmania, found that creation of the edge did not produce an immediate response, but also that damage to the edge of rainforest patches was very slow to recover (up to 100 years).

Within southern Tasmanian forests large-scale patchiness is largely determined by wildfires (Gilbert 1959, Jackson 1968, Read 1999). The edge of a burnt coupe, in terms of both vascular and non-vascular flora, may thus ultimately resemble the historical border between wildfire episodes, but this model remains speculative.

7.5 Conclusions

Edge effects in terms of both epiflora and vascular compositions were restricted to 10 m or less by high levels of background variability. This largely correlated with maximum temperature and VPD changes observed across all sites (Chapter 6) and epiflora composition is thus regarded a good indicator of edge effects. Specific taxa responses were more varied with the Lepidoziaceae, Hymenophyllaceae and Grammitidaceae considered the best indicators, although more information is required.

There was no increase in recruitment in vascular taxa within any edge and no evidence of either side canopy development or trends in canopy damage relative to the age of the edge. The notion of increasing PAR edge effects related to an age gradient of canopy disturbance is thus not supported. Evidence from the vascular response suggests, however, that edge effects in terms of microclimate and epiflora will persist for a prolonged period.

8 General discussion

The matrix of coupes and retained patches that comprise production forests (*sensu* Lindenmeyer and Franklin 2000) contain large distances of edge created at each coupe boundary. An understanding of edge effects is therefore essential to establish that core forest values can be maintained in production forests. However, there have been relatively few studies of microclimate and vegetational gradients in forest edges in Australian production forests and this study thus fills an important gap in our knowledge of wet forest matrices in southern Tasmania. Furthermore, the results of the current study have wide ranging implications for forest management and forest edge research, particularly in terms of sampling design and analysis.

8.1 Edge research in Tasmanian wet forests

Packham (1991) reported that damage from adjacent logging in Tasmanian coupes increased the risk of infection of *Nothofagus cunninghamii* by the myrtle wilt fungus (*Chalara australis*), which results in a gradual loss of canopy and, ultimately, the death of trees in the edge. Peacock (1994) considered the potential for edge effects on the filmy fern (Hymenophyllaceae) community on manfern in the Florentine Valley (Central Tasmania), as part of a wider study on the effects of cable logging and estimated a narrow edge effect (0 - 3 m), but possibly extending as far as 20 m. Neyland and Brown (1994) investigated the effect of anthropogenic disturbances (including clearfelling) on Tasmanian rainforest fragments and, like Peacock (1994), found a decline in the cover and health of delicate ferns in the edge of patches. They also observed increased rates of disease (myrtle wilt), loss of foliage (generally from *Atherosperma moschatum*) and increased cover of opportunists, notably the fern *Histiopteris incisa*. The latter was considered by Neyland and Brown (1994) to be a good indicator of disturbance in rainforests, although no increase in *Histiopteris*

occurred at any of the Warra edges. Neyland and Brown (1994) estimated that at least 40 m of buffering vegetation was required to adequately protect patches of rainforest. The current study shows gradients in microclimate and epiflora in forest edges extend to generally less than 10 m, which would suggest that the former distance is excessive. A conservative approach to such buffers (i.e. large rather than small) is certainly recommended, particularly when the influence of windthrow is considered.

Corridors of vegetation are a common result of timber harvesting in southern Tasmania. Understanding edge effects in these strips must be regarded as a priority in forest management, as these retained patches are the most vulnerable to change. In Washington State, USA, Brosofske *et al.* (1997) found that edge effects appear to penetrate all the way through streamside buffers from 10 – 90 m wide and suggested that these needed to be ~ 300 m wide to preserve interior forest values. In Tasmania, stream reserves vary in minimum width from 10 m on small (Class 4) to 40 m at large (Class 1) streams, while wildlife habitat strips are at least 100 m wide (Forestry Practices Board 2000). Vegetation corridors were not considered in this study, due firstly to a need for baseline information on the floristics and microclimate of Tasmanian forest edges, and secondly to a large number of confounding variables, including strip width, aspect, age of the coupes on either side and presence/absence of streams within the strip. The current study observed changes within an edge abutting continuous forest to extend up to 50 m as a result of windthrow, although the nature of mechanical disturbance, microclimate and vegetational changes in the edges of these strips is thus likely to be complex.

Laurance (1991) found a 200 m zone of physical disturbance at the edge of small tropical forest patches, whereas the zone microclimate gradients extended to only 30 m (Turton and Freiburger 1997). The current study found that mechanical disturbances could penetrate up to 100 m at some sites, even though the microclimatic gradient was only 10 m. If windthrow is a major factor in forest edges, the current vegetation corridors and streamside reserves in Tasmania may not be wide enough. However, once a patch of forest is large enough to buffer against the prevailing wind, the edge gradients in vegetation and microclimate are minimal. This also suggests that assessment of the conservation value of a patch of forest with

respect to edge effects cannot be determined by observations of microclimate gradients alone.

Prior to the current study, there had been no research on gradients of microclimate in edges in Tasmanian production forests and, although vegetational changes have been observed (e.g. Neyland and Brown 1994, Peacock 1994), there is little quantitative data. Importantly, both Peacock (1994) and Neyland and Brown (1994) regarded floristic changes at edges to be the product of both microclimatic and mechanical disturbance, and did not attempt to distinguish between them. This is consistent with the results of the current study, which indicated that the major changes in vegetation occurred in a region of overlap between the zone affected by mechanical disturbance from logging and firebreak construction, and the zone encompassing microclimate gradients. This raises questions as to whether gradients observed elsewhere in forest edges are at least partially driven by mechanical disturbances.

The importance of establishing controls in the undisturbed forest at the same scale as measurements undertaken at the edge was well demonstrated in the current study. Elsewhere, the size of many of the forest patches may restrict the placement of controls, but, in such cases, the question must arise as to the representativeness of the patch studied and whether or not the investigator is measuring edge or patch-size influences. In addition to the lack of controls, other studies suffer from the absence of data collected from the forest patch before the edge was created. While this cannot be helped in the majority of cases, it should be acknowledged as a potential confounding factor, as variability in undisturbed forest prior to edge creation was readily apparent in this study. Multiple visits allow an assessment of rates of change in the edge, rather than the prevailing static observations (Murcia 1995).

8.2 Epiflora regeneration on Tasmanian coupes

Within the confines of harvested coupes in southern Tasmania, the disturbance to vegetation caused by clearfell logging and burning has been well documented for the non-vascular flora (e.g. Cremer and Mount 1965, Duncan 1979, Duncan and Dalton 1982, Brasell and Mattay 1984). Following burning, coupe non-vascular flora comprises the fire mosses: *Funaria hygrometrica*, *Ceratodon purpureus*, *Polytrichum juniperinum*, *Campylopus* spp., *Bryum* spp. and *Tortella calycina* as well as the thallose liverwort, *Marchantia berteroana* (Brasell and Mattay 1984).

This community can attain coverage of up to 90 % within 12 months of the regeneration burn (Cremer and Mount 1965, Duncan 1979, Duncan 1985) and may limit the regeneration of pre-logging species. In spite of high levels of cover within coupes, the current study found no evidence in the current study of fire mosses or *Marchantia* invading the bryophyte community within the edges.

Differences in bryophyte community structure can persist between oldgrowth and regenerated forests in Tasmania after 20 years of regeneration (Jarman and Kantvilas 1997). Duncan (1979) considered that, in spite of the fact that burnt coupes in Tasmania were surrounded by forested areas rich in mosses and liverworts, these were unable to colonise the nearby burnt sites, probably due to limited dispersal capabilities of many bryophytes (Söderström 1989). The harsher environmental conditions within a coupe may also play a role. Substrate changes, including the reduction in manferns (*Dicksonia antarctica*) after logging (Ough and Murphy 1997), have also been considered a cause for the lack of regeneration in epiphytic fern taxa in 20 – 30 year old silvicultural regeneration in Tasmania (Hickey 1994). In addition, *Eucalyptus* sp. appears to be a poor substrate for epiphytes (Pers. Obs.) and forestry practices aimed at maximising the proportion of eucalypts in the regeneration are likely to have an adverse result for any associated bryophyte community. King and Chapman (1983) reported that all vascular and non-vascular taxa in a coastal New South Wales rainforest prior to logging were again present after 25 years regeneration, but, on balance, the evidence suggests that non-vascular/cryptogam communities are slow to recover (if indeed they recover at all) in regenerating coupes in Tasmania. These differences suggest that highly fragmented habitats, such as the matrix of forests managed for wood production, will be depauperate in oldgrowth mosses and liverworts and that the maintenance of reserves and buffer strips is vital to the biodiversity of the system.

Kantvilas and Jarman (1993) found considerable differences in cryptogam composition between isolated oldgrowth rainforest fragments and the surrounding sclerophyll vegetation in the southeast of Tasmania, and maintained that these patches were floristically unique “islands” that were highly vulnerable to small-scale disasters (generally wildfires) from which they would be unlikely to recover. They proposed that these rainforest fragments (and presumably its cryptogam complement) had persisted for over 2,500 years and thus differences in epiflora between

contrasting vegetation types, including regenerated coupes and retained forest patches, can be maintained for prolonged periods. Forest reserves within a matrix of coupes are also likely to be just as vulnerable to catastrophic disturbances, which suggests that a large number of reserved areas are required within production forests to assist in spreading the risk (*sensu* Lindenmeyer and Franklin 2002).

8.2.1 Microclimate changes in Tasmanian wet forest coupe edges

In southern Tasmanian wet forest coupe edges, the change in photosynthetically active radiation (PAR) was detectable up to 50 m. However, changes in the average daily maximum temperature and vapour pressure deficit (VPD) only penetrated up to 10 m at all sites, and correlated only with the degree of exposure of the edge to direct sunlight. The microclimate within an edge is thus likely to depend on the aspect of the edge, a point well documented elsewhere (e.g. Laurance and Yensen 1991, Matlack 1993, Fraver 1994, Young and Mitchell 1994, Parry 1997, Turton and Freiburger 1997) and, for this reason, not examined in the current study. Variation in PAR at distances greater than 10 m from the edge had no influence on maximum temperature and VPD, probably because the light regime, although increased relative to control levels, was more diffuse. Therefore, 10 m was thus considered the full extent of microclimate gradients. This was at the lower end of the range found in other edge research that extends from 5 m (Palik and Murphy 1990) to 137 m (Chen *et al.* 1992). Most microclimate studies in forest edges (> 60 % of reviewed literature) estimate an edge effect of more than 40 m.

High spatial and temporal variation in southern Tasmanian wet forest microclimates was a major limiting factor on the penetration of edge-related gradients, as changes associated with the edge were largely encompassed within background levels of change. Edge-related differences in microclimate were only identified in the spring and summer. The influence these changes may have, in terms of changes in vegetation, is thus also restricted to warmer periods and hence may take a considerable time to take effect, particularly if there is a degree of recovery in cooler seasons. While seasonal observations of microclimate gradients in edges may not be relevant for deciduous systems where there is no canopy for half the year (and thus little, if any, edge effect) or in the tropics where the seasonal variation may not be large, the temporal stability of microclimate gradients in edges is otherwise poorly

understood, even within a particular season, as most studies collect data from a few (or only one) season.

Previous research in forest edges would appear to assume a high level of climatic stability in undisturbed forests, which may explain the apparent lack of credence given to the need for controls and the disparity in the height of microclimate measurements. The current study has shown that both factors are relevant to estimating microclimate gradients in forest edges. The underestimation the natural variability of undisturbed forest microclimates may lead to an overestimation of the penetration distance of the edge effect. This may also explain, in part, why the microclimate gradients observed in the current study were at the lower end of the range observed elsewhere. If other research on microclimate in edges has overestimated the penetration distance, smaller patches of forest may retain more of their undisturbed microclimate character than that concluded by other authors. However, it is worth reiterating that the mechanical disturbance gradient at an edge would appear to be considerably larger than microclimate differences.

8.2.2 Epiflora changes in Tasmanian wet forest coupe edges

Changes in epiflora composition in coupe edges in southern Tasmanian wet forests generally correlated with microclimate gradients in temperature and VPD (i.e. < 10 m). High levels of variability in epiflora composition limited the degree of identifiable edge effect. Given that desiccation of the mesic community in edges has been noted elsewhere (Ranney *et al.* 1981, Peacock 1994) and that bryophytes are regarded as good indicators of microclimate and/or disturbance (Edwards 1986, Kenkel and Bradfield 1986, Piippo 1982, Frahm and Gradstein 1991, Kantvilas and Jarman 1993), this response was unexpectedly muted. The high variability in microclimate over small distances in undisturbed Tasmanian forests also suggests that the associated flora is capable of tolerating a substantial range of microclimatic changes, so that, at least in the short term, taxa within an edge may be at risk only under extreme ambient conditions (e.g. very hot, dry and windy days at the height of summer). More prolonged exposure to even small changes in the average microclimate may affect growth, recruitment and competitive ability of the flora within an edge, although there may also be some “hardening” of the flora at the edge (*sensu* Hearnshaw and Proctor 1982, see Chapter 7) which could also limit the influence of microclimate changes.

Research elsewhere on bryophytes in edges is limited, although a decrease in species richness has been observed within 2 m of the edge of a Polish forest (Luczaj and Sadowska 1997) and higher cover has also been noted within other European forest edges, which was attributed to the removal of leaf litter through the action of increased wind exposure (Gonschorrek 1977 in Luczaj and Sadowska 1997, Balcerkiewicz and Kasprowicz 1989 in Luczaj and Sadowska 1997). No loss of taxa was observed in any of the Warra edges, but there was a decline in frequency of occurrence of many species, which suggests the possibility complete removals over a prolonged period (although note the above about hardening). Litter removal was not observed in the current study. The rate of leaf litter input in European deciduous forest edges is very different from those of the evergreen southern temperate broadleaf systems of Tasmania. Furthermore, damage to canopies at the forest edges in Tasmania due to logging and wind exposure was thought more likely to increase rather than decrease litter loads.

Other studies to consider cryptogams in forest edges has focussed on lichens and, like bryophyte research, largely restricted to European forests (e.g. Renhorn *et al.* 1997, Esseen and Renhorn 1998, Kivisto and Kuusinen 2000, Dettki *et al.* 2000). Lichens, in particular crustose forms, can tolerate drier conditions than bryophytes (Pharo and Beattie 1997). This is apparent in Tasmanian forests, where lichens tend to grow in the forest canopy rather than at ground level that is otherwise favoured by bryophytes (Jarman and Kantvilas 1995). Lichens were thus not considered in the current study. Given that bryophytes and epiphytic ferns in southern Tasmanian wet forests are capable of tolerating substantial microclimatic variability, lichens may be even less responsive.

Increased plant recruitment has commonly been observed in forest edges, mostly those comprising early successional (pioneer) species (Wales 1972, Ranney *et al.* 1981, Laurance 1991, Laurance *et al.* 1998, Sizer and Tanner 1999, Gehlhausen *et al.* 2000, Oosterhoorn and Kappelle 2000). None of the pioneer bryophyte taxa (e.g. fire mosses and *Marchantia*) identified in the current study, invaded forest edges in Tasmania. Increased recruitment of bryophytes and epiphytic ferns in forest edges would seem less likely, as the edge has a drier microclimate and these plant groups are dependant on a film of water for at least a short period to allow sexual reproduction to occur (Richardson 1981, Scott 1985, Duncan and Isaac 1986, Jarman

and Fuhrer 1995, Pharo and Beattie 1997). However, this does not preclude recruitment by asexual means, either from established parent stock, from fragmentation and/or from gemmae (Jarman and Fuhrer 1995). Apart from the restriction of microclimate gradients to warmer seasons, the persistence of bryophyte colonies within an edge may be enhanced within damp refugia under logs and between root buttresses. This suggests that the edge effect on epiflora will depend on the structural complexity of the edge, such that open callidendrous forests (Jarman *et al.* 1994) may have larger edge effects than the shrubby thamnisc understoreys that prevailed at the sites in the current study. Higher structural complexity may also limit the intrusion of microclimate gradients.

Liverworts, such as the Lepidoziaceae, appeared to be more sensitive to edge effects than mosses, which is consistent with what is known about bryophyte tolerances to desiccation (Söderström 1988, Lesica *et al.* 1991, Kantvilas and Jarman 1993). Specific epiflora indicator groups/species were difficult to identify, but the Lepidoziaceae, Grammitidaceae (finger ferns) and Hymenophyllaceae (filmy ferns) were amongst the more consistent respondents. The sensitivity of filmy ferns has been noted in other Tasmanian forest edges (Peacock 1994, Neyland and Brown 1994), but both fern groups appear to be highly sensitive to climatic extremes, with desiccated and dying fronds apparent even within undisturbed forest at the height of summer (Pers. Obs.). The distances that changes in epiflora components extended into the edge varied from 10 – 50 m for the Lepidoziaceae, but were within 10 m for the Hymenophyllaceae and Grammitidaceae, which generally correlated with the microclimate regime and indicated a drier edge environment. However, spatial variability, both within and between edges of all three taxonomic groups in undisturbed forest, was considerable, and the importance of these groups as potential indicators could only be identified in the before and after, control and impact study (Chapter 5) through the calculation of the degree of change.

The best indication of the edge effect in terms of epiflora was found to be in terms of the total composition on logs, stems and across all substrates, again with a penetration distance of less than 10 m. This effect was manifest through the edge-based epiflora on all three substrates, tending toward compositions that were less typical of the general tenet of each site. Multivariate analysis of the epiflora composition was a better indicator of environmental change than the distribution of

individual taxa. Thus the edge effect *on balance* was less than 10 m, although individual taxonomic groups, such as the Lepidoziaceae, may indicate a greater penetration distance.

Substrate types were a major determinant of epiflora composition in the undisturbed forest. This added to the variation, both within and between sites, and restricted the identification of indicator groups. While manferns have otherwise been considered as important substrates for bryophytes and epiphytic ferns (Peacock 1994, Hickey 1994), their poor representation at sites in the current study meant that there could be no analysis of this substrate relative to forest edges. Site-specific differences for each substrate (in particular stems) were also substantial and it is worth noting that the focus of logging operations on particular forest types would consequently affect the particular suite of associated epiflora. This may pose no threat to individual species, but particular epiphytic community types (including associated invertebrate taxa) may be at risk.

8.2.3 Vascular plant changes in Tasmanian wet forest coupe edges

Changes in the vascular vegetation extended 50 m (possibly up to 100 m) from the forest edge at Small (One-year old) but this was largely attributed to the disturbance resulting from a single windthrown tree and did not appear to result in any microclimate changes that were discernable from control levels, at least within the timeframe of the current study. It is worth reiterating that the largest PAR gradient also penetrated to 50 m, but this was at the oldest site (15 years). Lack of change in microclimate near the windthrown tree at Small may have been due to the sheltering effect of the debris from the tree fall, which was largely above the height of the sensors. Apart from the Small coupe, there was limited evidence of an edge effect in vascular plant composition, due to the highly varied composition in the undisturbed forest, which, like the epiflora, accounted for most of the differences observed within edges. Lack of correlation between changes in the large vascular flora in Tasmanian forest edges and the associated microclimate regime, suggests that the edge effect in the former is largely a product of mechanical disturbance.

There was no evidence of increased recruitment of woody species at Tasmanian coupe edges, which is in contrast to observations from elsewhere (e.g. Wales 1972, Ranney *et al.* 1981, Whitney and Runkle 1981, Williams-Linera 1990, Brothers

1993, Sizer and Tanner 1999, Oosterhoorn and Kappelle 2000). The strong need for fire to facilitate or assist in successful recruitment (as is the case with much of the Australian vegetation) could be a limiting factor such that, on its own, the increased light at an edge elicits limited response. However, many Tasmanian rainforest taxa are capable of seedling germination and growth, as well as asexual reproduction under a closed canopy (Read 1999), and hence other mechanisms must be involved. This may include the intrusion of firebreak debris into the edge, which may smother established seedlings and prevent/inhibit germination from either coppice or seed. The compaction and disruption of the soil profiles within the firebreak itself often hinders woody vascular plant recruitment (P. Pennington, CSIRO Forestry, Pers. Com. 2002), similar to the inhibition observed on primary snig tracks on Tasmanian coupes (Williamson 1990), where colonisation is largely confined to sedges such as *Gahnia grandis*. A lack of increased recruitment may also result from the loss of pollinators and seed vectors under the influence of the edge (e.g. McDonnell and Stiles 1983, Burkey 1993, Kollman and Schneider 1997, Ostfeld *et al.* 1997, Restrepo and Gomez 1998).

Side canopy development at an edge is a consequence of higher recruitment and the development of a vertical wall of foliage on the established trees (e.g. Ranney *et al.* 1981, Williams-Linera 1990, Brothers and Spingarn 1992, Matlack 1993, 1994, Camargo and Kapos 1995, Sizer and Tanner 1999). This is often described in older forest edges and thought to alleviate strong microclimate gradients (Matlack 1993, 1994, Cadenasso *et al.* 1997, Kapos *et al.* 1997). No evidence of side canopy development was observed in any of the coupes edges in the Warra, possibly due to the apparent lack of increased vascular recruitment, as there was no thicket of saplings at the edge. Neither was there any evidence of vertical foliage development in the established trees, although species will differ in their ability to produce epicormic buds and lateral branches low on the trunk. A good example from Tasmanian forests is *Pomaderris apetala* that appears to be very capable of developing a side canopy following removal of adjacent trees (Pers. Obs.). Other Tasmanian wet forest trees are largely unknown in this respect. *Pomaderris* was rare or absent from most sites in the current study, occurring at the edge only at the Small coupe, which was also the youngest in the survey (< 1 year) and thus unlikely to have shown any signs of side canopy development that has elsewhere been shown to take from 10 – 20 years (Matlack 1994). Furthermore, the prevailing thamnian understory

at all sites in the current study may have masked both a flush of recruits and/or side canopy growth. It would thus otherwise appear that the dynamics of southern Tasmanian wet forest edges are unusual in their lack of side canopy. Microclimate gradients and their associated influence on the epiflora are thus likely to persist for a prolonged period (at least 15 years), even if their spatial extent is limited. Shading from the adjacent regeneration may also limit the development of side canopy in production forests (although see below).

There has been little research comparing artificially created edges with naturally occurring forest gaps (Restrepo and Vargas 1999), although Williams-Linera (1990) suggested that edges were intermediate between gaps and undisturbed forest. Numerous authors have found a number of shade intolerant plant species in edges that were normally associated with gaps (e.g. Wales 1972, Ranney *et al.* 1981, Whitney and Runkle 1981, Brothers 1993, Sizer and Tanner 1999, Oosterhoorn and Kappelle 2000). Gaps are regarded as integral to the dynamics of forest systems (e.g. Brokaw and Scheiner 1989, Connell 1989, Martínez – Ramos *et al.* 1989, Whitmore 1989), but may have been regarded in overly simplified terms in that the standard paradigm of comparing gaps with non-gaps grossly underestimates the inherent variability of mature forests (Lieberman *et al.* 1989). Interestingly, similar criticisms have been applied to edge research by Murcia (1995). Development of a side canopy is frequently described for anthropogenic forest edges, but has not been described for naturally occurring forest gaps. Most research in natural gaps has focussed on the nature of the gap itself (e.g. Brokaw and Scheiner 1989, Spies and Franklin 1989, Veblen 1989, Whitmore 1989) and perhaps better comparisons might be achieved through surveys of gap edges.

The effect of mechanical disturbance (chiefly windthrow) is widely regarded as an important factor in the dynamics of forest edges (e.g. Laurance 1991, 1997, Laurance *et al.* 1998, Restrepo and Vargas 1999, Oosterhoorn and Kappelle 2000), but there has been little specific research on wind velocity in edges. Chen *et al.* (1995) found a wind exposure gradient that penetrated up to 240 m from an edge, depending on its aspect. Broszofske *et al.* (1997) found a more complex situation, with topographic position and/or vegetation type/density having a substantial effect on wind velocity in edges. Exposure to windthrow is thus difficult to predict, although there has been some research on wind-induced damage in edges. Camargo and Kapos (1995) found

that forest gaps had been propagated up to 80 m from an edge within five years of creation. This was probably because of the increased turbulence caused by wind striking an abrupt edge (Laurance *et al.* 1998). Laurance (1991, 1997) and Laurance *et al.* (1998) suggested that the spatial extent of windthrown damage could be substantially larger than microclimate changes and that the resulting increased light may be responsible for a profusion of shade intolerant species near the edge, such that microclimate changes are the *product* of a mechanical disturbance regime in edges, rather than created by presence of the edge alone. However, there is little evidence of this in the current study, although a large penetration distance (50 – 100 m) was observed at Small less than one year after logging.

Destruction of canopy continuity at the edge starts with damage to standing trees caused by the adjacent logging (Chen *et al.* 1992). A high rate of leaf fall near recent edges has also been observed (Lovejoy *et al.* 1986, Neyland and Brown 1994), and might be in response to disease, water stress and/or the loss of shade-adapted subcanopy leaves through damage to photosynthetic processes under increased light (Bazzaz 1991, Packham 1991). The burning of the coupe may also cause some scorching or desiccation of the surrounding canopy and result in a further decline in canopy cover (Chen *et al.* 1992). However, research on disturbance in edges has tended to attribute damage to increased windthrow (e.g. Lovejoy *et al.* 1986, Laurance 1991, Chen *et al.* 1992, Fraver 1994, Laurance 1997, Laurance *et al.* 1998), in spite of the damage to the canopy that may result from logging and burning.

Younger edges present a more abrupt transition than diffuse older zones (Lovejoy *et al.* 1986, Fraver 1994), but there was no age pattern in the vascular plants responses to edges of Tasmanian coupes. In the longer-term, the dynamics of an edge will depend upon the harshness of the adjacent matrix (Ranney *et al.* 1981, Fraver 1994, Kapos *et al.* 1997, Mesquita *et al.* 1999, Gascon *et al.* 2000) and the rate of regeneration of the coupe. The edge adjacent to a regenerating coupe in southern Tasmania is likely to be most exposed to environmental extremes immediately following logging and burning, and thus the most profound floristic changes in response to microclimate and wind exposure are likely to occur within a short period of edge creation. The vagaries of the climate within this period may thus have far-reaching consequences for the forest edge.

There were no differences in microclimate gradients in edges of different ages, even though the oldest site abutted regeneration of substantial height and density. Lack of the development of side canopy was considered the reason for the prolonged exposure to climatic gradients, but the open eucalypt canopy dominating the regeneration at the 15-year site was considered likely to have limited buffering influence on the ambient climate, even though the height of these trees approached that of the unlogged understorey. The rate of canopy closure in these systems may depend on the speed of understorey development within the adjacent coupe, and is thus difficult to predict, but is likely to result in an alleviation of microclimate gradients in the edge. The associated flora within the overgrown edge might then revert to a state more typical of undisturbed forest. However, with the lack of recruitment of woody plants on firebreaks and the residual form of the edge may thus be more likely to result from the firebreak, rather than changes induced as a result of edge effects. Given that wet forest coupes in Tasmania are to be harvested on rotations of 85 to 100 years, the re-creation of the edge will add yet another level of complexity to the dynamics of these zones. There have been relatively few studies on coupe edges in production forests or edges that have become overgrown (although see Chen *et al.* 1992, Matlack 1993, 1994, Chen *et al.* 1995, Parry 1997), and none on edges of a coupe that has been harvested more than once (i.e. second rotation edges).

8.3 Implications and recommendations

Epiflora changes within forest edges in southern Tasmanian production forests penetrated less than 10 m and correlated with the prevailing microclimate regime, as well as the disturbance invoked by logging and firebreak construction. The combined influence of these forms of disturbance on the conservation values of retained patches of forest is thus thought to be minimal, although longer term monitoring of edge effects within both established and future coupe edges is required. Additional protection for the vegetation within coupe borders is considered unnecessary, even though the period of exposure to gradients in microclimate would appear to be prolonged. The current practice of limiting mechanical damage at the edges during logging, and firebreak construction by the felling trees and pushing firebreak debris away from the edge should be encouraged.

Changes in vascular plant communities at Tasmanian production forest edges appeared to be more of a response to wind exposure than temperature, VPD and light changes and logging disturbance. This form of edge gradient may pose the greater threat to reserved forests and any future monitoring of forest edges should include observations of disturbance in the vascular flora. The creation of vegetation corridors should allow for as much regeneration time as possible on the logged side before the other is harvested to limit the influence of wind exposure.

In the broader context, timber harvesting in southern Tasmanian wet forests needs to recognise the strong link between broad-scale forest composition and structural complexity, and the associated epiflora community, as the targeting of forestry operations on particular forest types may place some associated bryophyte communities at risk. The affinity between epiflora communities, and forest vascular composition and architecture suggests that the limiting of disturbance within either will be mutually beneficial.

An assessment of those taxa within Tasmanian forest systems that might assist in the formation of side canopy may provide managers with the means of positioning coupe borders such that they pass through patches of forest that are likely to “seal” the edge quickly. If a specific threat due to edge effects is identified, the sowing of such taxa at the edge may limit longer-term damage. It may also be beneficial to minimise the influence of compacted firebreaks by reducing their width, the degree of compaction or perhaps improving their fertility of by introducing fertiliser to exposed subsoils. The relative merits of bulldozers vs. excavators in the construction of firebreaks should also be evaluated in this respect.

If epiflora (or components thereof) are to be put to further use as environmental indicators, then there is evidence suggesting that consideration of some taxa at the family level will produce meaningful results. This would require a less exhaustive taxonomic knowledge for field identification. However, until such taxa have been properly identified, the collection of epiflora data as indicators should be done at the best possible taxonomic resolution.

8.4 Final conclusion

This study has shown that edge induced changes in microclimate and epiflora in southern Tasmanian forest coupe edges are limited in spatial extent, but appear likely

to persist for prolonged periods. Vascular flora changes at forest edges would appear to be less predictable, but potentially much larger in both spatial and temporal influence. Compared to other research on edges, the methods employed in this study were generally superior in terms of accounting for background levels of change in undisturbed forest systems and thus placing gradients relative to edges in an appropriate context.

Appendix A Vapour pressure deficit

A.1 Probe configuration

Fifteen single channel Tinytag temperature data loggers (Gemini Data Loggers (U.K.) Ltd., Chichester, U.K.) were modified such that each logger's exposed sensor was covered by a wick that was kept damp at all times through immersion of the end in a small reservoir (Figure A.1). Each sensor was paired with an unmodified temperature logger to form a series of fifteen unventilated wet/dry bulb humidity measurement devices. As the airflow over either probe is not known, this method does not measure humidity alone, but integrates changes in air movement as well.

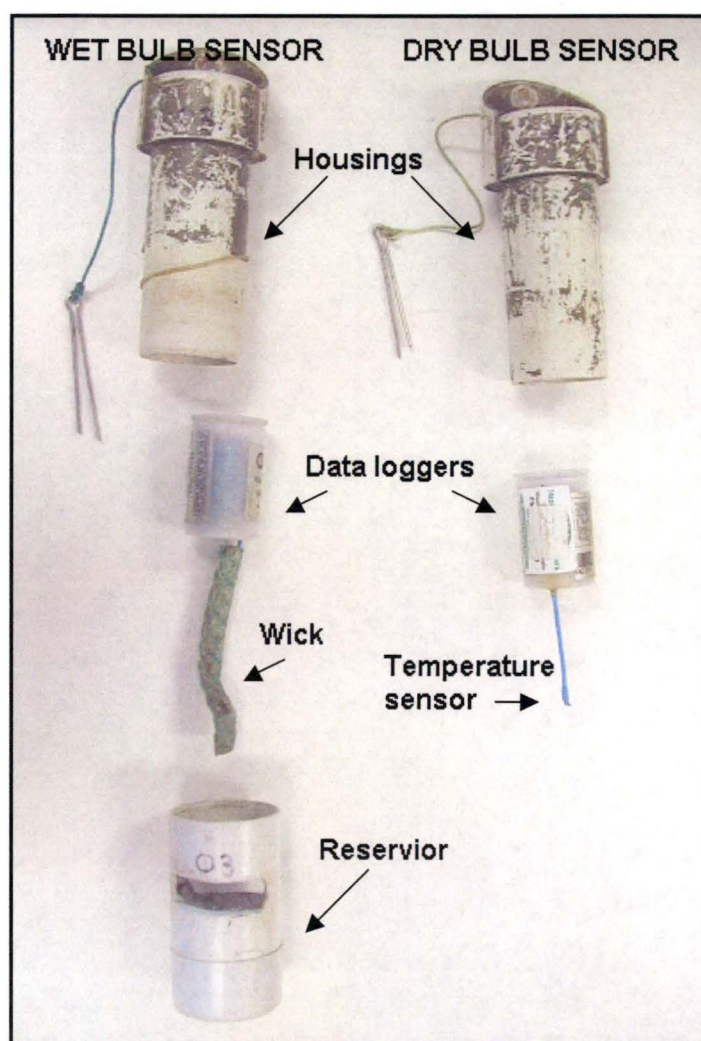


Figure A.1 - The Tinytag temperature data loggers configured to indicate vapour pressure deficit. An unmodified data logger is on the right with its protective housing (top). The left logger has a wick sheathing its probe that was kept moist from the small reservoir at the bottom. A total of fifteen groups of probes were arranged in this manner.

A.2 Vapour pressure deficit calculation

Temperature data from the wet and dry probes were used to calculate the vapour pressure deficit (VPD) using the formulae (Monteith and Unsworth 1990):

$$e = e_w - 0.667(T_a - T_w)$$

Where

e = vapour pressure (mb)

e_w = saturated vapour pressure at T_w (mb) – derived from tables (Monteith and Unsworth 1990)

T_a = dry bulb (probe) temperature (°C)

T_w = wet bulb (probe) temperature (°C)

And

$$VPD = e_a - e$$

Where

VPD = Vapour Pressure Deficit (mb)

e_a = saturated vapour pressure at T_a (mb) – derived from tables (Monteith and Unsworth 1990)

Vapour pressure deficit was converted to kilopascals (kPa) by dividing all values by a factor of 10.

Appendix B Temperature sensors and measurement consistency

The accuracy of the temperature data loggers was ± 0.1 °C. However, when comparing between probes further differences were found, due to built-in biases between individual sensors. A calibration of the temperature loggers at a constant temperature (13.6 °C ± 0.6) was undertaken across a thousand measurements (~ 3.5 days). The temperature sensors (dry probes) differed across a range of up to 1 °C, but for less than 1 % of readings with differences larger than 0.5 °C more common (~ 36 % of readings). Temperature loggers used as wet probes were less stable with 3.5 % of measurements differing across a range of more than 1 °C and 72 % of readings across a range of 0.5 °C. Within individual probes there were no consistent biases.

The presence of gradients is difficult to measure with confidence when the differences approached the accuracy of measurements (as they often were in this study). By randomising the order of every probe deployment, gradients that occurred consistently in different deployments were likely to be real rather than due to differences between probes. Small scale “noise” in temperature (both wet and dry sensors) was often reduced by using a running average spread over 12 samples (1 hour).

Appendix C TASFORHAB surveys

The TASFORHAB sampling protocol developed by Peters (1984) is a convenient format for combining structural and floristic data in Tasmanian forests by the estimation of the cover of species within a range of height classes. An indication of both forest composition and structural complexity can be obtained over a notional area of 0.1 ha. Symbols on the left side of the pad indicate species, horizontal lines indicate cover estimates, with each row representing a height class (Figure C.1).

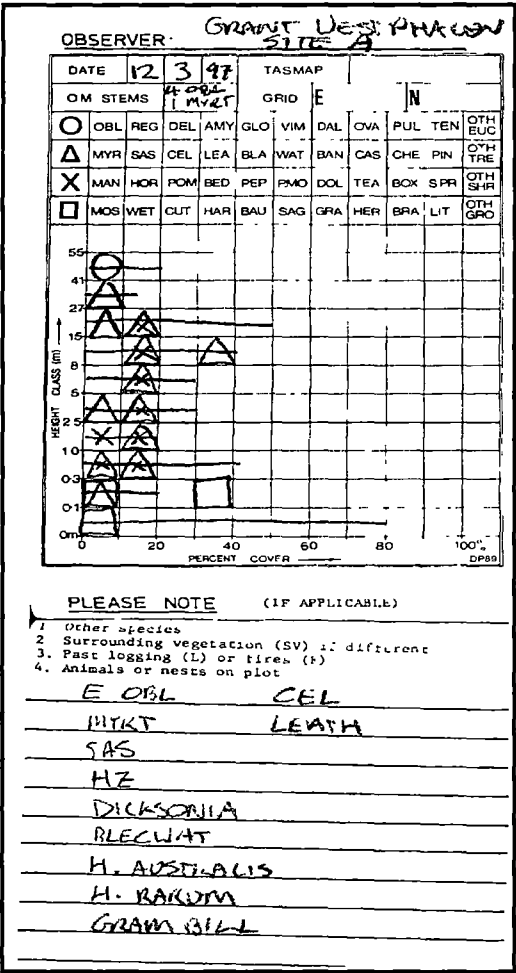


Figure C.1 - Scan of a TASFORHAB notebook showing the information collected from a site in the vertical survey (Chapter 3) that was a 300 - 400 year old mixed forest and rainforest.

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