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Developing models to predict the effects of fuel reduction burning on habitat complexity, ground-dwelling mammals and understorey birds

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Developing Models to Predict the Effects of Fuel Reduction Burning on Habitat Complexity, Ground-dwelling Mammals and Understorey Birds.

A thesis submitted in fulfilment of the requirements for the award of the degree

Master of Environmental Science - Research

From

UNIVERSITY OF WOLLONGONG

By

Gillian Basnett BSc, MEnvSc

School of Earth & Environmental Sciences

2005

Certification

I, Gillian E. Basnett, declare that this thesis, submitted in fulfilment of the requirements for the award of Master of Environmental Science – Research, in the School of Earth & Environmental Science, University of Wollongong, is wholly my own work unless otherwise referenced or acknowledged. The document has not been submitted for qualification at any other academic institution.

Gillian E. Basnett

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Abstract

The variation in vegetation structure is often recognised as one of the main factors attributing to the wide diversity of wildlife supported by Australian *Eucalyptus* forests. Disturbances that affect the vegetation structure can have repercussions to the animals that rely on certain compositions of plants. Many plants and animals are able to survive under certain disturbance regimes. However, changing the regime can threaten the flora and fauna species within a community.

Inappropriate fire regimes are one such threatening process. Yet fuel reduction is a key element of fire management. There is often a conflict between the fire regime needed to keep fuel loads at a level thought to be adequate to assist in managing unplanned fire, and those that would maintain vegetation structure and therefore wildlife diversity. Therefore, in areas where the protection of biodiversity is particularly important there is a need to predict the ecological effects of a fuel reduction burn regime.

A number of studies had shown that abundance and distribution of ground-dwelling mammals and understorey birds can be estimated from measures of habitat complexity and is has been demonstrated that the effects of fire on these groups can be predicted by changes to vegetation structure. This study uses fuel levels and habitat complexity scores to develop a model to predict the impacts of prescribed burns with different intensities and extents on distribution and abundance of ground-dwelling mammals and understorey birds in 6 different vegetation communities at Coolah Tops National Park, NSW.

Within each of the six vegetation communities 25 survey sites were randomly selected. Fuel loads were estimated using litter depth, the dominant plant species were identified and both mammal and bird habitat complexity scores established using revised tables from the literature. The model, devised using the data collected in the field, was used to calculate the change in habitat complexity scores after four different fire scenarios. These modifications were then used to predict the likely affects of the different fire models on ground-dwelling mammals and understorey birds and to produce some implications and recommendations for management.

Fire extent had a larger impact on ground-dwelling mammals then fires intensity, with fires that left fewer patches unburnt reducing overall vegetation structure regardless of intensity. Birds however, were predicted to be affected by both intensity and extent, with the greatest impact being seen in the high intensity low patchiness burn models and the lowest impact in the low intensity high patchiness model.

The implications for management of this study is that, at least for mammals, fire extent needs to be controlled more then the intensity in order to maintain some refuge areas. Overall, at least temporarily, mammal diversity may be expected to decline by 50-100% and bird diversity by half in the sort of fuel reduction burns that may be applied in a fire management program. Small ground-dwelling mammal abundance is likely to be reduced to zero, while medium to large ground-dwelling mammal abundance is likely to increase dramatically from zero under this fire management program. Understorey bird species likely to be promoted are those able to tolerate open vegetation while those that need dense understoreys will be disadvantaged.

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Chapter 1 Introduction and Literature Review

1.1 Forest and Wildlife Diversity

Around the world, there is a general correlation between areas of high plant diversity and areas of high wildlife diversity, demonstrated by the great variety and abundance of flora and fauna species found in tropical forests (Bourlière, 1983; Myers, 1983; Krebs, 1994 (Chap 23)). *Eucalyptus* forests of Australia support an enormous range of wildlife (Catling *et al.*, 1981), partly because of the great diversity of vegetation structure, which provides habitats for a wide variety of species of fauna (Coops and Catling, 1997a).

Broad-scale spatial prediction of animal distributions can be achieved by modelling of biophysical or environmental attributes such as climate, geology and landform (Cork and Catling, 1996); for example BIOCLIM. BIOCLIM is a bioclimatic analysis and prediction system that characterises annual, seasonal and extreme components of the climatic environment which can be used to map the distribution of an entity (Busby, 1986; Busby, 1991). The type of habitat at a site can roughly be predicted using these types of models; for example the type and distribution of canopy species. However, vegetation structure can vary greatly over a short distance within a single forest type (Catling and Freudenberger, unpublished), and there can be changes in structure over short time frames in a single area. Models based on gross factors such as climate, substrate and vegetation type are unlikely to be useful in predicting distribution and abundance of many Australian mammals at an ecologically relevant scale (Cork and Catling, 1996), particularly as environmental variables may be inadequate in determining the abundance and distribution of ground-dwelling mammals (Catling *et al.*, 2002).

Several studies have shown that there is an association between the structural diversity of vegetation and abundance and distribution of wildlife, and that this factor is often as important (if not more so) than the plant species and variety or nutrient status of a floristic community. For example, MacArthur and MacArthur (1961) demonstrated that bird species were more abundant in forests than in fields of similar size. They also found that the evidence for this preference was that birds responded to different configurations of plants, or "height profile of foliage density", particularly in vegetation layers 0-2 feet, 2-25 feet and >25 feet (MacArthur and MacArthur, 1961). Plant species diversity did not affect bird species diversity except where it influenced habitat structure (MacArthur and MacArthur, 1961; MacArthur, 1965). This same pattern has been demonstrated in a number of other studies as summarised by Krebs (1994: pp 530-532). Freudenberger (1999; 2001; 2002) found a similar effect when surveying birds around ACT, Australia. The distribution and abundance of bird species depended on landscape variables such as habitat patch size and structural diversity (canopy, shrub, ground and litter cover) (Freudenberger, 1999; 2001; Watson *et al.*, 2001; Freudenberger and Stol, 2002). Habitat structure might therefore be expected to be useful in explaining or predicting the abundance and diversity of wildlife (Newsome and Catling, 1979; Catling and Burt, 1994; Catling and Burt, 1995b; Catling and Coops, 1999).

Examples of the association between vegetation structural variety and wildlife abundance and diversity can be found in studies on native Australian mammals. For example, Catling and others (Newsome and Catling, 1979; Catling *et al.*, 1981; Catling and Burt, 1995a; Cork and Catling, 1996; Catling *et al.*, 1998; Catling *et al.*, 2000; Catling *et al.*, 2002), have demonstrated that vertebrate fauna of southeastern Australia, from the coast to the alps, are most abundant in sclerophyll woodlands and forests with dense understoreys. This is particularly true for small ground-dwelling mammals such as *Antechinus* or *Rattus* species, which prefer forests with dense shrub, ground and litter layers (Barnett *et al.*, 1978; Fox and McKay, 1981; Friend and Taylor, 1985). Although flora species and plant nutrients can have an effect on small ground-dwelling mammal abundance and diversity, this usually occurs at sites with sparse understorey vegetation (Catling and Burt, 1995a). Otherwise, ground-dwelling mammals have been found to have high abundance on all sites with dense understoreys (Catling and Burt, 1995a).

Structural composition can also affect medium ground-dwelling mammal compositions such as some wallabies, the red-necked pademelon (*Thylogale thetis*) and the long-nosed potoroo (*Potorous tridactylus*) which prefer denser understorey cover for shelter and food (Southwell, 1987). A few small native mammals such as the white footed dunnart (*Sminthopsis leucopus*) (Lunney and Ashby, 1987) and the New Holland mouse (*Pseudomys novaehollandiae*) (Fox and McKay, 1981) and medium to large mammals such as the eastern grey kangaroo (*Macropus giganteus*) and common wombat (*Vombatus ursinus)* are adversely influenced by dense understorey cover.

These mammals prefer open grassy forests with little shrub understorey as they provide a greater abundance of grass and roots used for food (Lunney and Ashby, 1987; Southwell, 1987; Lunney and O'Connell, 1988; Catling and Burt, 1995a; Cork and Catling, 1996; Catling *et al.*, 1998; Catling *et al.*, 2000).

Preferences can also vary within species, particularly between different sexes, age class and breeding season. For example, Friend and Taylor (1985) concluded that vegetation structure preferences determined for *Antechinus* during the non-breeding season was for females only, as males die after breeding and did not contribute to the data collected. Similar findings for other small mammals are seen where males disperse after the breeding season (Friend and Taylor, 1985).

Possible explanations for the penchant for dense vegetation shown by some species or subgroups within populations are that it provides food from plants and insects and protection from predators (Friend, 1999). Braithwaite and Gullan (1978) and Fox and Fox (1981) suggested that species' preferences for particular structural attributes reflect the division of food resources, space and shelter (against predators, competitors or climatic conditions) among the species of small mammals in a community. Although the majority of native mammals live in areas with dense understoreys, there are some which require more open habitats. Therefore, to maximise mammal diversity, a high level of habitat diversity is needed (Fox, 1983).

Some researches have developed a scoring system to evaluate habitat complexity, which appears to work over large areas; for example, Catling's long-term study of small mammals in southeastern Australia (Newsome and Catling, 1979; Catling, 1991; Catling and Burt, 1995a; Catling *et al.*, 1998; Catling and Coops, 1999; Catling *et al.*, 2002) and Freudenberger's work with understorey birds in the ACT (Freudenberger, 1999; Freudenberger, 2001; Watson *et al.*, 2001; Freudenberger and Stol, 2002). Habitat complexity scores are a visual assessment of the spatial distribution of vegetation, litter, logs, rocks and soil moisture; all factors that are related to the provision of protection, breeding and foraging locations for animals inhabiting an area (Catling and Freudenberger, unpublished). Structural composition can vary greatly over a short distance of forest and the scoring system developed by Catling and Freudenberger (unpublished) allows such variations to be distinguished.

1.2 Fire and Forests

Fire is a frequent disturbance in many ecosystems around the world (Bradstock *et al.*, 2002), especially in Australian eucalypt forests (Keith, 1996). Wildlife that is dependent on forest habitat is affected by fire, both through the direct effects of the fire and by the indirect effects through alteration of habitat. Although fire can kill animals and cause others to flee, most long-term effects appear to be through the alteration of habitats (Recher, 1981; Williams and Gill, 1995). Available food can be lost through the destruction of trees and shrubs and habitat for invertebrates (Catling *et al.*, 1981). Protection against predators, competitors and the climate is also reduced due to the loss of vegetation (Braithwaite and Gullan, 1978).

Both unplanned fire and prescribed burns affect the structure of the vegetation in the short and probably the long-term (Fox and McKay, 1981; Tolhurst, 1996b; Catling and Burt, 1997; Catling *et al.*, 2000). Short-term species alterations, for example from ephemeral herbaceous species to progressively taller perennial herbs, shrubs and trees, occur as forests recover after fire (Noble and Slatyer, 1981). Habitat complexity increases from areas with predominantly sparse ground and understorey cover, immediately post fire, to more structurally complex habitats in later years (Catling *et al.*, 2001). When the forest reaches maturity, changes in habitat complexity tend to be slow and minimal, with specific site conditions, such as soil and climate, determining final forest structure. This situation will remain until the forest starts to senesce or another disturbance such as another fire occurs (Coops and Catling, 2000).

Fires are often patchy, leaving a mosaic of burnt and unburnt vegetation (Gill and Bradstock, 1995). This mosaic may allow wildlife to escape into unburnt patches and utilise them for food and shelter during the regeneration of the surrounding burnt vegetation (Wilson, 1996). Temporal changes in habitat complexity, as the forest transforms from regrowth to senescence, along with the influence of disturbances such as fire and logging, also create a mosaic (Coops and Catling, 1997a). This variation in seral stages allows for a greater abundance and composition of species to be present in the region and allows re-colonisation of sites after disturbance (Coops and Catling, 1997b). High intensity and very frequent fires are unlikely to promote a mosaic effect (Christensen and Kimber, 1975). This is because high intensity fires tend to occur when fuel loads are high and create a more homogeneous burn, in the sense that fairly large areas are totally burnt. Very frequent fire can remove shrub communities resulting in less variation in plant species and structure, as seen below (Christensen and Kimber, 1975; Williams and Gill, 1995; Catchpole, 2002).

Changes in flora species and habitat complexity over the longer term can be brought about by inappropriate fire regimes, such as the frequent use of fire, either in fuel reduction burns, or as a management tool to produce required seral stages (Fox and McKay, 1981), regularly burning in a certain season (Brown and Whelan, 1999), and consistent fire intensities (Cary and Morrison, 1995). If plants are not given enough time between fires to recover, for example to reach important life stages such as primary and secondary reproduction, species will become locally extinct, the vegetation dynamics will change, and the structure of the forest will be altered (Christensen *et al.*, 1981; Gill, 1981; Noble and Slatyer, 1981; Kruger, 1983; Gill and Bradstock, 1992; Cary and Morrison, 1995; Gill and Bradstock, 1995; Keith, 1996; Tolhurst, 1996a; Clarke and Knox, 2002; Gill and Catling, 2002; Whelan *et al.*, 2002). For example, two fires within the critical juvenile period of a fire-sensitive species will result in its local extinction despite the length of the subsequent inter-fire intervals (Ashton, 1981). Also, repeated frequent burning of resprouters will deplete their resources of 'buds' and eventually remove them from an area (Ashton, 1981; Whelan, 1995).

Cary and Morrison (1995) outlined minimum inter-fire intervals for vegetation types for the sandstone communities around the Sydney region. Some flora species such as grasses, herbs and fire- tolerant species recover quickly after fire and will produce seed or reach the secondary juvenile period even with fires intervals as low as 1-3 years (Cary and Morrison, 1995; Morgan, 1999). Juvenile species of most fire-sensitive plants will be able to reach primary reproduction and juvenile herbaceous fire-tolerant species will be able to reach fire tolerant size within 4-6 years. Intervals of 7-14 years are required for juveniles of shrubby fire-tolerant species to reach a fire-tolerant size. Greater then 15 years will see some plants begin to senesce with old age (Cary and Morrison, 1995).

Conversely, fires that are too infrequent may also cause a change in the flora species present, at least in the above-ground component, and therefore the habitat complexity. The absence of fire in fire prone areas may hinder some plant species from completing their life-cycles (Keith, 1996). For example, woody fruits may not open to allow seed dispersal before seeds contained in them lose viability, likewise for soil-stored seed banks. Seedlings that do appear may be unsuccessful, as fire may be needed to enhance the release of nutrients into the soil (Keith, 1996; Clarke, 1999; Clarke *et al.*, 2000; Clarke and Knox, 2002). It has been observed that the long term absence of fire can result in forests becoming less diverse as grass, herb and shrub species are lost due to lack of disturbance and an increase in competition (Crawley, 1998; Lunt, 1999).

Plant species response to fire is determined by life history characteristics such as method of persistence and dispersal ("obligate seeders" or "resprouters"), ability to grow and establish and the time required to reach critical life stages (Gill, 1982; Benson, 1985; Cary and Morrison, 1995; Keith, 1996; Brown and Whelan, 1999; Whelan *et al.*, 2002). The impact of a fire on plant species will depend on when in the life cycle it occurs, how long since the last fire, inter-fire intervals and seasonality of the fire (Gill, 1981; Gill, 1982; Bradstock *et al.*, 1995; Gill and Bradstock, 1995; Keith, 1996; Brown and Whelan, 1999; Whelan *et al.*, 2002). Disturbance regimes may determine the type of species present in an ecosystem by favouring those that can resprout after fire, germinate between fires or those that require fire for seed germination (Clarke *et al.*, 2000).

Variations in the abundance of small mammals need not be a direct result of the occurrence of fire, but rather a reaction to vegetation changes, which are themselves responding to specific fire regimes (Fox and McKay, 1981; Monamy and Fox, 2000). Some native animal species have preferences for certain vegetation stages reached at different times after fire (Fox and McKay, 1981). For example, if vertebrates utilized grass and herb layers, they would favour sites 2-3 years after fire (Catling and Newsome, 1981). If shrub layers are of greatest importance, then sites would be best suited to these animals between 5 and 15 years after fire. If, however, the tree layer is essential, then at least 10 years is needed after fire, and if holes in senescent trees are required at least 25-50 years after fire is necessary, assuming the previous fire history eliminated these habitat features (Catling and Newsome, 1981; Monamy and Fox, 2000).

The initial response of many populations of small ground-dwelling mammals is often, but not always (Whelan *et al.*, 1996), to drop sharply after fire (Fox and McKay, 1981; Fox, 1983; Lunney *et al.*, 1987; Catling, 1991; Tolhurst, 1996a; Wilson, 1996; Coops and Catling, 2000; Catling *et al.*, 2001). However, in the long term many of these populations will expand again, sometimes to greater numbers than initially found, as the recovery of the vegetation increases the habitat complexity of the area and animals migrate from remnant patches (Fox and McKay, 1981; Fox, 1983; Lunney *et al.*, 1987; Catling, 1991; Tolhurst, 1996a; Catling *et al.*, 2001). It has been seen, however, that if habitat complexity does not recover, then many native mammal species are disadvantaged and introduced species are advantaged (Catling, 1991).

1.3 Fire Management for Wildlife

Typically, management of fire involves one of two objectives, fuel reduction to assist in the control of unplanned fires and the protection of life, property and other assets such as plantations and crops; and/or ecological burns for the conservation of biodiversity through preserving assemblages of species and the ecological processes related to those species (Bradstock *et al.*, 1995). Certain fire regimes are needed for each of these objectives and the most appropriate fire regimes for achieving each may or may not overlap. It is possible that a fire regime used in fuel reduction for reducing fire intensity and increasing the possibility of control will reduce the value of the habitat for animals (Whelan, 1995). Where objectives are in conflict, the difficulty is deciding which objective to manage for, protection of life and property or conservation.

The primary objective of burning for the protection of life and property is to reduce the intensity, rate of spread, and damage during unplanned fires in hot and windy conditions by decreasing fuel loads and structure at a time when weather conditions are mild (Tolhurst, 1996c). However, as stated above, many flora species decrease in abundance post burning and will therefore be disadvantaged by the frequency of burning needed for effective fuel reduction (Tolhurst, 1996b). Change in vegetation species and structural complexity could result in a change in the diversity and abundance of wildlife (Christensen *et al.*, 1981; Cary and Morrison, 1995; Gill and

Catling, 2002). Other features of the fire regime such as fire season can also affect the response of fauna, for example spring season fires, often used to reduce fuels, can significantly disrupt breeding activities in some species (Wilson, 1996).

In sites reserved for conservation, legislation may require the maintenance of all species within that site (Gill and Bradstock, 1995). This means that management needs to be sensitive to the species, both resident and transitory, that inhabit the site (Gill and Bradstock, 1995). The ability of forest managers to develop policies and practices that will protect many native fauna species requires knowledge of the habitat complexity of the area (Coops and Catling, 1997a). There are a number of issues that affect the ability of conservation managers to protect the biodiversity in their care. These include:

- Which areas to set aside for the protection of life and property and which areas to set aside for conservation of biodiversity (Whelan, 2002b).

- Paucity of knowledge on species, their response to fire regimes, and ecological and special requirements makes it difficult to determine what effects different fire regimes will have (Olson *et al.*, 2002).

- The knowledge that we do have is restricted to a small number of species in a limited number of areas, making it difficult to extrapolate information to whole populations and between sites and species (Bradstock *et al.*, 1995; Wilson, 1996), especially as responses vary greatly across species and community types (Whelan *et al.*, 2002).

- Imposition of inflexible and unsuitable fire regimes by bureaucratic/political pressures is exacerbated by limited knowledge of their effects (Bradstock *et al.*, 1995).

- Habitats have been severely fragmented since European occupation. Past fire regimes and knowledge may no longer be appropriate, as changes in the connectivity between vegetated areas makes it difficult for species re-colonisation (Bradstock *et al.*, 1995).

- Fire impacts on flora and fauna result from a complex interaction between a number of aspects such as fire characteristics, previous fire regime, habitat quality, climate conditions, and the biology of the organisms (Whelan *et al.*, 2002).

- Effects of fire need to be viewed in conjunction with effects of other disturbance factors such as introduced predators, land clearance, habitat fragmentation, logging, grazing, drought, etc (Wilson, 1996).

- What is the scale at which species should be managed? Should it be across the whole of Australia, at a Bioregional level (Gill and Bradstock, 1995) or, as more commonly happens, within political boundaries, such as local government areas (Gill and Bradstock, 1995)?

- Not only are species responses to fire important, but also community responses, food resources and habitat (Wilson, 1996).

- How effective is fuel reduction in decreasing the incidence and severity of wildfire?

- No single prescribed burning regime will encourage maximum population levels of all mammal species in an ecosystem (Christensen and Kimber, 1975).

- Improved incorporation of fire research into fire management is needed through better communication between fire researches and fire managers (Wilson, 1996).

- Pest and weed species need to be managed after fire as they are often advantaged by such disturbances (Catling, 1991; Whelan, 1995).

The Department of Environment and Conservation (DEC) is the agency responsible for the protection of native flora and fauna and their habitats in NSW (Section 2A *National Parks and Wildlife Act 1974*). Fire is a relatively inexpensive tool, which can be used to reduce the risk of high intensity fires, maintain certain flora and fauna species, manage pest and weed species and increase species diversity (Whelan, 1995). However, to ensure that biodiversity is not compromised within national parks, ecological knowledge is needed to understand the possible effects of particular fire regimes on flora and fauna species, their communities and habitats. It is important that all fires, planned and unplanned, are used as a learning tool to increase public, scientific and manager's knowledge of fire impacts (Burrows and Abbott, 2003). Prior to a burning program, some areas should be maintained as a 'control' site to enable monitoring of the effects of the regime (Burrows and Abbott, 2003).

Coolah Tops National Park is a new park (gazetted in 1996) managed by DEC. Little research has been done, especially since DEC took over management. As part of the proposed fire management plan, it is proposed that a 2.5km² portion (Figure 2.2) of the park will be regularly burnt with low intensity fire to maintain an area of lower fuel levels in the 'narrow neck' portion of the Park. Such a fire-break is expected to aid in the control of possible unplanned fires within the park. This fire regime has the potential to alter the species diversity and structure, and therefore the habitat complexity of the site. As mentioned above, mammal and understorey bird diversity and abundance can be greatly affected by alterations in the complexity of the habitat. It is therefore possible that this regime may have a detrimental effect on the local biodiversity of the site.

By studying the potential impacts that a single fire might have on the flora of the proposed burn site, it is possible to determine the likely effects of a fire regime on the habitat complexity, and therefore to predict changes in the abundance of native mammals and understorey birds, over time within the site. It is the duty of DEC to protect, and where possible, to maintain the biodiversity in the park (Section 2A *National Parks and Wildlife Act 1974*), as well as to protect the park, life and property at risk from bushfire (DEC, 2004). It is therefore important to determine a fire regime that would both protect this biodiversity, and maintain the integrity of the reduced fuel zone.

1.4 Aim of this Study

Prior to carrying out the management program for maintaining an area of low fuel levels with a burning regime, DEC sought research to be carried out on possible effects of fire on wildlife within the park.

As part of the fire management strategy for Coolah Tops National Park, the fine fuel load (up to 6 mm in diameter) in a small area of the Park will be maintained below 8 t/ha with a prescribed burn regime (M. Sharp pers. comm.). This will provide a reduced fuel zone to aid in the control of any unplanned fire. Due to the lack of research since the Park's inception in 1996, the managers requested a study be carried out to determine the impacts of a prescribed burn on habitat complexity and therefore mammal diversity and abundance. As the weather conditions during the study were not suitable to carry out any burning, empirical data on the actual effects of a fire could not be collected. Therefore, a computer model was devised to predict the likely outcomes of a range of different burns on habitat complexity and diversity and abundance of ground-dwelling mammals and understorey birds.

The aims of this study were:

(i) To determine the fuel load and habitat complexity of the proposed burn area,

(ii) To use this information to produce a model to predict the possible impacts of a range of fires, in terms of extent and intensity, on that habitat complexity and therefore ground-dwelling mammal and understorey bird abundance and diversity, and

(iii) To use the model to establish some implications for the management of fire within this particular area of Coolah Tops National Park, with the intention of informing the development of more effective fire management program.

Chapter 2 Study Site

2.1 Introduction

Coolah Tops National Park is situated in the Liverpool Range, 30 km east of Coolah, in central NSW (Figure 2.1), bordered approximately by latitude 31º41’ to 31º15’S and longitude 149º58’ to 150º15’E (Binns, 1997). The park is on an isolated basalt plateau 1000-1200 m above sea level, surrounded by mostly cleared undulating farming land to the south and west and forested ranges that extend to the north and east (Shields *et al.*, 1995; Binns, 1997; NPWS, 2002a). The area was managed by the Forestry Department of NSW as Warung and Bundella State Forests until tenure was transferred to NSW National Parks and Wildlife Service (NPWS), now the Department of Environment and Conservation (DEC), in 1996 (Kavanagh, 1995). With recent additions, the Park now covers 12, 056 ha (Figure 2.2) (NPWS, 2002a).

Please see print copy for Figure 2.1

Figure 2.1: Map of NSW and the Location of Coolah Township.

Coolah Tops National Park is the most westerly and driest of a series of conservation reserves representative of the basalt country of the Mount Royal and Liverpool Ranges (Kavanagh, 1995). According to DEC, the park is an important corridor for flora and fauna species between the reserves on the Liverpool Range and Warrumbungle National Park (NPWS, 2002a).

Please see print copy for Figure 2.2

Figure 2.2: Coolah Tops National Park and Study Site (NPWS, 2002a)

2.2 Climate

The climate at Coolah Tops National Park is cool and temperate, with an annual rainfall of 950-1000mm evenly distributed throughout the year (Shields *et al.*, 1995). The average temperatures range from 11.9 to 29.5°C in the summer with a maximum, but very unusual, temperature of 40.3°C and 1.9 to 15.9°C in the winter and a minimum temperature of -6.7°C (BOM, 2004). Frosts are frequent in winter with the occasional fall of snow.

2.3 History

In 1917, the area was dedicated a State Forest, but it was not until 1941 that formal harvesting of the area began. Prior to harvesting, the area was used for grazing by sheep and cattle. This continued right up until the creation of Coolah Tops National Park (Shields *et al.*, 1995). *Eucalyptus laevopinea* (silvertop stringybark) was the most desired timber in the area for commercial use. Very few trees were therefore extracted from stands dominated by *E. pauciflora* (snow gum) (Shields *et al.*, 1995). In the 1980s, harvesting increased, but never exceeded 2000 tonnes/yr (Kavanagh, 1995) and was restricted mainly to forest three types (167, 167a, and 159; see section 2.4) (Shields *et al.*, 1995). Logging intensity was estimated by Shields *et al.* (1995) to be a minimum of 0 and a maximum of 10 stumps/ha.

Fire within Coolah Tops National Park is uncommon, as a result of the moist environment which is sustained by high rainfall. Fire was used by NSW State Forest to reduce fuel accumulation and promote tree growth post logging (Shields *et al.*, 1995). There is also a possibility that many areas were burnt during the decades of grazing, to promote forage production (Anon, 1982). There have been no prescribed burns within the park since its inception, but there was a small unplanned fire in the west of the park outside the chosen area for this study (M. Sharp pers. comm.). Records show that the last fires in the park were between 15 – 40 years ago (Shields *et al.*, 1995). M. Sharp (pers. comm..) estimates that the study site has not burned in over 20 years. Fires in the park tend to be low intensity, due to the dominance of grassy ground cover, the history of grazing, and the use of low intensity fires as a management tool by both graziers and NSW State Forests (Shields *et al.*, 1995). This has resulted in little impact on established trees, but a potentially great impact on understorey plants, possibly resulting in the promotion of fire tolerant species (Shields *et al.*, 1995).

2.4 Flora

High rainfall and rich basalt soils result in Coolah Tops National Park being a significant western outlier of moist montane habitat (Shields *et al.*, 1995; NPWS, 2002a). Binns (1997) recorded a total of 297 native vascular taxa and 33 naturalised taxa within the park. The canopy contains a gradient in tree species ranging from exclusively *Eucalyptus laevopinea* (silvertop stringybark) to exclusively *E. pauciflora* (snow gum), both of which are mutually exclusive, with usually one, but occasionally two or more associated species located along this gradient (Kavanagh, 1995; NPWS, 2002a). These associated species are typically *E. nobilis* (mountain ribbon gum or manna gum) and/or *E. dalrympleana* (mountain white gum).

E. bridgesiana (apple box), *E. praecox* (brittle gum), *E. stellulata* (black sally), *E. melliodora* (yellow box) and *Angophora floribunda* (rough-barked apple) are also found in these associations but are more limited in their distribution (Kavanagh, 1995; NPWS, 2002a).

An important attribute of the forest is the sparse nature of the understorey in many areas. Generally there is a grassy or herbaceous ground cover mostly made up of tussocks (*Poa labillardieri, P. sieberiana*) and *Pteridium esculentum* (bracken) (Kavanagh, 1995; NPWS, 2002a). Where topography or surface rocks limit drainage, natural clearings and dense scrub thickets occur (Shields *et al.*, 1995). Where there is a shrubby understorey, the main species appear to be *Acacia dealbata* (silver wattle), *Leptospermum gregarium* (tea tree), *Olearia elliptica* (sticky daisy-bush) and *Cassinia quinquefaria* (Kavanagh, 1995; NPWS, 2002a).

2.4.1 Vegetation Associations

Binns (1997) classified the vegetation within the study site as “grassy plateau forests (floristic group 3.2 and 3.6)”. This is an open forest, 25-35 m tall, with an overstorey community dominated by *E. pauciflora* or at lower altitudes, *E. laevopinea,* with *E. nobilis* as a less common associate. *E. stellulata* is often present as an infrequent understorey species with some localised assemblages (Binns, 1997). Understorey cover is a sparse to moderately dense shrub layer 1-4 m tall dominated by *A. dealbata* and a predominantly dense grassy ground cover of *Poa sieberiana* and *Pteridium esculentum* (Binns, 1997). A survey carried out by NSW State Forests (1995) identified four dominant forest types in the study area (Appendix 1 and 15), which are described by Shields *et al.* (1995) as follows:

> **Type 138: Snow Gum** – dominated by *E. pauciflora* in pure or mostly pure stands with 15 % other eucalypt canopy species. This forest type inhabits sites with gentle topography and occurs as pure stands on skeletal basalt soils in the more exposed locations. Canopy height ranges between 25-35 m.
>
> **Type 140: Mountain / manna gum and snow gum** – This forest type occurs mostly in cold moist areas between types 159 and 138. It is characterized by an association of *E. pauciflora* and *E. nobilis* often in equal proportions with an average canopy height ranging between 25-35 m.
>
> **Type 159: Mountain / manna gum** – *E. nobilis* and *E. dalrympleana* are dominant in this forest type and exist in association with *E. laevopinea* and *E. pauciflora* in varying proportions. These forests generally occur on deeper soils with gently sloping topography, particularly in moist areas with a sheltered aspect. Average canopy height is 30-35 m.

Type 167: Silvertop stringybark – *E. laevopinea* are the dominant species in this forest type and occur in association with *E. nobilis, E. dalrympleana* and *E. pauciflora*. These forests tend to occupy better drained areas with a progression from almost pure *E. laevopinea* on steep rocky sites to *E. laevopinea* with a high proportion of *E. nobilis* on moderate slopes with poorer drainage and deeper soils. The average canopy height is 30-35 m. (NSW State Forests, 1995; Shields *et al.*, 1995). During the survey it was found that the site designated as Type 167 had none to very little *E. laevopinea* and was instead dominated by *E. nobilis* and *E. dalrympleana.*

I defined two other forest types for the purpose of the study, because they contained very different vegetation types to those of the surrounding vegetation mapped by the NSW State Forests and described by Shields *et al.* (1995). Habitat complexity in these areas is likely to differ substantially from those of the surrounding forest.

Type SB: Silvertop Stringybark – Type SB is the almost pure stand of *E. laevopinea* described in Type 167. It has been separated from Type 167 as it has a very different understorey make-up. The average hight of the canopy is 30-35 m. The understorey is sparse, dominated by *Poa* sp., *Pteridium esculentum* and *Lomandra longifolia*. Leaf litter and fallen trees is greater than anywhere else in the study site. This may be because of increased logging in this stand due to dominance of *E. laevopinea* (Appendix 15).

Type Creek - *Leptospermum gregarium* is the dominant species in this forest type sometimes occurring in association with *Lomatia arborescens* and *Smilax australis*. The canopy is more open but the understorey is very dense in places, particularly in lower lying areas. Average shrub height is 2-5 m (Appendix 15).

2.4.2 Species Composition

In most sites across the study area, the shrub vegetation was fairly open and easy to walk through, with a dense grassy understorey. Over the total area, 18 flora species made up the majority of the ground and shrub floristic composition (Table 2.1). Of these 18 species, most sites in all vegetation types had a ground layer dominated by *Poa* spp. In many areas, *P. esculentum*, *A. dealbata* and sometimes taller *P. esculentum* occupied the lower shrub layer. The tall shrub layer usually consisted of a fairly open cover of *A. dealbata* (Appendix 2).

Table 2.1: The Main Plant Species Affecting Habitat Complexity Scores in the Study Area.

Scientific Name	Common Name	Vegetation Layer	Vegetation Types
Acacia dealbata	Silver Wattle	Tall and low shrub	138, 140, 159, 167, SB, Creek
Acacia melanoxolyn	Blackwood	Tall shrub	167, Creek
Coprosma quadrifida	Prickly currant-bush	Low shrub	138, 140, 167, SB, Creek
Eucalyptus stellulata	Black Sally	Short tree	138, 140, 159, 167, Creek
Eustrephus latifolius	Wombat berry	Vine	138, 140, Creek
Exocarpus cupressiformis	Native Cherry	Tall shrub	138, 140, 159, 167, Creek
Hibbertia obtusifolia	Grey guinea flower	Low shrub	138, 140, 167, Creek
Hydrocotyle spp	Pennywort	Ground cover	140, 167
Leptospermum gregarium	Tea Tree	Tall shrub	Creek
Leucopogon hookeri	Mountain beard-heath	Low shrub	140, 159, Creek
Lomandra longifolia	Spiny-headed mat-rush	Ground cover	138, 140, 159, 167, SB, Creek
Lomatia arborescens	Smooth Lomatia	Tall and low shrub	138, 140, 159, 167, SB, Creek
Poa spp *(labillardieri* and/or *sieberiana)*	Tussock grass	Ground cover	138, 140, 159, 167, SB, Creek
Pteridium esculentum	Bracken Fern	Ground cover, low shrub	138, 140, 159, 167, SB, Creek
Smilax australis	Native Sarsparilla	Vine	138, 140, 167, Creek
Solanum spp *(aviculare*?)	Kangaroo Apple	Tall and low shrub	140, 167
Solanum spp *(opacum* or *pungetium)*	Nightshade	Ground cover	140
Swainsona galegifolia	Darling Pea	Ground cover	138, 140, 159, 167

Vegetation type 138 followed the above pattern, with some sites containing *Lomandra longifolia* and *Swainsona galegifolia* in the ground layer and *L. arborescens* present in the shrub layer in many sites (Table 2.1 and Appendix 2). *Eucalyptus stellulata* was present on some sites.

Many species occurring in vegetation types 140 and 159 occurred also in 138 (Table 2.1 and Appendix 2). *Solanum* spp. (possibly *aviculare*) was common in 140 and was the only vegetation type other than 167 where this species was present, most likely due to disturbance along the fence line bordering the park (M. Sharp pers. comm.).

The ground layer in vegetation type 167 was dominated by *Poa* spp., but had less *P. esculentum* and a higher proportion of *L. longifolia* then most other vegetation types. The shrub layer was dominated by *A. dealbata,* with *Hibbertia obtusifolia* and *Coprosma quadrifida* also present on many sites (Table 2.1 Appendix 2).

Poa spp. dominated the ground cover of vegetation type SB. However, it was not as densely covered, or as tall, as the other vegetation types. *P. esculentum* was sparse with a greater cover of *L. longifolia* taking its place. The shrub canopy was open, with. *A. dealbata* the only species present on all but 3 sites (Appendix 2).

The low and tall shrub layers in vegetation type Creek (particularly in the top and bottom creeks) were often dominated by a thick covering of *L. arborescens* and *Leptospermum gregarium* entangled with *Smilax australis* (Appendix 2). The shrub layer was more diverse in this vegetation type than any other. A larger amount of *C. quadrifida,* in the low shrub layer, and *E. stellulata,* in the tall shrub layer, was found in this area. *Poa* spp. and *P. esculentum* were still plentiful in areas not covered by taller shrub vegetation. Other than vegetation 167, Creek was the only vegetation type that contained *A. melanoxolyn*. The middle creek was more open with less *L. arborescens* and *L. gregarium* (Appendix 2).

Using the number of stumps as an indicator of past disturbance by logging, SB and Creek were the most disturbed areas. SB had 21 sites with stumps present, ranging from 1 to 8 stumps per site. Creek had 5 sites with stumps present, ranging from 1 to 5 stumps per site (Appendix 3). The sites in vegetation type Creek, which had had trees removed, were the easily accessible sites. SB was predominantly *E. laevopinea*, which is the most heavily logged species in the region (Shields *et al.*, 1995).

2.5 Fauna

Native fauna populations appear to be high, but species richness is not (NPWS, 2002a). Records from the DEC's Atlas of NSW Wildlife (NPWS, 2004) show that there are 26 native mammal species, 128 bird species, 24 reptiles and 6 amphibians in Coolah Tops National Park. Compared to other areas such as Royal National Park, that has 43 mammal species, 241 bird species, 40 reptile species and 30 amphibian species (NPWS, 2004), or even Goulburn River National Park, in the same region, that has 34 native mammal species, 158 birds, 35 reptile species and 14 amphibian species (NPWS 2004), the number of species is small. Low species diversity may be due to the park's isolation as new species would have difficulty crossing the farming land and small size (although Royal National park is comparable in size). In addition, there is little habitat variability, possibly a result of past management practices, which reduces the number of habitat niches for different species. Another reason may be a lack of survey and research work, particularly compared to Royal National Park.

Common native ground-dwelling mammals are *Macropus gigantus* (eastern grey kangaroo), *M. robustus* (common wallaroo), *M. rufogriseus* (red-necked wallaby), *Wallabia bicolor* (swamp wallaby), *Vombatus ursinus* (common wombat), *Antechinus stuartii* (brown antechinus), *A. flavipes* (yellow-footed antechinus), *Rattus fuscipes* (bush rat) and *Tachyglossus aculeatus* (echidna) (NPWS, 2002a; NPWS, 2004). Most of the 128 bird species are forest and woodland birds with a few waterbirds, raptors and generalists (NPWS, 2002a). Introduced mammal species include *Sus scrofa* (pig), *Vulpes vulpes* (fox), *Capra hircus* (goat), *Oryctolagus cuniculus* (rabbit) and *Rattus rattus* (black rat) with the pig, fox and goat causing particular problems at different times of the year.

Chapter 3 Fuel and Habitat Complexity

3.1 Introduction

The survey site was an area selected by DEC staff for active fuel management to assist with the control of unplanned fires that might spread through the Park. I established 150 survey sites throughout the proposed burn area. This sample was designed to cover the range of forest canopy types found in the area. The site was stratified into 6 main areas based on the four vegetation types identified in the GIS survey carried out by NSW State Forest (1995) and the two additional types I defined: the creek lines and an area dominated by *E. laevopinea* (see Chapter 2 and Appendix 1). Each vegetation association was then divided into 5 sections, and 5 survey points were placed in each section. A grid placed over each stratum and a table of random numbers was used to determine the survey points, with the constraint that at least 50 meters separated each survey point.

3.2 Methods

3.2.1 Fuel loads

A combination of litter depth and shrub cover was used to establish fuel loads (NPWS, 2002b). Using a ruler to measure from litter surface down to soil or rock, 4 samples were taken at each survey point on the North, South, East and West axes, each 10 metres away from the survey point. An average was then taken as the measure of the overall litter depth at that site. Percentage litter cover for each site was estimated visually by walking around the site to determine an approximate percentage of ground covered by plants, litter and bare earth.

Using the following equation, litter fuel levels were estimated, using the assumption that every 10% of cover and 2cm litter depth equals 1 tonne/ha (NPWS, 2002b).

$$\text{Litter fuel level} = (a / 2) \times (b / 10)$$

Where: a = average litter depth, b = litter cover.

Shrub fuels were estimated using a NPWS (2002b) method. The understorey was divided into 3 sections; 0-0.5 m (top of litter layer to knee), 0.5 -1 m (knee to waist) and 1-1.5 m (waist to shoulder). Percentage cover of vegetation (live and dead) with a diameter of ≤ 6 mm within a 2 metre radius was then assessed for each layer. Shrub fuels were then calculated by assuming that 20% cover of vegetation in each layer is equal to 1 tonne/ha (NPWS, 2002b). To calculate the total fine fuels, litter fuel loads were added to the total of the 3 shrub layer fuel loads.

ANOVA was used to determine whether the litter, shrub and total fuel loads varied significantly among vegetation types. All fuel load data needed to be converted to log, in order to produce a normal distribution from which an analysis of variance could be carried out.

3.2.2 Habitat Complexity Scores

A habitat complexity score is a visual estimation of the spatial distribution of plants, leaf litter, logs and rocks (Catling and Freudenberger, unpublished[1]). As birds tend to utilize different components of the vegetation structure and differentiate between tall and low shrubs much more then ground-dwelling mammals, two measurements of habitat complexity were calculated at each survey site. One set of measurements, first developed by Newsome and Catling (1979), was used to calculate habitat complexity scores for mammals, while a second set of measurements, adapted from Freudenberger (1999; 2002), was used to calculate habitat complexity scores for understorey birds.

From the centre of each survey site, percentage cover of canopy, shrub, ground herbage, litter, logs and rocks in a 25 m radius was visually assessed using Table 3.1, for ground-dwelling mammals, and Table 3.2, for understorey birds. A visual estimate of tree canopy cover was taken using the 4 categories 0, <30%, 30-70% and >70% (Catling and Freudenberger, unpublished). Categories are broad enough to minimise surveyor error.

[1] The unpublished work was used in this study because it was recommended by the author, P. Catling, as a useful and workable guide to calculating habitat complexity, especially as the methods in many of the published papers were not as detailed. Although at the time of study this paper was unpublished, I am of the understanding that it will be published in the future.

The shrub layer (< 4 m) included small trees up to 4 m high and *Pteridium esculentum* when it was taller then 0.5 m. Visual assessment of the shrub layer was made by estimating the percentage of shrub foliage cover. Numbers from 0 to 3 were given for foliage cover categories 0, <30%, 30-70% and >70% (Catling and Freudenberger, unpublished). For the understorey bird surveys, shrub layers were split into tall (2-4 m) and low (0.5-2 m) and measured separately as they are both important for bird species (Catling and Freudenberger, unpublished).

Ground cover including grasses, herbs, sedges, small ferns, bracken and very small shrubs was also assessed separately from shrub and canopy cover. To establish which section of Table 3.1 to use for calculating ground cover scores for ground-dwelling mammals, measurements of the general height of the ground-herbage were first established (Catling and Freudenberger, unpublished). If more than 90% of cover was < 0.5 m high, then scores were calculated in the <0.5 m section of the table. If more than 10 % of the ground vegetation was > 0.5 m high then scores were assessed in > 0.5m section of the table. If scored in the >0.5 m section, the remaining ground in between the herbage was evaluated to determined if it was bare or covered with litter in between the herbage or whether most of it has herbage >3 cm in height. Ground herbage for understorey birds was calculated as the total percentage of ground covered by plants less then 0.5 m high (Catling and Freudenberger, unpublished).

Percentage cover of litter, logs and rocks for mammal habitat complexity was determined in the areas not covered by ground-vegetation. Litter depth had to be greater than 5cm to be considered in the habitat complexity score, otherwise the litter component was scored as 0. The logs and rocks that were considered were those that could provide shelter for small mammals. For understorey bird habitat complexity, ground cover was established by separating out the logs and branches from litter and twigs and estimating the percentage of ground covered by both.

Soil moisture was determined by how wet the soil would be for most of the year, independent of recent rain, and the proximity of the site to permanent water. A score of 0 was given for sites that were dry (most forest sites). A score of 1 was used for sites that are moist for most of the year often on sheltered slopes and drainage lines. Sites that include or have permanent water within a 25m radius were scored as 2, sites that are waterlogged but not covered by surface water as 3 (Catling and Freudenberger, unpublished). The methods of determining vegetation complexity from the habitat complexity scores was derived from Catling and Freudenberger (unpublished).

Each feature listed was given a score of 0-3 and the scores of all the features were summed to give an overall figure for the site (see example in Table 3.1). Because more categories are used in quantification of habitat complexity for understorey birds, the total score can potentially sum to a maximum of 21 rather than 15 (Table 3.2).

For ground-dwelling mammals, a score or 4-5 indicates a forest with poor structure, and little in the way of understorey shrubs and ground cover (Figure 3.1a) (Newsome and Catling, 1979; Catling and Burt, 1995a). A score of 7 represents a moderately structured forest (Figure 3.1b). Scores greater than 9 suggest a complex structure with thick understorey and good ground and litter cover (Figure 3.1c) (Newsome and Catling, 1979; Catling and Burt, 1995a).

For understorey birds, the scores can be slightly higher because the shrub layer is divided into 2, the logs and fallen branches are calculated separately from litter and the percentage of ground covered needed for each separate score is slightly different for understorey birds (Table 3.2). A score of 6 or below represents a forest with poor structure, no understorey shrubs and little logs or ground cover (Freudenberger, 2001; Catling and Freudenberger, unpublished). Moderate structure is represented by scores of 7-12. Greater than 12 represents a structurally complex forest where the view is blocked by shrubs and saplings (Freudenberger, 2001; Catling and Freudenberger, unpublished).

ANOVA tests were applied to both mammal and bird habitat complexity scores to determine the similarity or difference of habitat complexity scores for each vegetation type.

Table 3.1: Features and scoring criteria for the habitat complexity score for ground-dwelling mammals in forests. Maximum score possible is 15.

FEATURE	SCORE				
	0	1	2	3	Example
1. Tree Canopy (% cover or trees > 4m high)	0	< 30 %	30-70 %	> 70 %	2
2. Shrub Canopy (% cover of trees < 4m high)	0	< 30 %	30-70 %	> 70 %	2
3. Ground Herbage (% of total site)					
– Herbage < 0.5m	< 30 %	30-70 %	>70 %	N/A	0
– Herbage > 0.5m. Mostly bare in between	< 10 %	10-50%	50-70 %	> 70 %	1
– Herbage >0.5m. Mostly >3cm in between	0	N/A	< 70%	> 70 %	-
4. Litter (>5cm deep), logs, rocks, etc (% total of site)	0	< 30 %	30-70 %	> 70 %	1
5. Normal Soil Moisture	Dry	Moist	Permanent water adjacent	Water-logged	0
Total (Max = 15)					6

Table 3.2: Features and scoring criteria for the habitat complexity score for understorey birds in forests. Maximum score possible is 21.

FEATURE	SCORE				
	0	1	2	3	Example
1. Tree Canopy (% cover or trees > 4m high)	0	< 30 %	30-70 %	> 70 %	2
2. Tall Shrub Canopy (% cover of shrubs 2- 4m high)	0	< 50 %	50-70 %	> 70 %	2
3. Low Shrub Canopy (% cover of shrubs 0.5-2m high	0	< 50 %	50-70 %	> 70 %	1
4. Ground Herbage (% of cover or flora < 0.5 m high)	0-10 %	10-40 %	40-70 %	> 70 %	2
5. Logs and fallen branches (% ground covered)	0-10 %	10-40 %	40-70 %	> 70 %	2
6. Litter (% of ground covered by leaves and twigs)	0-10 %	10-40 %	40-70 %	> 70 %	0
7. Soil Moisture	Dry	Moist	Permanent water adjacent	Water-logged	0
Total (Max = 21)					9

Please see print copy for Figure 3.1

Figure 3.1: Example of Mammal Habitat Complexity Scores, in a Forest, of (a) 9, (b) 7 and (c) 4-5.
(Catling and Freudenberger, unpublished)

3.3 Results

3.3.1 Litter Fuels

Litter levels for all vegetation types were low relative to other systems, ranging from 1.24 t/ha to 3.29 t/ha (Table 3.3). Few sites (c. 10%) had litter loads greater than 5 t/ha (Appendix 5). The larger litter loads, which occurred in all vegetation types except 167, were mostly due to samples being taken under large eucalypt trees that were shedding bark (Appendix 15 (h)). Vegetation type SB had the greatest litter fuel loads with 28% of sites greater than 5 t/ha but none greater than 8 t/ha (Table 3.3). The relatively high fuel load in vegetating type 159 was caused by one site having an extraordinarily high litter load (19t/ha) Table 3.3.

Low litter levels were a result of a thin layer of litter on a relatively small proportion of the study site, with *Poa* grass or bare ground covering the rest. More than half the sites had less then 30% of the ground covered by litter. At least 70% of the ground, in each vegetation type, had a litter cover of less than 50%, and no site was > 80% covered (Table 3.4). Of the area with litter, the average depth was generally < 3 cm (Table 3.5). Thirteen sites out of 150 had average depths between 3.5 and 5cm. These samples were taken under larger trees that were shedding bark.

Table 3.3: Mean (±se), Maximum and Minimum Values for Litter Fuel Loads (t/ha) for Each Vegetation Type.

Vegetation Type	Mean	St. Error	Maximum	Minimum
138	2.54	0.57	12.50	0.31
140	2.16	0.45	9.00	0.19
159	2.80	0.73	19.00	0.25
167	1.24	0.19	3.75	0.19
SB	3.29	0.40	7.50	0.56
Creek	2.27	0.40	9.00	0.00

Table 3.4: Percentage of the Total Area of Each Vegetation Type Covered with Litter.

Vegetation Type	% of total area with < 30% litter coverage	% of total area with < 50% litter coverage	% of total area with ≤ 80% litter coverage
138	56	96	100
140	67	96	100
159	56	88	100
167	80	100	100
SB	28	80	100
Creek	24	72	100
Mean of total	51.83	88.67	100

Table 3.5: Percentage of the Ground Covered by Leaf Litter in Each Vegetation Type with Litter Depths of ≤ 1cm, ≤ 2cm, ≤ 3cm and ≤ 5cm.

Vegetation Type	% of area with ≤ 1cm litter depth	% of area with ≤ 2cm litter depth	% of area with ≤ 3cm litter depth	% of area with ≤ 5cm litter depth
138	20	68	84	100
140	12	72	92	100
159	9	68	88	100
167	40	88	100	100
SB	12	68	88	100
Creek	64	88	96	100
Mean of total	26.17	75.33	91.33	100

Fuel loads in the litter layer varied significantly among vegetation types ($F_{5,144}$ = 2.58; P = 0.029; Appendix 4 (a)). Pair-wise comparison revealed that 167 differed significantly from SB, but both were similar to all other vegetation types (Figure 3.2).

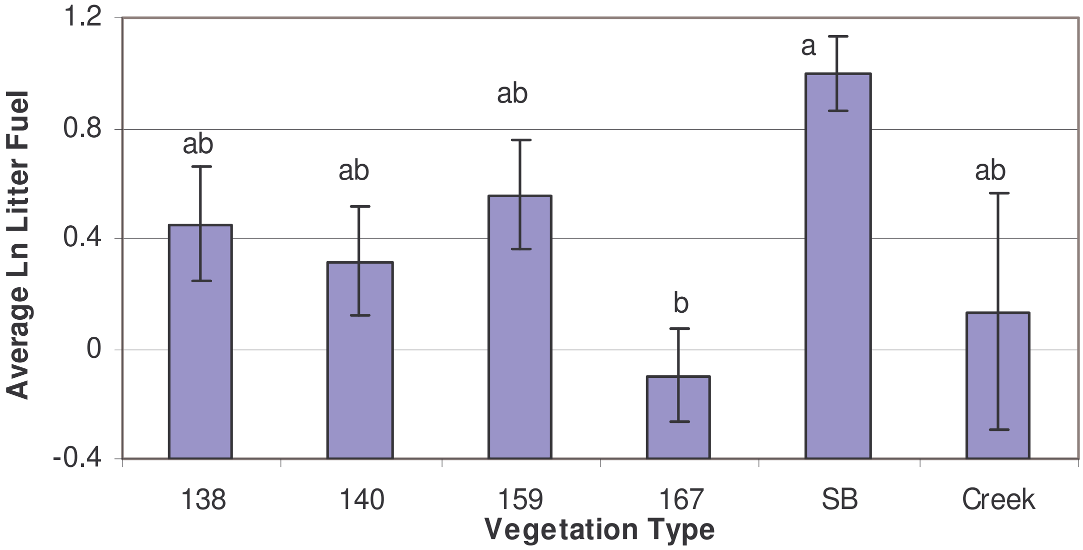

Figure 3.2: Comparison of Litter Fuels in Different Vegetation Types. Bars show the standard error. The letters above each column indicate significance of the differences between columns at α = 0.05. Columns with the same letter are not significantly different.

3.3.2 Shrub Fuels

The fuel loads for the shrub layer were greater than those for the litter component. This was mostly due to the 0-0.5m layer, where there was a large amount of *Poa* sp. (Appendix 2). *Pteridium esculentum* and *Lomatia arborescens* and occasionally *Acacia dealbata* were the main species present in all vegetation types except Creek, where the 0.5-1m layer contributed a great degree to the shrub fuel loads. In vegetation type Creek, *Leptospermum gregarium* and *Lomatia arborescens* made up the greatest proportion of the 0.5-1.5m layers; with the 0-0.5m layer mostly bare.

Average shrub fuel loads varied from 3.44 t/ha (SB) to 4.79 t/ha (Creek) (Table 3.6). Shrub fuel loads varied greatly among sites within each vegetation type (Table 3.6). Shrub fuels loads in vegetation type Creek were the most varied, ranging from 0.75 to 10.50t/ha (Appendix 6).

Table 3.6: Mean (±se), Maximum and Minimum Values for Shrub Fuel Loads (t/ha) for Each Vegetation Type.

Vegetation Type	Mean	St. Error	Maximum	Minimum
138	4.76	0.34	9.50	2.50
140	4.46	0.23	6.50	1.50
159	4.71	0.28	7.25	2.50
167	4.61	0.23	6.75	2.00
SB	3.44	0.13	4.50	2.00
Creek	4.79	0.49	10.50	0.75

The total shrub fuel load was made up of the biomass in the three layers of shrub vegetation, 0-0.5m, 0.5-1m and 1-1.5m. All vegetation types, except Creek, had relatively dense cover for the 0-0.5m layer, from 62% and 73% (Table 3.7). Creek had lower cover values, averaging 46.4% (Table 3.7). Biomass in the 0.5-1m layer was generally lower, ranging from 6.8% for SB to 25.8% for Creek (Table 3.7). The biomass coverage was least in the 1-1.5m shrub layer in all vegetation types, ranging from 0% in SB to 23.6% in Creek, due the dense stands of *L. gregarium* and/or *L. arborescens* (Table 3.7).

Table 3.7: (Mean (±se), Maximum and Minimum Values for Percentage Vegetation Cover for 0-0.5m, 0.5-1m 1-1.5m Shrub Layers for Each Vegetation Type.

Vegetation Type and Shrub Layer	Mean	St. Error	Maximum	Minimum
138: 0-0.5m	62.2	3.61	90	30
138: 0.5-1m	21.6	4.18	70	0
138: 1-1.5m	11.4	3.76	70	0
140: 0-0.5m	69.4	3.90	90	10
140: 0.5-1m	14.2	2.64	50	0
140: 1-1.5m	5.6	1.33	30	0
159: 0-0.5m	64.2	4.98	95	0
159: 0.5-1m	22.8	4.17	80	0
159: 1-1.5m	7.2	2.22	50	0
167: 0-0.5m	72.8	3.37	95	40
167: 0.5-1m	13.8	2.93	50	0
167: 1-1.5m	5.6	1.81	35	0
SB: 0-0.5m	62.0	2.24	80	40
SB: 0.5-1m	6.8	1.58	30	0
SB: 1-1.5m	0.0	0.00	0	0
Creek: 0-0.5m	46.4	5.39	90	0
Creek: 0.5-1m	25.8	5.68	80	0
Creek: 1-1.5m	23.6	6.15	80	0

Fuel loads in the shrub layer varied significantly among vegetation types ($F_{5,144}$ = 2.46; P = 0.036; Appendix 4 (b)). Pair-wise comparison revealed that vegetation types 138 and 159 differed from SB but were similar to all the other vegetation types (Figure 3.3). Vegetation type SB was similar to 140, 167 and Creek (Figure 3.3).

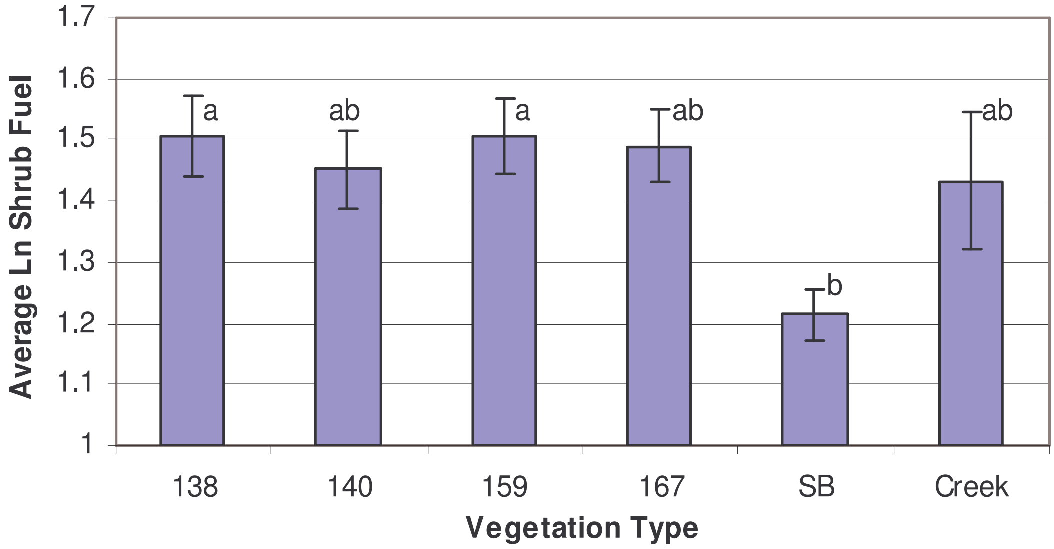

Figure 3.3: Comparison of Shrub Fuels in Different Vegetation Types. Bars show the standard error. The letters above each column indicate significance of the differences between columns at α = 0.05. Columns with the same letter are not significantly different.

3.3.3 Total Fuels

Total fuel levels ranged from 5.85 to 7.26 t/ha across the six vegetation types (Table 3.8). Although total fuel loads for individual sites ranged from 2.94 to 23 t/ha, over 90% of the sites were below 10 t/ha, with only 4 sites having total fuel loads greater than 12 t/ha (Appendix 7). All except one of the higher total fuel values (10-22 t/ha), were due to high litter levels (see section 3.1.1), rather than higher shrub fuel loads. The one with a high shrub value (9.5 t/ha) was due to a thick cover of *L. arborescens.* Total fuel loads did not vary significantly among vegetation types ($F_{5,144}$ = 1.40; P = 0.227; Appendix 4 (c) and Figure 3.4).

Table 3.8: Mean (±se), Maximum and Minimum Values Total Fuel Loads (t/ha) for Each Vegetation Type.

Vegetation Type	Mean	St. Error	Maximum	Minimum
138	7.26	0.60	15.25	3.88
140	6.62	0.41	12.38	4.25
159	7.51	0.69	22.00	4.38
167	5.85	0.25	8.75	3.75
SB	6.73	0.37	11.5	4.31
Creek	7.06	0.50	12.25	3.94

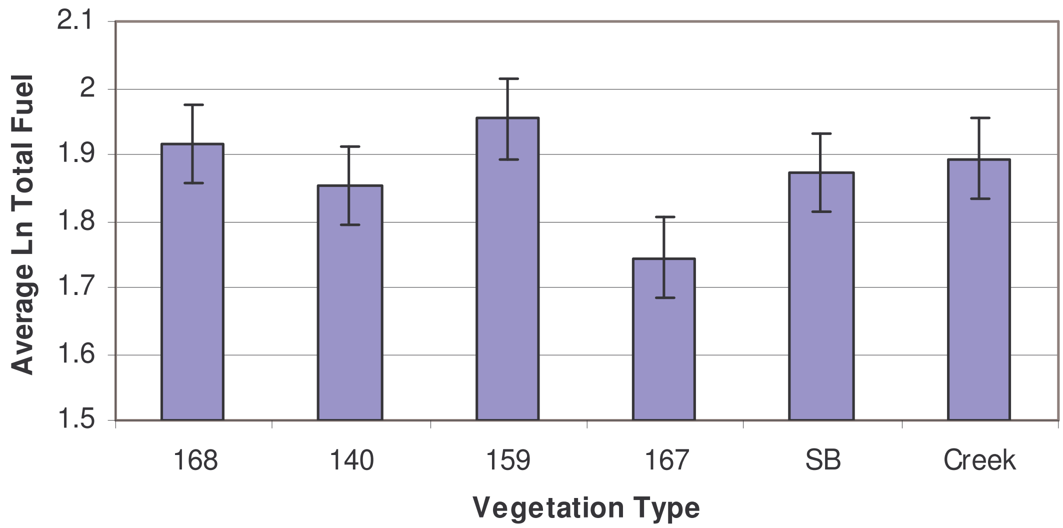

Figure 3.4: Comparison of Total Fuels in Different Vegetation Types. Bars show the standard error.

3.3.4 Mammal Habitat Complexity Scores

Mammal habitat complexity scores varied significantly among vegetation types ($F_{5,144}$ = 10.81; P <0.0001; Appendix 4 (d)). Habitat complexity scores were not normally distributed, and standard transformations failed to correct this, so α was set at 0.01. Pair-wise comparison (Figure 3.5), revealed that vegetation type SB differed from all other vegetation types except 140. Vegetation type 140 differed from 159 and Creek but was similar to all other vegetation types. Vegetation types 138, 159, 167, and Creek were all similar to each other (Figure 3.5).

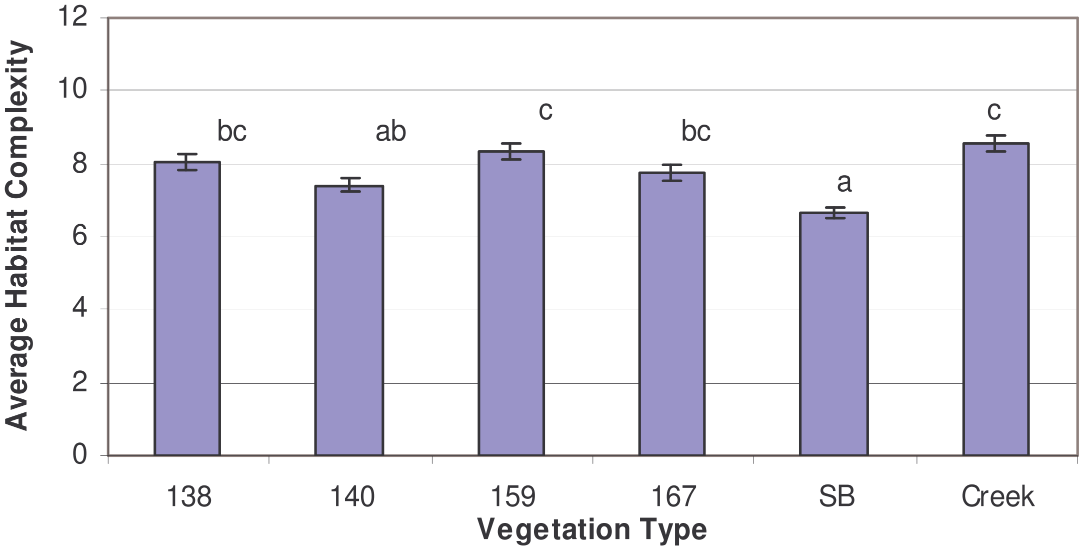

Figure 3.5: Comparisons of Mean Mammal Habitat Complexity Scores Between Different Vegetation Types.
Bars show the standard error. The letters above each column indicate significance of the differences between columns at α = 0.01. Columns with the same letter are not significantly different.

Variation in the mammal habitat complexity scores between vegetation types was mainly due to variation in the shrub and ground cover and the percentage cover of logs. The majority of sites had tree canopy cover of between 30% and 70%, and the soil moisture was dry except in vegetation type Creek, where it was moist on most sites. Litter was not counted as contributing to the habitat complexity score in all but two sites, as it was less then 5 cm deep.

The majority of sites supported moderately structured forest, with habitat complexity scores between 7 and 9. SB was the main vegetation type that differed from this, because 44% of the sites were poorly structured with habitat complexity scores of 4 and 5. Vegetation types 159 and Creek had a higher proportion of sites with more complex forest; 40% of sites had a score of 9 and some had habitat complexity scores of 10. The only other vegetation types to have sites with complex vegetation were 138 (12% of sites with scores of 10) and 167 (4% of sites with a habitat complexity score of 11 - the highest score recorded).

When sites were grouped into categories of below-average (<7), average (7) and above-average (>7) habitat complexity scores (Catling and Burt, 1995a), then the percentage of sites with below average scores were between 4% (138, 167 and Creek) and 44% (SB). The percentage of sites with average scores ranged from 16% (159 and Creek) and 40% (167 and SB) and above average sites varied from 16% (SB) to 80% (Creek) (Figure 3.6 and Appendix 8).

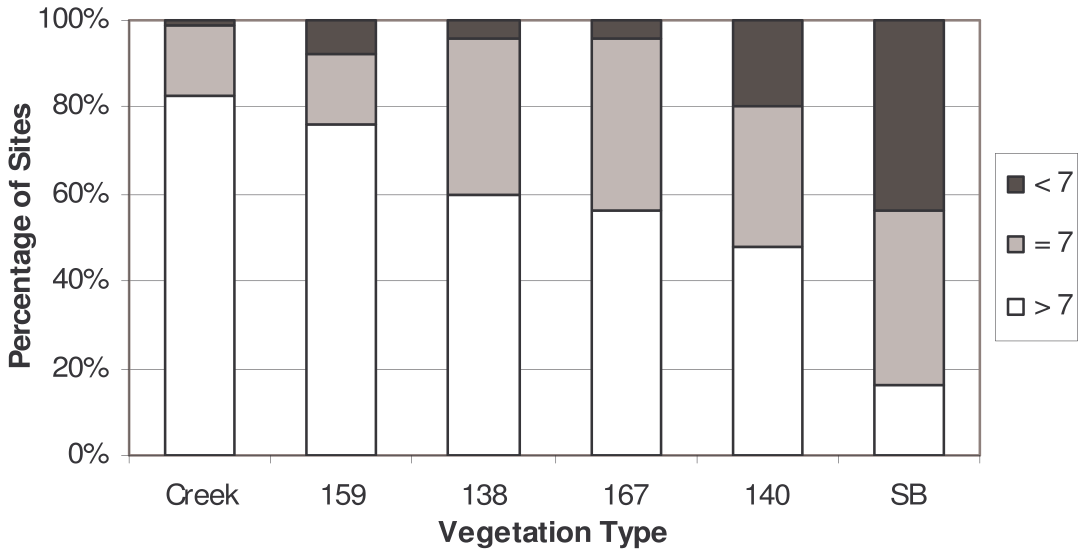

Figure 3.6: Percentage of Sites Found in Each Vegetation Type with Grouped Mammal Habitat Complexity Scores Less than 7, 7 and Greater than 7.

3.3.5 Bird Habitat Complexity Scores

Bird habitat complexity scores varied significantly among vegetation types ($F_{5,144}$ = 11.23; P <0.0001; Appendix 4 (e)). Pair-wise comparison, Figure 3.7, revealed that SB differed from all other vegetation types except 140. Vegetation type 140 differed from Creek but was similar to all other vegetation types. Vegetation types 138 and 159 were similar to each other and to 140, 167, and Creek, while 167 was different from SB and Creek (Figure 3.7).

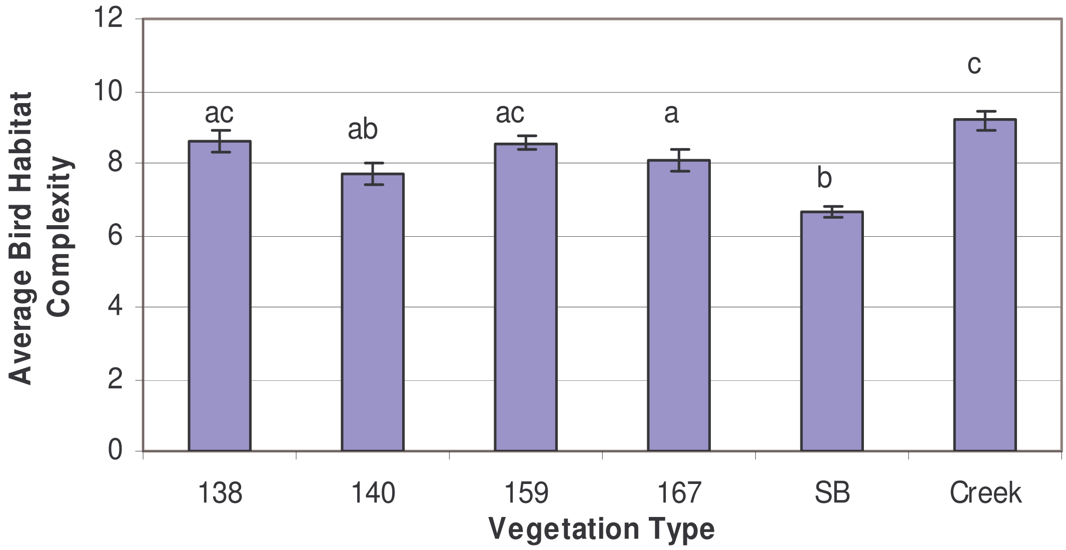

Figure 3.7: Comparisons of Mean Bird Habitat Complexity Scores Between Different Vegetation Types.
Bars show the standard error. The letters above each column indicate significance of the differences between columns at α = 0.01. Columns with the same letter are not significantly different.

The majority of sites in all vegetation types except SB had moderate vegetation structure with habitat complexity scores ranging between 7 and 12 (Appendix 9). No vegetation type had complex vegetation structures (scores greater then 12). The percentage of sites with moderate (6-12) and poor vegetation structure (< 6) respectively in each vegetation type ranged from 100% and 0% in Creek, 159 and 167, 96% and 4% in 138 and SB, and 88% and 12% in 140 (Figure 3.8). Moisture content did not factor into the final scores in this study, because all sites, except in Creek, were dry and therefore scored a 0.

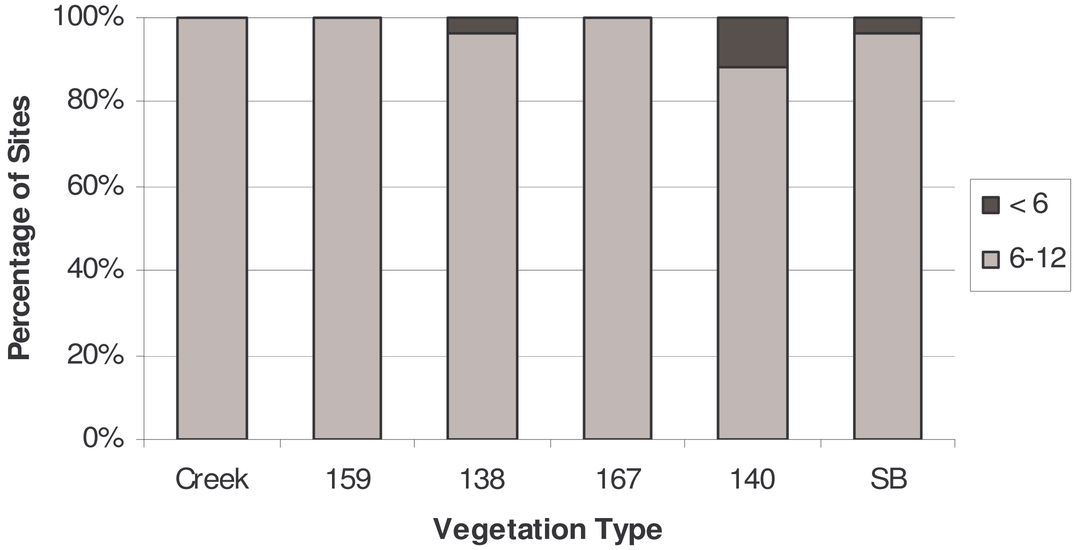

Figure 3.8: Percentage of Sites Found in Each Vegetation Type with Grouped Bird Habitat Complexity Scores Less Than 6, and 6-12.

However, of the sites in the moderate habitat complexity group, the percentage of sites with scores in the higher range (10-12), varied from 0% (SB) to 44% (Creek). The mid range (9) had between 0% (SB) and 44% (159) of sites and the lower range (6-8) had between 32% (Creek) and 100% (SB) (Figure 3.9).

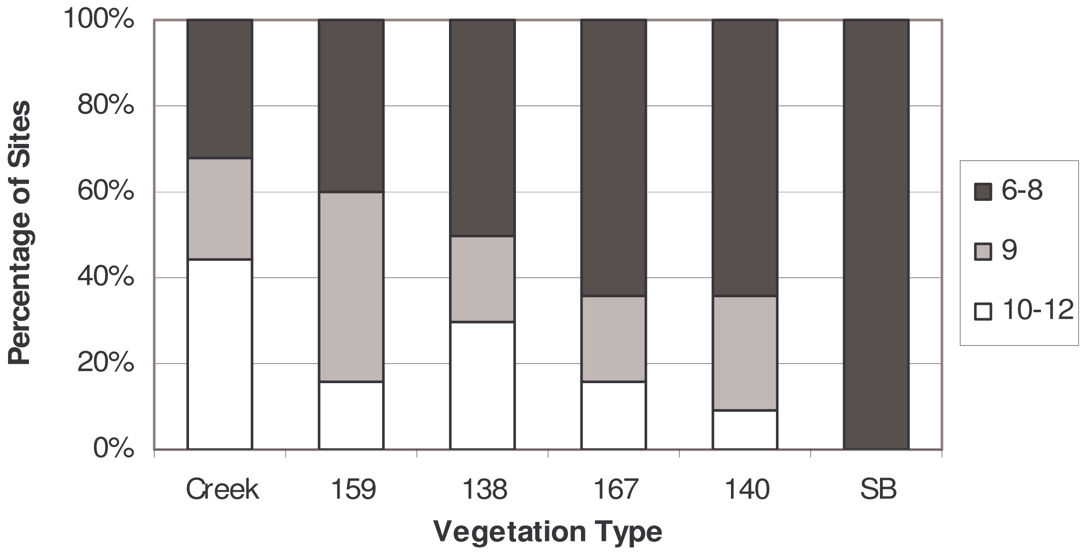

Figure 3.9: Percentage of Sites in the Moderate Habitat Complexity Group with Habitat Complexity Scores in the 6-8, 9 and 10-12 Range.

Chapter 4 Modelling Habitat Complexity Change After Fire

4.1 Introduction

Every fire leaves an imprint on the landscape. Many authors have documented the effect of periodic fires in a landscape creating a mosaic, even stating its benefits in the re-colonisation of areas after fire (for example: Christensen *et al.*, 1981; Bradstock *et al.*, 1995; Gill and Bradstock, 1995; Kavanagh and Bamkin, 1995; Williams and Gill, 1995; Morrison *et al.*, 1996; Wilson, 1996; Whelan and Baker, 1998). However, there is a paucity of published, quantitative data, on actual percentages of areas burnt during fire. Even in papers that do suggest percentages, the information varies. For example, Wilson (1996) stated that "low intensity fires may leave up to 40 percent of an area unburnt" and that " low intensity fires such as those used in fuel reduction burning practice can leave up to 25% of an area unburnt". This section provides a summary of the information found in the literature on percentages of land burnt during fire and uses that information to determine the fire parameters used in the studies model.

Catchpole (2002) stated that, in mild conditions, burnt areas will be minor and unburnt patches may be left within the fire boundary. In severe conditions, however, the area burnt will be extensive and all vegetation within the fire boundary may be burned, resulting in a more homogeneous fire imprint (Williams and Gill, 1995; Catchpole, 2002). Variations in topography and fuel quantity and flammability will shape fire behaviour and determined the final mosaic on a local scale (Williams and Gill, 1995). Adams and Simmons (1996) found that the area of bare ground was 10 to 20 times greater in an area burnt with a moderate intensity fire than in an area burnt in a low intensity fire.

Under many conditions, wetter areas, such as gullies, are less likely to burn (Williams and Gill, 1995). On average, 20-30% of the vegetation, especially in moister areas, may be left unburnt (Catchpole, 2002). Tolhurst (1996a) argued that, if the rapid recovery of some native small mammals is important, fire management regimes should endeavour to limit the burning of gully vegetation and burn no more than 70-80 per cent of an area overall. Recovery time would be extended if a greater percentage of their habitat was burnt (Tolhurst, 1996a).

Whelan (1995) stated that the typical fuel-reduction burn program generates fires which do not burn all the vegetation on the site and may want to achieve as little as 40% of an area burned. Some of the Western Australian National Parks management plans aim to burn between 50% and 80% of the vegetation under prescribed conditions to reduce fuel levels (CALM, 1999 pp iv).

Only a few studies researched percentages of burnt and unburnt vegetation, Lunney and Ashby (1987) found that, immediately after an intense unplanned fire, 84% of the survey area had less the 9% ground vegetation cover. Christensen and Kimber (1975) examined 11 prescribed fires (intensity not described) in wet, mixed and dry sclerophyll forests in southwestern Western Australia, and discovered, on average, 77% of the area was burnt with a range between 55%-90%.

Even within a mosaic burn, not all the fuel components are combusted within the burnt areas. Grass fires generally completely consumed fuel, while this rarely occurs in forest fires, due to greater volume of woody material and higher moisture content of living vegetation, resulting in more patchy fuel consumption (Luke and McArthur, 1978; Williams and Gill, 1995). Low intensity fires used for fuel management usually result in incomplete combustion even of leaf litter and understorey vegetation (York, 1999). Saplings, thick twigs and branches, bark and deep litter will burn in medium and high intensity fires, but not in low intensity fires (Catchpole, 2002).

The normal limit for fire intensity in planned low intensity (prescribed) fires in the Sydney region is about 500 kWm^{-1} (Morrison *et al.*, 1996). The upper limit for practical fire control occurs during mid intensity fires up to 3500 kWm^{-1} (Morrison *et al.*, 1996). Low intensity fires have a maximum flame height of 1.5m while a moderate intensity fire has a maximum flame height of 6 metres (Cheney, 1981). Scorch height (height where vegetation is killed but not fully combusted) may be 6 times the flame height (Luke and McArthur, 1978).

Low intensity fires recommended for fuel reduction may totally consume dead fuel below 6 mm, partly or totally damage the understorey shrub layer but do little damage to the tree canopy (Christensen *et al.*, 1981; Catchpole, 2002). Intensities between 500-1700 kWm^{-1} defoliate and kill above-ground sections of understorey shrubs, damage small branches of the overstorey (Christensen *et al.*, 1981). Moderate to high intensity fires usually result in compete crown scorch in most forests (Cheney,

1981) and usually defoliate the tree canopy, burn the understorey shrubs and totally remove the forest floor cover (Catling, 1991). As forests become more open, grass fuel tends to increase and at a certain stage can become more important than eucalypt litter. Fires are then likely to behave more like grass fires except that the trees tend to reduce the strength of the wind (Luke and McArthur, 1978).

Numerous studies demonstrate the incomplete combustion of litter, twigs, and bark fuels in forests during fire (Walker, 1981; O'Connell, 1991; Tolhurst, 1996c; York, 1999; Burrows, 2001; Catchpole, 2002). From the studies cited, on average 73.4% of litter, 45.5% of twigs and 49.5% of bark is consumed during low intensity fires. James (1999) found that, on average, less than 20% of prescribed burns in the Blue Mountains, NSW, removed more than 50% of the low to mid understorey fuels and less than 5% removed more than 30% of upper understorey fuels. Fires every eight years consume considerably less of the litter component than those every 16 years (O'Connell, 1991).

4.2 Methods

Based on the published information on fire patchiness, four different fire scenarios were devised to develop a model which would predict the impact of fire on habitat complexity at Coolah Tops National Park: low intensity fire with high patchiness (40% burnt), low intensity with low patchiness (80% burnt), moderate intensity fire with high patchiness and moderate intensity with low patchiness. These scenarios encompass the maximum and minimum percentages burnt found in other studies and encompass the parameters of fire intensity and patchiness that is likely to occur during a fuel reduction burn.

Bird rather than mammal habitat complexity scores were used to determine the parameters used in the model as they divided the litter from the logs and the tall from the low shrubs. By using the average bird habitat complexity score of all vegetation types for litter and tall and low shrubs, I determined that the habitat complexity score at a point would be reduced by 3 in a low intensity fire, based on the assumption that all the leaf litter and ground cover would be consumed (reducing the score to 0) and 50% of the low shrubs (0.5-2 m) would be burned, halving the average score while tall shrubs (2-4 m) and logs would not be affected. Using the same principal I determined that a moderate intensity fire would reduce the habitat complexity score by 5, based on the assumption that all the leaf litter, ground and low shrub layers and 50% of the logs and tall shrub layer would be consumed, but no damage to tree crowns would occur. A lower limit of 3 was set for the final habitat complexity score, so that a site with a pre-fire score of 5, for example, would only be reduced to 3 in either low or moderate intensity fire. This was based on the assumption that there would not be enough fuel for the fire to reach the tall shrub or canopy layers.

Fire patchiness was modelled by applying the respective reduction in habitat complexity score (3 or 5) to either 40% (for high patchiness) or 80% (for low patchiness) of the sites in an area – randomly selected. For each vegetation type, the RAND function in Microsoft Office Excel™ was used to randomly select 10 out of 25 sites for the 40% burn and 20 out of 25 sites for the 80% burn. Then using the IF function values were calculated to subtract 3 for the low intensity burn scenarios and 5 for the moderate intensity burn scenarios from the scores at each of these randomly selected sites (with the lower threshold set at 3). The macro function was used to run this simulation 100 times, to create an average habitat score for each vegetation type after each modelled fire. Statistical analysis was used to determine if there were any significant differences after the 4 fire scenarios.

4.3 Results

4.3.1 Ground-Dwelling Mammals

Habitat complexity scores were reduced more by the low patchiness fire models than the high patchiness fires models (Figure 4.1) as expected, based on the way the model was configured. For the low intensity 40% burn model, the average habitat complexity scores were reduced by between 1.07 (167) and 1.19 (Creek). The low intensity 80% burn model reduced scores by between 2.33 (167) and 2.40 (159 and SB) (Figure 4.1).

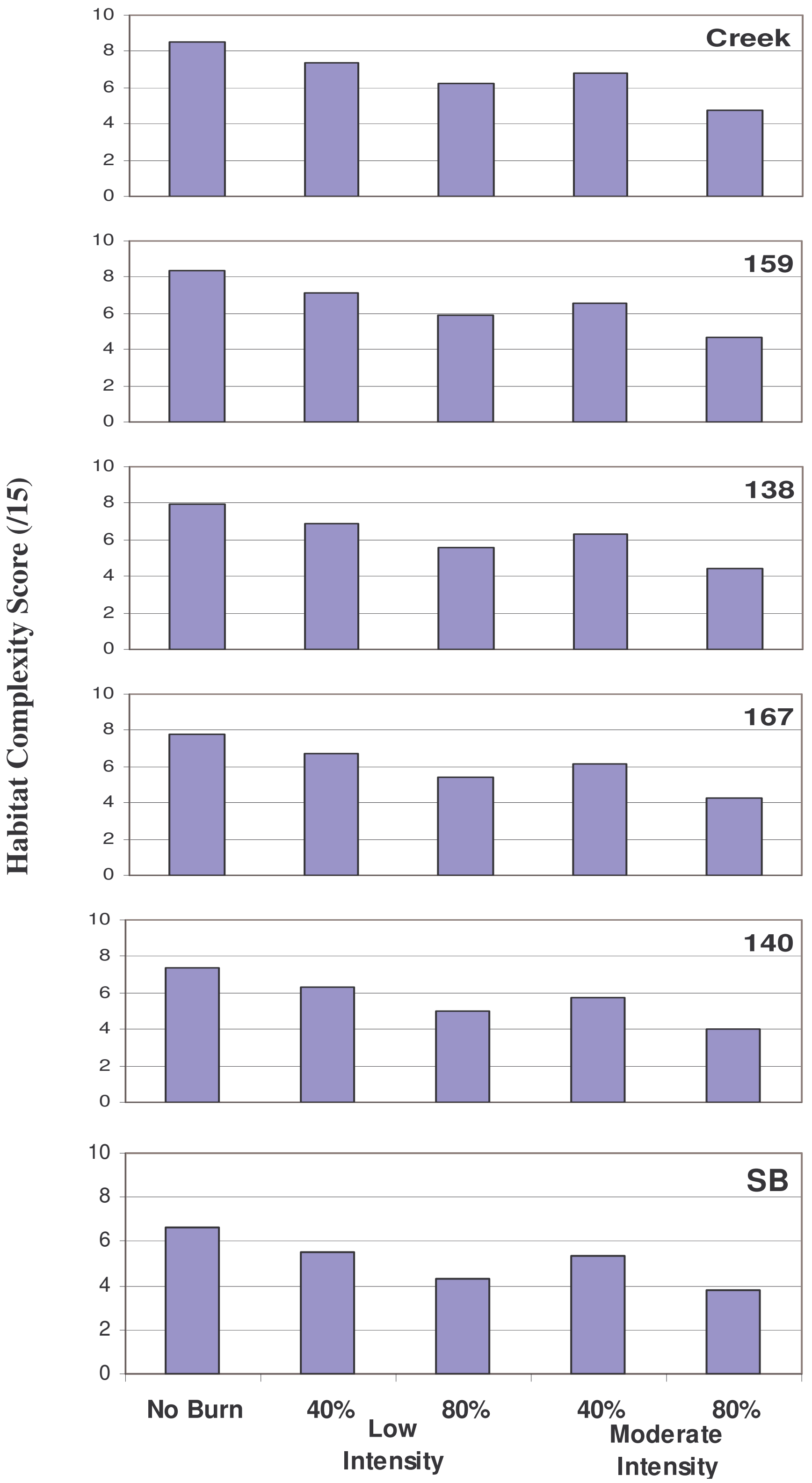

Figure 4.1: Average Mammal Habitat Complexity Scores for Each Vegetation Type Before and After the Low Intensity 40% and 80% and Moderate Intensity 40% and 80% Burn Models.

The moderate intensity fuel reduction scenarios reduced average mammal habitat complexity scores even further. The reduction after the moderate intensity 40% burn scenario was between 1.36 (SB) and 1.75 (159 and Creek) (Figure 4.1). The greatest drop was seen in the moderate intensity 80% burn scenario which reduced the habitat complexity scores by between 2.87 (SB) and 3.97 (Creek) (Figure 4.1).

All four of the fire models caused a decrease in the mammal habitat complexity scores. More than 50% of sites in all vegetation types, except Creek, were reduced to values between 3 and 7. When the scores are grouped into below average (<7), average (7) and above average (>7), the percentage of sites in each category are similar for each vegetation type for both low patchiness burn models and both high patchiness burn modes (Figure 4.2).

For the low intensity 40% burn model, the percentage of each vegetation type with scores with below average habitat complexity ranged from 34% (Creek) to 65% SB (Figure 4.2). The percentage of average scores ranged between 14% (159) and 28% (138), and above average scores varied from 10% (SB) and 48% (Creek) (Figure 4.2). The moderate intensity 40% burn model produced similar percentages, with between 9% (138) and 65% (SB) of sites with below average, 10% (Creek) and 26% (167) with average and 10% (SB) and 52% (Creek) with above average habitat complexity scores (Figure 4.2; Appendix 10).

The low patchiness burn models produced smaller mean habitat complexity scores than the high patchiness burn models (Figure 4.1). The low intensity 80% burn scenario produced scores ranging from 64% (Creek) to 90% (SB) for below average, 7% (140) to 19% (Creek) for average and 3% (SB) to 17% (Creek) for above average habitat complexity (Figure 4.2). Similar percentages were produced by the moderate intensity 80% burn scenario, ranging from 79% (138) to 88% (SB) for below average, 3% (Creek) to 9% (SB) and 4% (SB) to 16% (159 and Creek) for above average habitat complexity scores (Figure 4.2). All vegetation types had a large proportion of sites with habitat complexity scores of 3 and 4 after both 80% burn scenarios with between 64% (Creek) and 79% (140) of sites in this range (Appendix 11).

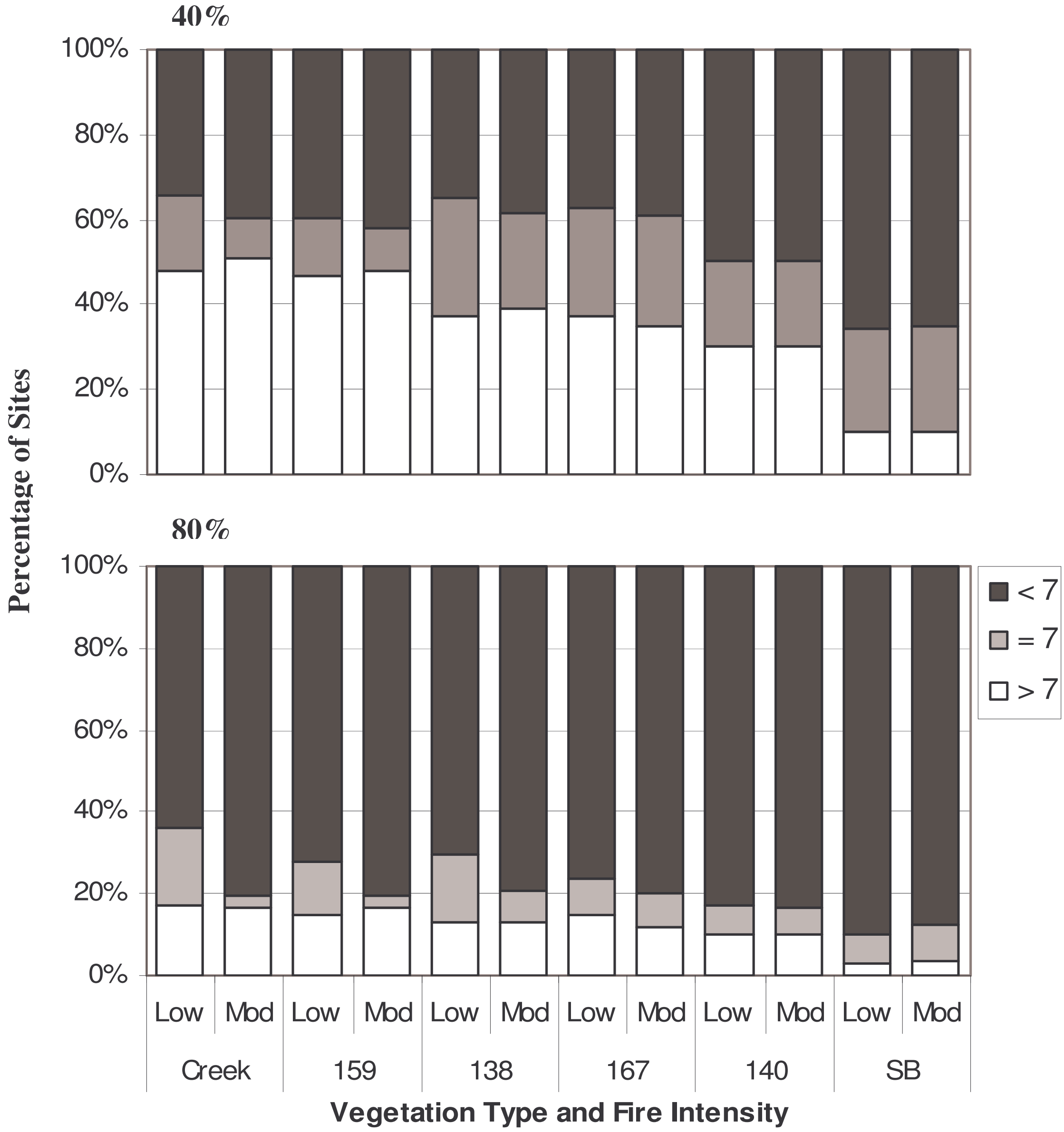

Figure 4.2: Percentage of Sites Found in Each Vegetation Type After a 40% Low and a 40% Moderate Intensity Fire Scenario and an 80% Low and an 80% Moderate Intensity Fire Scenario, with Grouped Mammal Habitat Complexity Scores Less than 7, 7 and Greater than 7.

No vegetation type, except 167 (with a score of 11), had a habitat complexity score above 10 after any of the four burn scenarios (Appendix 10 and 11). Of those sites with habitat complexity scores > 8, more than half had a score of 8, except in vegetation type 159 and Creek, where more than half the sites had a value of 9 (Appendix 10 and 11).

4.3.2 Understorey Birds

Again as expected, greater reductions in habitat complexity scores were seen in the low patchy burn scenarios compared with the high patchy scenarios (Figure 4.3). Average habitat complexity scores reduced by between 1.05 (140 and 159) and 1.18 (Creek) by the low intensity 40% burn model. The low intensity 80% burn model reduced scores by between 1.31 (SB) and 1.96 (138) (Figure 4.3).

The moderate intensity burn scenarios produced a greater decrease in scores compared with their low intensity counterparts. The moderate intensity 40% burn model reduced habitat complexity scores by between 1.37 (SB) and 1.83 (159) (Figure 4.3). Again the greatest reduction was seen in the moderate intensity 80% burn scenarios with a reduction of between 2.91 (SB) and 3.85 (Creek) being found (Figure 4.3).

Understorey bird preferences for different habitat complexity scores were based on Freudenberger's (1999; 2001; 2002) studies. He determined that woodland bird species could be split into 3 groups, "tolerant", "moderate" and "sensitive" depending on their ability to tolerate landscape threats like simplification of vegetation structure. "Tolerant" species occur in open landscapes with a poor structure (habitat complexity scores < 6), "moderate" species inhabited areas with moderate structured vegetation (habitat complexity scores 6-12) and "sensitive" species occupied complex vegetation (habitat complexity scores >12) (Freudenberger, 1999; Freudenberger, 2001).

Like the mammal habitat complexity scores, all four treatments reduced the bird habitat complexity scores (Appendix 12 and 13). Unlike for mammals, when the habitat complexity scores are grouped into "poor" (<6), "moderate" (6-12) and "complex" (>12), the changes seen in the bird habitat complexity scores after each burn scenario were not similar for both of the low patchiness and high patchiness models (Figure 4.4).

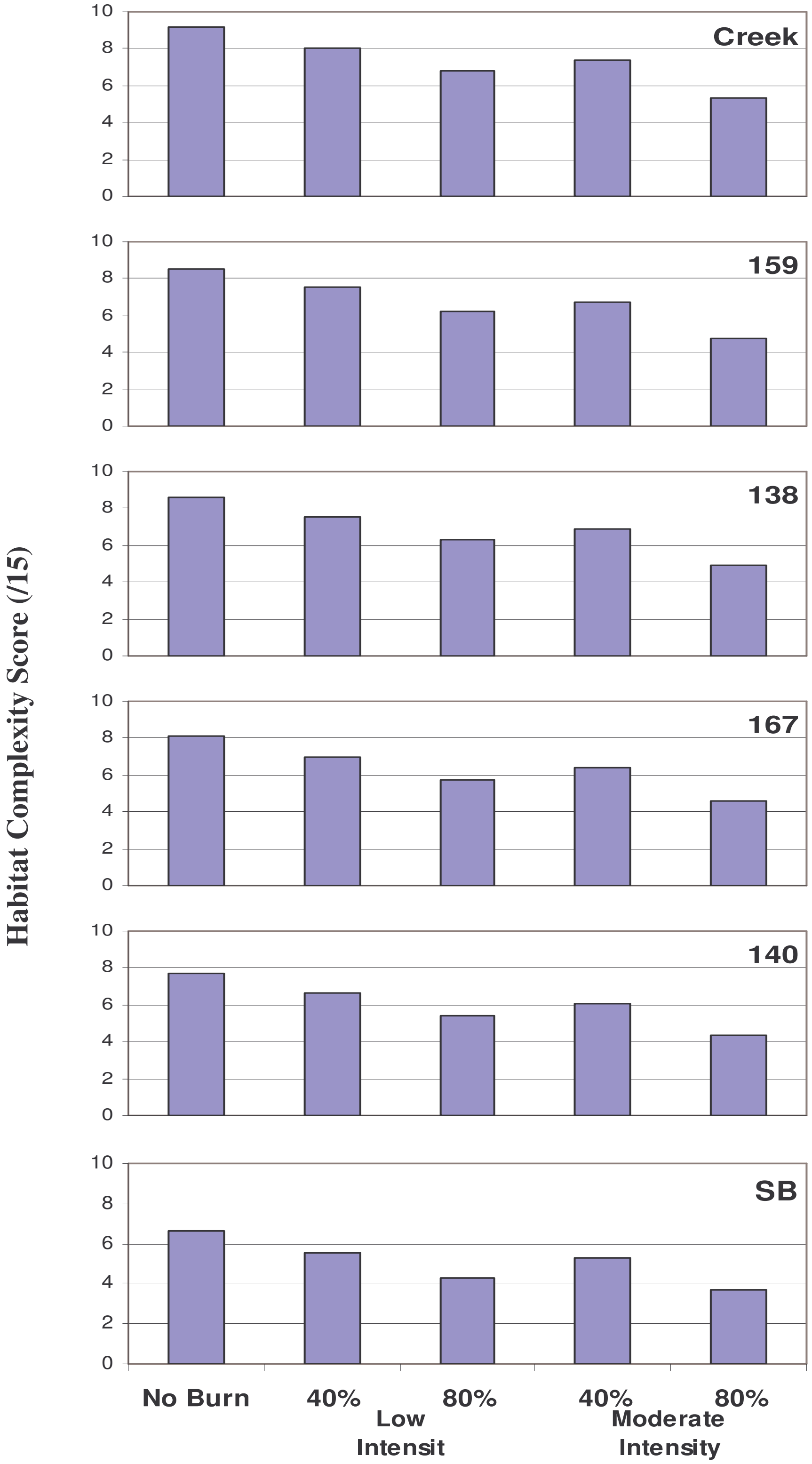

Figure 4.3: Average Bird Habitat Complexity Scores for Each Vegetation Type Before and After the Low Intensity 40% and 80% and Moderate Intensity 40% and 80% Burn Models.

The greatest reduction in habitat complexity scores was seen in the moderate intensity high patchiness model and the least was seen in the low intensity low patchiness model (Figure 4.4). All vegetation types except Creek and 159 were reduced more by the moderate intensity low patchiness scenario compared to the low intensity high patchiness burn scenario. However, these two burn models produced fairly similar results with percentage of sites being within, at most, 14 % (167) of each other, except for SB which had much lower scores after the moderate intensity 40% burn (Figure 4.4).

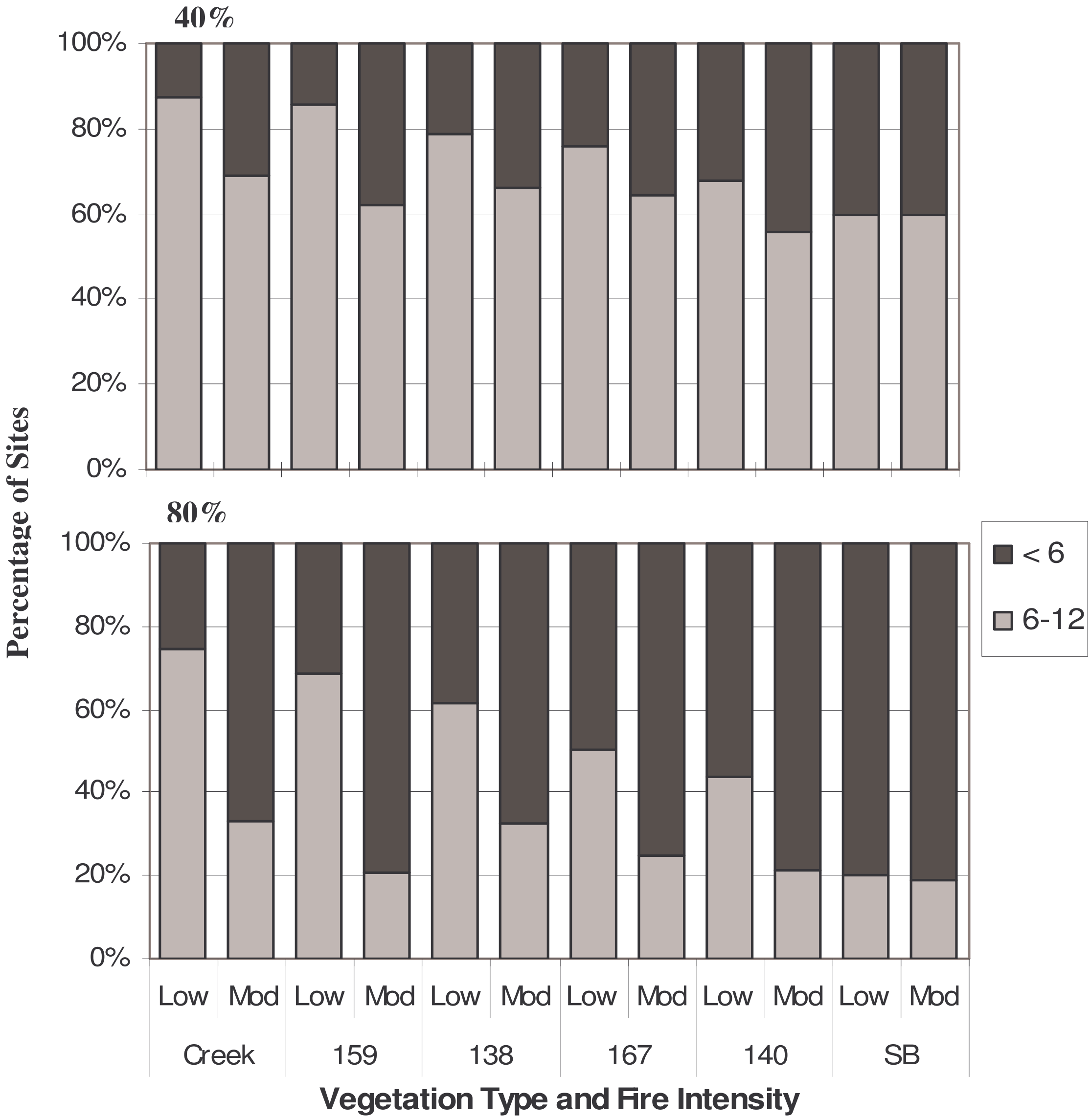

Figure 4.4: Percentage of Sites Found in Each Vegetation Type After a 40% Low and a 40% Moderate Intensity Fire Scenario and an 80% Low and an 80% Moderate Intensity Fire Scenario, with Grouped Bird Habitat Complexity Scores Less than 6, and 6-12.

No sites in any vegetation type before or after the burn models had bird habitat complexity scores greater than 12 (Appendix 9, 12 and 13). After the low intensity 40% burn model, the percentage of sites with a poor habitat complexity (<6; poor) ranged between 12% (159) and 40% (SB) and sites with moderate habitat complexity (6-12; moderate) varied from 60% (SB) to 86% (159) (Figure 4.4). The moderate intensity 40% burn scenario produced slightly different proportions with poor scores ranging from 31% (Creek) to 44% (140) and moderate scores between 56% (140) and 69% (Creek) (Figure 4.4).

After the low intensity 80% burn model, the percentage of sites which contained tolerant scores varied between 25% (Creek) and 56% (140), and the percentage of sites with moderate scores ranged from 44% (140) to 75% (Creek) (Figure 4.4). The moderate intensity 80% burn scenario produced the lowest scores with the percentage of sites with poor scores ranging from 67% (Creek) to 80% (SB) and moderate scores varying between 20% (SB) and 33% (Creek) (Figure 4.4).

Chapter 5 Discussion

The aims of this study were to use fuel loads and habitat complexity scores to predict the effects of a range of fuel reduction burns with different intensities and extents on the abundance and diversity of ground-dwelling mammals and understorey birds (see section 1.4 pp12). These results are used in this chapter to explain the potential impacts of management activities at Coolah Tops National Park.

5.1 Summary of Main Findings

5.1.1 Overview

The results from the fuel and habitat complexity score surveys indicated that the area had low fuel loads in all vegetation types and a range of vegetation structures from open forest to densely vegetated streams. This information, particularly the cover of shrub, litter and logs, was used as the basis of a model that predicted the change in vegetation structure under four different fire scenarios. As expected, based on the way the model was constructed, fire decreased habitat complexity scores in all scenarios and both the intensity and extent of the fire affected the degree of this reduction.

The reduction in habitat complexity seen in all four burn scenarios means that an overall decline in species richness of ground-dwelling mammals is predicted based on Catling's work (for example: 1979; 1983; 1991; 1997; 1998; 1999; 2001). It is likely that both small to medium-sized ground-dwelling mammals and understorey birds will be disadvantaged, while larger mammals and other bird species will be advantaged. There was, however, a contrast between the effect of fire intensity and/or patchiness on mammal and bird habitat complexity scores.

Reductions in mammal habitat complexity scores were similar for both the low patchiness burn scenarios and also both the high patchiness burn scenarios regardless of intensity. The results of this fire model showed that mammals are more likely to be affected by the extent of a fire rather than its intensity. Both the 80% burn models produced the greatest reduction in mammal habitat complexity scores resulting in almost double the number of sites with below average scores (<7) compared with the 40% burn models (Figure 4.2).

Unlike the mammals, the 40% and 80% burn scenarios did not produce similar results (except in vegetation type SB) (Figure 4.4) for understorey birds. The greatest reduction was produced by the moderate intensity low patchiness model and the smallest change was seen in the low intensity high patchiness model. The low intensity low patchiness and moderate intensity high patchiness models produced results in between these two extremes, with some vegetation types generating lower scores after the 40% burn and some after the 80% burn (Figure 4.4).

5.1.2 Fuel

The levels of total fuel loads thought to be effective in limiting, and allowing control of, unplanned fire during extreme conditions range from 5t/ha (Fensham, 1992), through 8t/ha (Luke and McArthur, 1978; Gill *et al.*, 1987; Williams and Gill, 1995) to 10-12t/ha (Raison *et al.*, 1983). The proposed burn site at Coolah Tops National Park had relatively light loads, with 97.3% of sites below 12 t/ha (see Appendix 8). Average fuel loads ranged between 5.9 and 7.5t/ha (Table 3.8). Total fuel loads for the various sites ranged between 2.9 and 22t/ha. This was a result, in most places, of a sparse understorey, thin layer of litter, and the occupation of much of the ground layer by *Poa* sp. (Appendix 2).

Studies in similar and different vegetation types have found much higher fuel loads than those found during this survey. Raison *et al.* (1986) found litter loads in sub-alpine *E. pauciflora* forests in the Brindabella Range, ACT of 16.9t/ha. A literature review carried out by Simmons and Adams (1999) found that in wet forests, litter loads alone were between 21.8 t/ha, in a mature *E. regnans* forest in Victoria (Ashton, 1975) and 27 t/ha in Western Australian *E. diversicolor* forests (Grove and Malajczuk, 1985). Total fuel loads ranged between 26 and 42t/ha in tall open forest with a dense understorey (Grove and Malajczuk, 1985) and 37 and 40t/ha in forest with a thick litter layer (McCaw *et al.*, 1997).

Dry forests in coastal NSW were found to have fine fuel loads of 16.7t/ha with other data ranging from 12.2 to 27t/ha (Fox *et al.*, 1979). Tasmanian dry eucalypt forests, were reported by Fensham (1992), to have total fuel loads of 12.2t/ha in forests with grassy understoreys and 15t/ha in forests with shrubby understoreys. Tussock grasslands in temperate climates can have fuel loads up to 15t/ha in long unburnt areas (Cheney and Sullivan, 1997). A grassy *E. fastigata, E. oblique, E. viminalis* forest in the New England National Park had litter loads of 3.96t/ha (Watson 1977 in Simmons and Adams, 1999), the closest fuel loads to the ones found in this study.

The differences in fuel loads between the above studies and this one could be due to differences in vegetation type and climate, differences in interpretations of fuel size and height classes, and variation in sampling techniques (Simmons and Adams, 1999). The vegetation in the proposed burn area at Coolah Tops National Park was tall open montane forest. The understorey in most areas consisted of sparse *Acacia dealbata*, *Pteridium esculentum*, and *Poa* spp. A few areas had dense thickets of *Lomatia arborescens, Leptospermum gregarium*, or *Pteridium esculentum* (Appendix 2). Litter cover was predominantly patchy and less than 3.29 cm deep (Table 3.3).

Although measurement of litter depth has been found to be a reliable method to estimate litter load (Sneeuwjagt, 1973), the litter needs to be homogeneous and deep enough to allow accurate measurement with a ruler, which was often not the case at Coolah Tops National Park (Gill and Knight, 1991). Results gained from this easy-to-use method may not be as precise as using other methods (Gill and Knight, 1991), but the trade-off is that many samples may be measured rapidly.

The assessment of shrub fuel levels using the methods published by NPWS (NPWS, 2002b) is open to observer interpretation and requires a level of experience to undertake it accurately. As actual shrub and litter fuel loads were not measured here, I recommend that this be undertaken prior to finalising a management strategy.

5.1.3 Habitat Complexity

Abundance and diversity of small ground-dwelling mammals have been shown to have a positive correlation with habitat complexity (Catling and Burt, 1995a). Catling and Burt (1995a) found that the higher the habitat complexity score the more individual native, small ground-dwelling mammals were captured. Areas with above-average habitat complexity scores (>7) typically supported medium to high numbers of small ground-dwelling mammals, while sites with below-average scores (<7) and average scores (7) supported fewer (Catling and Burt, 1995a). Sites with low habitat complexity scores tend to favour large native herbivores, especially *Macropus gigantus* (eastern grey kangaroo) and *Vombatus ursinus* (common wombat), and the European rabbit. Large wallabies tend to occur in all habitat complexity scores but populations declined as scores increase (Catling and Burt, 1995a). Introduced predators such as *Vulpes vulpes* (red fox) and *Felis catus* (cat) displayed no preference for any particular habitat complexity score and have been found to be abundant throughout the range (Catling and Burt, 1995a).

Studies by MacArthur and MacArthur (1961), and Freudenberger (1999; 2001) showed similar patterns for woodland bird species with a greater abundance being contained in sites with higher habitat complexity scores. Freudenberger (1999; 2001) found that few woodland birds, and only those described as "tolerant", were found in areas with poor habitat complexity scores less than 6. "Moderate" bird species inhabited vegetation with moderate habitat complexity scores of between 6 and 12 while "sensitive" bird species preferred scores greater than 12 (Freudenberger, 1999; Freudenberger, 2001).

Many other studies have drawn similar conclusions to those above (for example: MacArthur, 1965; Barnett *et al.*, 1978; Braithwaite and Gullan, 1978; Newsome and Catling, 1979; Catling *et al.*, 1981; Fox and Fox, 1981; Fox, 1983; Friend and Taylor, 1985; Lunney *et al.*, 1987; Southwell, 1987; Lunney and O'Connell, 1988; Catling, 1991; Catling and Burt, 1994; Cork and Catling, 1996; Tolhurst, 1996a; Wilson, 1996; Coops and Catling, 1997a; Tasker *et al.*, 1999; Catling *et al.*, 2000; Knight and Fox, 2000; Watson *et al.*, 2001; Freudenberger and Stol, 2002). The conclusions drawn in this research paper were based on the assumption that ground-dwelling mammals and understorey birds in Coolah Tops National Park would behave in a similar manner to those in the above studies. Mammal and bird species were taken from records of species known to exist in the Park, using the Atlas of NSW Wildlife (NPWS, 2004)

5.1.3.1 Ground-dwelling Mammals

Habitat complexity varied significantly between vegetation types (Appendix 4 (d)), and was highest in vegetation type Creek followed by 159, 138, 167, 140 and then SB. Almost half to more than half the sites in all vegetation types, except SB, had above-average (>7, based on Catling, 1991) habitat complexity scores. Between 80% and 100% of sites in all vegetation types had scores of 9 or less and all sites, except 1, had scores of 10 or less (Appendix 8). Therefore, sites burnt by a low intensity fire are likely to have a habitat complexity score of 6 or less, and sites burned by a moderate intensity fire are definitely going to have below average (<7, based on Catling, 1991) habitat complexity scores, as the model was designed to lower the scores by 5.

In the pre-burn habitat, small ground-dwelling mammal abundance, particularly *Antechinus stuartii, A. flavipes* and *Rattus fuscipes*, would most likely be greatest in vegetation types Creek and 159 due to a greater number of sites with above average habitat complexity (Figure 3.6). These vegetation types are also more likely to contain *Wallabia bicolor* as it is a browser and both cover and food is provided by denser vegetation (Lunney and O'Connell, 1988). Vegetation types 138, 140 and 167 have the potential to have medium abundance of small ground-dwelling mammals in some sections as the higher habitat complexity scores tend to be grouped together (Appendix 14).

Based on the habitat complexity scores, vegetation type SB and the rest of 138, 140 and 167 that had low or average habitat complexity scores (5, 6, 7) are more likely to contain greater numbers of medium to large ground-dwelling mammals like *Macropus gigantus, M. robustus,* and *Vombatus ursinus*. Vegetation type SB, however, contained very little grass for larger mammals, but had many more logs, which have been shown to be an important habitat component for some ground-dwelling mammals like *Antechinus* spp. *M. rufogriseus* is a grazier and require open grassy habitat for food as well as the protection of denser vegetation structure for shelter. Therefore they are most likely to be found in vegetation types 138, 140 and 167, but could potentially utilise the whole study area.

The change in vegetation structure, seen after all four burn models, suggests that the suitability of the vegetation for ground-dwelling mammals would also change. The low and moderate intensity 40% burn models increased the percentage of sites with average and below average scores. All vegetation types following both 40% and 80% fire models still had above average habitat complexity scores, between 8 (SB) and 11 (167) (Tables 4.2 and 4.3, Appendix 10 and 11).

The results from the 40% area burn models predict that the suitability of the habitat for small ground-dwelling mammals would be reduced, leaving it more suitable for medium to large ground-dwelling mammals. However, there would still be some areas in vegetation type 159 and Creek and to a lesser extent 138, 167 and possibly 140 which could provide refuge areas for small ground-dwelling mammals while vegetation structure recovered in the surrounding area. Suitability of sites for medium to large mammal species including introduced predators may, however, be increased.

Both 80% burn models suggest an even greater reduction of the percentage of sites with above average habitat complexity (Table 4.3 and Appendix 11). All vegetation types had more then 80% of their sites with average and below average habitat complexity scores, with a large number of sites with very low scores of 3 and 4 (Appendix 11). With both the low patchiness burn scenarios, very few refuge areas remain due to the large percentage of the area burnt. Therefore, small ground-dwelling mammals that survived the fire would have difficulty remaining in the area due to the lack of food and shelter from predators and climate provided by the burnt patches. Once grass re-established itself, however, the site would be suitable for medium to large ground-dwelling mammals.

Although moderate intensity fires may result in slightly lower habitat complexity scores due to the removal of larger amounts of the material from the understorey, it would appear that in both low and moderate intensity fires it is the percentage burnt that has a greater impact. Therefore, if maintaining small ground-dwelling mammals on site is important, fire management needs to control fire extent rather then intensity.

It has been shown that small ground-dwelling mammals find open areas such s roads barriers to movement (Oxley *et al.*, 1974; Mader, 1984; Andrews, 1990; Burnett, 1992). As the burn site is surrounded by well-maintained dirt roads on two sides and regularly ploughed tracks on the other two sides, there is a possibility that small ground-dwelling mammals will not readily migrate from outside regions into the burn zone. Recolonisation of the burnt areas may therefore need to occur from within the proposed burn site. As a result, it is important that some places for refuge are maintained within the fire zone in which animals can shelter during the fire and re-establish the burned sites post fire.

5.1.3.2 Understorey Birds

As with mammal scores, habitat complexity varied significantly between vegetation types (Appendix 4 (e)). Vegetation type 138, 159 and Creek were statistically similar to each other, as were 138, 140, 159 and 167, and 140 and SB (Figure 3.7).

No vegetation type had complex habitat complexity scores (>12), the vegetation structure needed for “sensitive” understorey bird species (Freudenberger, 1999). Between 88% and 100% of the sites in all vegetation types had moderate habitat complexity scores (6-12), and were suitable for moderate bird species. Despite this high proportion of sites in the moderate range, all vegetation types, except Creek, had more then 75% of sites with scores of 9 or less, meaning that any decrease in structure by fire may result in poor habitat complexity only suitable for tolerant bird species. This was borne out by all four fire models.

The average habitat complexity score showed a greater drop after the 80% burn models regardless of intensity (Figure 4.3). However, the response of each vegetation type, when individual sites were classified into poor, moderate and complex scored groups, showed that this was not true for vegetation types 159 and Creek. Despite lower habitat complexity scores being seen after the low patchiness scenarios, 159 and Creek showed a greater reduction after moderate intensity burns regardless of percentage of area burnt (Figure 4.4). Across all the vegetation types, the change in habitat complexity was greatest for the moderate intensity 80% burn model and least for the low intensity

40% burn model. The low intensity 80% burn and the moderate intensity 40% burn models produced grouped percentages in between the two extremes with vegetation types 138, 159 and Creek producing fairly similar results, while 140, 167 and SB had many more sites with scores less than 6 (Figure 4.4).

As there was no habitat suitable for “sensitive” understorey bird species, the focus of the study was the effect of fire on “moderate” and “tolerant” bird species. The field survey showed that more than 88% of all sites had moderate scores and were suitable for “moderate” bird species (Figure 4.3). As stated above, the greatest impact was seen after the moderate intensity 80% burn scenario, where habitat suitable for “moderate” understorey birds was greatly reduced in all vegetation types (Figure 4.3). The low intensity 40% burn model had far less impact on the vegetation structure, retaining a much higher proportion of sites in the range suitable for “moderate” birds. The moderate intensity 40% and low intensity 80% burn models produced percentages between these two extremes. Similar percentages of poor and moderate habitat complexity scores were seen as a result of these two burn scenarios except for vegetation type SB (Figure 4.4). All vegetation types except Creek and 159 were reduced more by the moderate intensity 40% than the low intensity 80% burn scenario (Figure 4.4).

These results demonstrate a far greater impact is likely for the higher intensity more extensive burn model, with much of the resulting habitat being unsuitable for “moderate” understorey bird species. This would lead to a probable loss of these bird species from the area and an introduction of greater numbers of “tolerant” bird species.

More of the “moderate” understorey bird species would be retained by the low intensity 40% burn scenario. At least 43% of sites in all vegetation types except SB, retained habitat complexity scores between 6-12 after the low intensity 80% and moderate intensity 40% burn models (Figure 4.4). Although these two scenarios reduce the number of sites originally found with scores between 6 and 12 by almost half they do allow for a greater reduction in fuel then the low intensity 40% burn model while retaining higher habitat complexity scores then the moderate intensity 80% burn model.

Once vegetation structure had re-established enough to provide suitable habitat for "moderate" bird species, it would be likely that they would recolonise from refugia. However, ground and understorey birds may have greater difficulty doing this than birds who readily cross open areas or travel above the canopy (Whelan *et al.*, 1996) due to the roads bordering the burn area.

5.1.4 Predictions of Bird and Mammal Responses to Fire

Recolonisation of individuals into burnt patches may only be successful if they can survive in the area, meaning that vital resources, i.e. food and cover, need to be accessible (Christensen and Kimber, 1975; Fox and McKay, 1981; Catling, 1991; Catling *et al.*, 2001). There is little experimental evidence, however, that shows animal recolonisation is prevented if vital food and shelter resources are reduced by fire (Whelan *et al.*, 2002). In fact, it would seem that the variation in recolonisation by different species is due to the stage of vegetation recovery at which their habitat needs are satisfied (Fox, 1982; Sutherland and Dickman, 1999). As fires, particularly controlled burns, rarely remove all the vegetation it is likely burnt areas would be recolonised given sufficient time for vegetation structure to be restored.

Dispersal from refugia into burnt areas depends also on the degree of mobility (Whelan *et al.*, 2002). If numbers of mammals and birds in unburnt patches are low post fire, then species will have to migrate from outside the burnt area. This would involve crossing open land in the form of a dirt road or cleared track. There may also be issues with species crossing occupied habitats or areas in which they are not going to breed or settle.

Burnett (1992) found that the *Antechinus flavipes* and *Rattus fuscipes* were rarely trapped on both sides of a road. Barnett *et al.* (1978) established similar findings for these species using a 4.5 and 3.25m unsealed low-usage road such as those found at Coolah Tops National Park. Even an overgrown, unused 3m wide fire trail prevented *Melomys cerinipes* from crossing (Barnett *et al.*, 1978). The restriction of small mammals to one side of a linear barrier such as a road has been seen by a number of authors (Oxley *et al.*, 1974; Russell, 1978; Mader, 1984; Swihart and Slade, 1984;

Andrews, 1990). Some birds have been found to keep a certain distance from roads (van der Zande *et al.*, 1980). Bird species that readily cross exposed areas or fly above the canopy or that have larger home ranges would be more likely to recolonise the burnt area than ground and shrub-layer species that typically maintain separate territories (Whelan *et al.*, 2002).

5.2 Implications for Management

With such low fuel loads present in Coolah Tops National Park, conducting a fuel reduction burn across the whole site may be unnecessary, as most sites are within the range where fuel is deemed low enough to stop crowning and aid in control of unplanned fire (Luke and McArthur, 1978; Gill *et al.*, 1987; Fensham, 1992; Williams and Gill, 1995; Adams and Simmons, 1996) as well as being below the 8 t/ha desired by the park managers. It is my recommendation therefore that a fuel reduction burn should not be carried out until fuel loads start to exceed 8 t/ha. Because the fuel loads were unexpectedly low, an independent assessment of the range of fuel loads across the study areas is recommended prior to any further management of the site.

If, despite low fuel loads, a fuel reduction burn is carried out, this study gives a prescribed “best outcome” fire which will reduce fuel in the areas with the highest loads as well as maintain biodiversity, especially of ground-dwelling mammals and understorey birds, within the site. Along with the recommendations below, fire frequencies, as much as possible, should be kept within the thresholds laid out by Kenny *et al.* (2003) or any peer reviewed local frequencies, if they are available, in order to maintain biodiversity.

During any planned burn, some of the vegetation with higher habitat complexity scores should be retained as refuge for wildlife. This is particularly important for ground and shrub-layer bird species that typically maintain separate territories and small ground-dwelling mammals, as many have been shown to be reluctant to cross the open areas produced by roads (Oxley *et al.*, 1974; Russell, 1978; Mader, 1984; Swihart and Slade, 1984; Andrews, 1990; Burnett, 1992; Whelan *et al.*, 2002).

Vegetation types 159, 138, and Creek all have average total fuel loads between 7.06 and 7.51 t/ha (Table 3.8). Vegetation types SB and 140 have total fuel loads between 6.62 and 6.73, while 167's total fuel load is 5.85 t/ha (Table 3.8). Although vegetation type Creek has one of the highest fuel loads, it also has the highest habitat complexity scores for both ground-dwelling mammals and understorey birds, therefore every effort should be made to retain this vegetation community. If a fuel reduction burn was carried out between the top and bottom creeks on the site (Appendix 14), then the three communities with the highest fuel loads would be burnt while valuable refuge areas were retained.

Fauna has been shown to be fairly resilient to single fire events if they are small and have a low intensity (Friend, 1999). This was also predicted in this study with both the 40% burn models producing the least impact for mammals and a low to moderate affect on understorey birds. In order to lessen the impacts on ground-dwelling mammals and understorey birds, fire extent should be minimised rather then attempting to control the fire intensity.

There are two limitations to immediately implementing the above recommendations. Firstly the model is, as yet, untested, and secondly the collection of more pre-burn and post-burn data is recommended to validate the information used in this study. Therefore an adaptive management framework needs to be employed to ensure that the results are correct and that outcomes of an actual fire are related back to the model to determine its accuracy and make adjustments if and where they are needed.

An adaptive management framework helps to determine an experimental method of land management, in circumstances where accurate predictions of an action cannot be made due to a lack of scientific knowledge (Whelan, 2002a). Adaptive management allows for management to proceed in a way that creates information through its experimental design (Walters, 1997). The Canadian Ministry of Forests (2000) outlines the adaptive process they use very well (Figure 5.1) and define it as follows:

> *Adaptive management is a systematic process for continually improving management policies and practices by learning from the outcomes of operational programs. It's most effective form – "active"*

adaptive management – employs management programs that are designed to experimentally compare selected policies or practises, by evaluating alternative hypotheses about the system being managed.

Please see print copy for Figure 5.1

Figure 5.1: Six-step cycle defining the adaptive management process, as used by the Canadian Ministry of Forests (2000).

Following this six-step process, an adaptive management framework can be prescribed for the fire management at Coolah Tops National Park. In this case, the problem has already been assessed by the managers of the Park and studied in this project. The implications for management and a design for future fuel reduction burns in the Park have been outlined above.

Funding, time and/or assistance to future staff or students should be set aside to check some of the assumptions and findings in this study. Along with an independent assessment of fuel loads, survey work before and after a fire should be carried out to test the relationship between habitat complexity and diversity and abundance of ground-dwelling mammals and understorey birds at Coolah Tops National Park to determine if Habitat Complexity is a good predictor for those species found in the Park. Once this is done management should be applied using the adaptive management approach summarised above.

Firstly using the results of this study and the survey outlined above, management should be designed and implemented to maximise the habitat available for as many of the species of, in this case, small ground-dwelling mammals and understorey birds (this could also include plants, animals and even insects) present in the site. Control sites outside the burn area in similar vegetation and habitat should be set up as part of the design, so that comparisons can be made between the sites to determine if any changes in habitat complexity and diversity and abundance of ground-dwelling mammals and understorey birds are due to the management carried out or other site factors.

Secondly, post-fire habitat complexity outcomes and ground-dwelling mammal and understorey bird reactions should be monitored to determine if they are the same as predicted by the models. Some useful aspects to monitor include: the actual extent of the fuel reduction burn; how much material was consumed; the actual reduction in the habitat complexity scores; and the level of persistence and recolonisation of the area by ground-dwelling mammals and understorey birds post fire.

Finally, the outcomes from the monitoring need to be used to evaluate the predictions of this study and the actual impacts of the fire on habitat complexity scores and wildlife. The suggested fire management of the site can then be adjusted where, and if, needed, to determine if any further fuel reduction burns are needed and if so, how to maintain both an area of low fuel for fire control and enough structure in the vegetation to ensure biodiversity is preserved. It may also allow for similar methods to be used to predict the impact of fires on the habitat complexity and therefore ground-dwelling mammals and understorey birds in other areas.

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Appendix 1: Map of Vegetation Types at Coolah Tops National Park.

Please see print copy for Appendix 1

Appendix 2: Vegetation Species Dominating Every Site in Each Vegetation Type.

Plant species are listed from most common to least common. ** indicates species that are widespread throughout the site. * indicates species that are common throughout the site.

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Vegetation	1	2	3	4	5	6	7	8	9
Ground	**Pteridium Poa	**Poa *Pteridium	**Poa Pteridium Lomandra	**Poa Pteridium Lomandra	**Poa **Pteridium Lomandra	**Poa Pteridium Swainsona	**Poa *Pteridium Swainsona Lomandra	**Poa Pteridium Lomandra	Pteridium Poa Eustrephus
Shrub	**Lomatia A. dealbata	A. dealbata Lomatia	**A. dealbata	**A. dealbata Lomatia	A. dealbata Lomatia	**A. dealbata *Lomatia	A. dealbata Lomatia E. stellulata	**Lomatia A. dealbata	**Lomatia Coprosma

Vegetation	10	11	12	13	14	15	16	17
Ground	**Pteridium **Poa Smilax Lomandra	**Pteridium **Poa Smilax Lomandra	**Poa **Pteridium Lomandra	**Pteridium **Poa Lomandra	**Poa **Pteridium	**Pteridium *Poa	**Poa **Pteridium Lomandra	**Poa **Pteridium Lomandra
Shrub	**Lomatia *A. dealbata	A. dealbata	*A. dealbata Exocarpus	A. dealbata Lomatia	A. dealbata Lomatia E. stellulata	A. dealbata Lomatia E. stellulata	**A. dealbata Lomatia E. stellulata	**A. dealbata Hibbertia

Vegetation	18	19	20	21	22	23	24	25
Ground	**Pteridium **Poa Lomandra	**Poa **Pteridium Lomandra	**Poa *Pteridium Lomandra	**Poa Pteridium Lomandra	**Pteridium **Poa Smilax	**Pteridium **Poa Lomandra	**Poa Pteridium Lomandra	**Poa *Pteridium Swainsona
Shrub	**Lomatia A. dealbata	**A. dealbata *Lomatia Hibbertia	**A. dealbata (dying) Lomatia	A. dealbata Lomatia Hibbertia	**A. dealbata Lomatia	**A. dealbata *Lomatia	**A. dealbata Lomatia	**A. dealbata *Lomatia Exocarpus

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Vegetation	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**
Ground	**Pteridium **Poa	**Pteridium **Poa	**Poa *Pteridium Eustrephus	**Pteridium **Poa	**Pteridium **Poa Swainsona Lomandra	**Poa Pteridium Lomandra	**Poa Pteridium Lomandra	**Poa Lomandra	**Poa *Pteridium *Lomandra
Shrub	*A. dealbata E. stellulata	*A. dealbata	**A. dealbata Solanum E. stellulata	*A. dealbata Coprosma	Hibbertia	**A. dealbata	**A. dealbata	**A. dealbata Hibbertia	**A. dealbata

Vegetation	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**
Ground	**Pteridium Poa Lomandra	**Pteridium **Poa Lomandra	**Poa **Pteridium Swainsona Lomandra	**Poa Pteridium	**Pteridium **Poa Hydrocotyle Nightshade	**Pteridium Poa Smilax	**Pteridium **Poa *Lomandra Nightshade Swainsona	**Poa Pteridium Swainsona
Shrub	**A. dealbata Hibbertia	A. dealbata	**A. dealbata Solanum	A. dealbata	**A. dealbata Solanum	**A. dealbata Solanum	**A. dealbata Solanum	**A. dealbata Solanum

Vegetation	**18**	**19**	**20**	**21**	**22**	**23**	**24**	**25**
Ground	**Pteridium **Poa Nightshade Lomandra	**Pteridium **Poa Swainsona Lomandra Hydrocotyle	**Poa **Pteridium Lomandra	**Poa **Pteridium	**Poa **Pteridium Lomandra	**Poa Pteridium	**Poa	**Poa Pteridium Lomandra
Shrub	Solanum Coprosma	*A. dealbata	*A. dealbata Lomatia	*A. dealbata	*A. dealbata Leucopogan	*A. dealbata *Leucopogan Exocarpus	*A. dealbata *Leucopogan Coprosma	E. stellulata Lomatia

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Vegetation	1	2	3	4	5	6	7	8	9
Ground	**Poa Pteridium Lomandra	**Poa **Pteridium Lomandra	**Poa Pteridium Lomandra	**Poa **Pteridium Lomandra	**Poa **Pteridium	**Poa **Pteridium Lomandra Swainsona	**Poa *Pteridium Lomandra	Poa	**Poa **Pteridium Lomandra
Shrub	**A. dealbata Exocarpus	**A. dealbata	**Lomatia *A. dealbata	**A. dealbata Lomatia Exocarpus	**A. dealbata *Lomatia	A. dealbata Lomatia Hibbertia	*A. dealbata Lomatia	**Lomatia Directly under Lomatia	*A. dealbata Exocarpus E. stellulata

Vegetation	10	11	12	13	14	15	16	17
Ground	**Poa **Pteridium Lomandra	**Poa **Pteridium Lomandra	**Poa **Pteridium Lomandra	**Poa **Pteridium Lomandra	**Poa **Pteridium Lomandra	**Poa **Pteridium	**Pteridium **Poa	**Pteridium Poa
Shrub	**A. dealbata Lomatia	**A. dealbata	A. dealbata Leucopogon	**A. dealbata Lomatia	**A. dealbata Lomatia	**Lomatia *A. dealbata	A. dealbata	**Lomatia

Vegetation	18	19	20	21	22	23	24	25
Ground	**Poa **Pteridium Lomandra	**Pteridium **Poa	**Pteridium *Poa	**Poa Pteridium Lomandra Swainsona	**Poa **Pteridium	**Poa **Pteridium	**Pteridium *Poa	**Pteridium Poa
Shrub	*A. dealbata Lomatia	*A. dealbata	*A. dealbata Lomatia	A. dealbata Lomatia	*A. dealbata	*A. dealbata (dying) Lomatia	Lomatia Exocarpus	A. dealbata Lomatia

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Vegetation	1	2	3	4	5	6	7	8	9
Ground	**Pteridium **Poa *Lomandra Swainsona Hydrocotyle	**Pteridium **Poa *Lomandra Hydrocotyle	**Poa **Pteridium Smilax	**Poa **Pteridium *Lomandra	**Poa **Pteridium Lomandra	**Poa *Pteridium *Lomandra	**Poa Pteridium Lomandra	**Poa Pteridium Lomandra	**Poa Pteridium Lomandra
Shrub	*A. dealbata Hibbertia	*A. dealbata Hibbertia		*A. dealbata	**A. dealbata Hibbertia	**A. dealbata	A. dealbata E. stellulata	**A. dealbata	**A. dealbata E. stellulata Hibbertia

Vegetation	10	11	12	13	14	15	16	17
Ground	**Poa Pteridium Lomandra	**Poa Pteridium Lomandra	**Pteridium **Poa Lomandra	**Poa *Pteridium Lomandra	**Pteridium **Poa Lomandra	**Poa Pteridium Lomandra	**Poa Pteridium Lomandra	**Poa *Pteridium Lomandra
Shrub	**A. dealbata Exocarpus Solanum	**A. dealbata Coprosma	*A. dealbata	**A. dealbata Exocarpus	*Lomatia A. dealbata	**A. dealbata	**A. dealbata	*A. dealbata

Vegetation	18	19	20	21	22	23	24	25
Ground	**Poa **Pteridium Lomandra	**Poa **Pteridium Lomandra	**Poa Lomandra Pteridium	**Poa **Pteridium Lomandra	**Poa Pteridium Lomandra	**Poa Pteridium Lomandra	**Poa Pteridium	**Poa Pteridium Lomandra
Shrub	**A. dealbata Lomatia Hibbertia Coprosma	**A. dealbata Hibbertia	**A. dealbata Hibbertia	*A. dealbata Hibbertia	A. dealbata Lomatia	*A. dealbata Lomatia	A. melanoxolyn Coprosma Hibbertia	*A. dealbata E. stellulata

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Vegetation	1	2	3	4	5	6	7	8	9
Ground	**Poa Pteridium	**Poa Pteridium Lomanrda	**Poa **Pteridium Lomandra	**Poa Pteridium	**Poa Pteridium Lomandra	**Poa Pteridium Lomandra	**Poa **Pteridium Lomandra	**Poa Pteridium Lomandra	**Poa Pteridium
Shrub	A. dealbata	**A. dealbata	A. dealbata	A. dealbata	*A. dealbata	A. dealbata	A. dealbata Lomatia	*A. dealbata	**A. dealbata

Vegetation	10	11	12	13	14	15	16	17
Ground	**Poa Pteridium Lomandra	**Poa *Pteridium Lomandra	**Poa Pteridium Lomandra	**Poa *Pteridium Lomandra	**Poa Pteridium Lomandra	**Poa **Pteridium Loamndra	**Poa Pteridium	**Poa *Pteridium Lomandra
Shrub	*A. dealbata	A. dealbata	*A. dealbata	A. dealbata	*A. dealbata	A. dealbata Coprosma	**A. dealbata Lomatia Coprosma	A. dealbata

Vegetation	18	19	20	21	22	23	24	25
Ground	**Poa Pteridium Lomandra	**Poa *Lomandra Pteridium	**Poa **Pteridium Lomandra	**Poa Pteridium Lomandra	**Pteridium **Poa	**Poa *Pteridium Lomandra	**Poa Pteridium Lomandra	**Poa **Pteridium Lomandra
Shrub	**A. dealbata	*A. dealbata	A. dealbata	**A. dealbata	A. dealbata	A. dealbata	*A. dealbata	*A. dealbata

Creek

Vegetation	1	2	3	4	5	6	7	8	9
Ground	**Poa **Pteridium Lomandra	Poa Pteridium Smilax	**Pteridium *Poa Smilax Lomandra	**Poa *Lomandra *Smilax	**Poa **Pteridium	**Poa Pteridium Swinsona	**Poa Lomandra	**Poa	**Poa *Pteridium
Shrub	*A. dealbata Lomatia Coprosma Hibbertia E. stellulata	**Leptospermum **Coprosma Lomatia	**Lomatia A. dealbata *Coprosma E. stellulata	**A. dealbata *Lomatia *Coprosma E. stellulata	*A. dealbata E. stellulata	**A. dealbata Lomatia	**A. dealbata Coprosma E. stellulata	**A. dealbata E. stellulata	*A. dealbata

Vegetation	10	11	12	13	14	15	16	17
Ground	*Pteridium Poa	*Poa Lomandra Pteridium Smilax Eustrephus	**Pteridium **Poa *Smilax	**Pteridium **Poa *Smilax	**Poa **Pteridium Smilax	*Pteridium *Poa *Smilax Lomandra	**Poa *Lomandra *Pteridium	**Poa **Pteridium *Lomandra
Shrub	**Lomatia *Coprosma	**Lomatia A. dealbata	A. dealbata Lomatia	*A. dealbata Coprosma	*Lomatia A. dealbata	**Leptospermum **Lomatia A. dealbata Coprosma	*A. dealbata *Lomatia	A. dealbata Exocarpus Lomatia

Vegetation	18	19	20	21	22	23	24	25
Ground	**Poa **Lomandra Pteridium	**Poa **Pteridium Lomandra	**Poa **Lomandra Pteridium	**Poa	Poa Pteridium	**Poa	*Poa	*Poa
Shrub	**Lomatia **A. dealbata Hibbertia	**A. dealbata **Lomatia	**A. dealbata	**Leptospermum A. melanoxolyn *Coprosma	**Leptospermum A. melanoxolyn Coprosma	**Leptospermum A. dealbata Coprosma Leucopogan	**Leptospermum A. melanoxolyn E. stellulata	**Leptospermum A. melanoxolyn

Appendix 3: Number of Eucalypts with Diameter at Breast Height (dbh) > 50cm and the Number of Stumps Found in Each Vegetation Type

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	1	2	3	4	5	6	7	8	9	10	11	12	13
Approx. Slope	5	0	5	5	5	0-5	0-5	5	15-20	15	5	5	10
Aspect	SW	E	E	SE	SW	S	W	W	S	S	S	W	W
No. Eucalypts dbh >50cm	6	10	8	16	8	7	4	3	11	10	8	5	13
# of stumps	5	0	0	0	0	0	0	0	0	0	0	0	0

	14	15	16	17	18	19	20	21	22	23	24	25
Approx. Slope	0-5	0-5	0-5	5	0-5	0-5	5	5	0-5	5	5	5
Aspect	SW	NW	NW	S	W-SW	W	W	NW	N	SW	SW	NW
No. Eucalypts dbh >50cm	11	13	11	8	12	8	11	8	2	7	5	6
# of stumps	0	1	0	0	0	0	0	0	0	0	0	0

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	1	2	3	4	5	6	7	8	9	10	11	12	13
Approx. Slope	0-5	0-5	0-5	0-5	5-10	5	15	5	5-10	15	5	0-5	0
Aspect	S	S	SW	SW	SW	W	NW	SW	SW	W	W	NE	-
No. Eucalypts dbh >50cm	10	11	15	10	9	4	5	8	7	8	9	3	3
# of stumps	1	0	0	2	0	0	0	0	0	0	0	3	0

	14	15	16	17	18	19	20	21	22	23	24	25
Approx. Slope	0-7	0	5-10	5	0-5	10	5	0-5	0-5	0	0	0-5
Aspect	SW	-	W	S	S	E	W	SW	SW	-	-	SW
No. Eucalypts dbh >50cm	13	6	6	5	8	15	?	7	4	5	3	3
# of stumps	0	0	0	0	0	0	?	0	0	0	0	0

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	1	2	3	4	5	6	7	8	9	10	11	12	13
Approx. Slope	0-5	0-5	5	5	5	5	0	0-5	0	0-5	0	5	5
Aspect	W	SW-W	SW	W	W	W	-	W	-	W	-	S	SW
No. Eucalypts dbh >50cm	8	7	11	7	11	11	6	7	12	6	18	11	9
# of stumps	0	0	0	0	0	0	0	0	0	0	1	0	0

	14	15	16	17	18	19	20	21	22	23	24	25
Approx. Slope	5-10	5-10	5	5	15-20	0-5	5	5	0-5	0-5	0-5	0
Aspect	S	S-SW	S	S-SE	S-SE	SW	SW	SW	W	W	N	-
No. Eucalypts dbh >50cm	6	5	10	5	11	12	4	9	8	10	3	7
# of stumps	0	0	0	0	0	0	0	0	0	0	0	0

167

	1	2	3	4	5	6	7	8	9	10	11	12	13
Approx. Slope	0	0-5	5	10-15	5-10	15	0	5	10-15	0-5	5	5	5
Aspect	-	W	N	N	N	NW	-	W	W	SW	W	W	W
No. Eucalypts dbh >50cm	12	6	6	12	7	4	9	4	7	8	8	7	9
# of stumps	0	0	0	0	0	0	0	0	0	0	0	0	0

	14	15	16	17	18	19	20	21	22	23	24	25
Approx. Slope	5-10	5	0	0-5	10	5	5	0-5	0-5	0	0	5
Aspect	SW	W	-	W	SW	W	W	SW	S	-	-	SW
No. Eucalypts dbh >50cm	8	11	6	7	5	4	8	9	7	13	7	9
# of stumps	0	0	0	0	0	0	0	0	0	0	0	0

SB

	1	2	3	4	5	6	7	8	9	10	11	12	13
Approx. Slope	0	10	5	5	5	5	10	10	10	20	5	15	15
Aspect	-	NW	W	W	NW	NW	N	N	N	N	N	N	NE
No. Eucalypts dbh >50cm	8	4	5	5	7	10	7	4	5	4	8	5	5
# of stumps	8	1	1	1	2	0	2	4	3	1	2	1	2

	14	15	16	17	18	19	20	21	22	23	24	25
Approx. Slope	10	15	10	0-5	5	0	10	20	15	10	0	0
Aspect	N	NW	NW	N	N	-	N	NE	NW	NE	-	-
No. Eucalypts dbh >50cm	8	6	6	5	?	4	2	4	5	4	5	2
# of stumps	1	2	0	0	?	4	4	1	6	2	3	1

Creek

	1	2	3	4	5	6	7	8	9	10	11	12	13
Approx. Slope	10	5	10	5	5	5	0	0	0-5	5	5-10	0	0
Aspect	NW	NW	NW	NW	NW	N	-	-	SE	S	S	-	-
No. Eucalypts dbh >50cm	5	5	5	8	2	7	5	7	16	9	7	16	9
# of stumps	0	0	0	1	2	3	5	1	0	0	0	0	0

	14	15	16	17	18	19	20	21	22	23	24	25
Approx. Slope	0	5	5	5	5-10	5	10	0-5	5	0	0	0
Aspect	-	S	W	W	NW	W	S-SW	NW	N	-	-	-
No. Eucalypts dbh >50cm	7	6	24	15	14	11	7	3	4	2	2	4
# of stumps	0	0	0	0	0	0	0	0	0	0	0	0

Appendix 4: Analysis of Variance Tables Testing for Significance of the Effect of Vegetation Type on (a) Log of Litter Fuel Loads, (b) Shrub Fuel Loads, (c) Total Fuel Loads, (d) Mammal Habitat Complexity Scores, and (e) Bird Habitat Complexity Scores.

(a)

Source	DF	Sum of Squares	Mean Square	F Ratio	Prob>F
Veg Type	5	19.65	3.53	2.44	0.0369
Error	144	280.00	1.44		
Total	149	225.65			

(b)

Source	DF	Sum of Squares	Mean Square	F Ratio	Prob>F
Veg Type	5	1.54	0.31	2.46	0.0358
Error	144	18.04	0.13		
Total	149	19.58			

(c)

Source	DF	Sum of Squares	Mean Square	F Ratio	Prob>F
Veg Type	5	0.64	0.13	1.40	0.2266
Error	144	13.11	0.09		
Total	149	13.74			

(d)

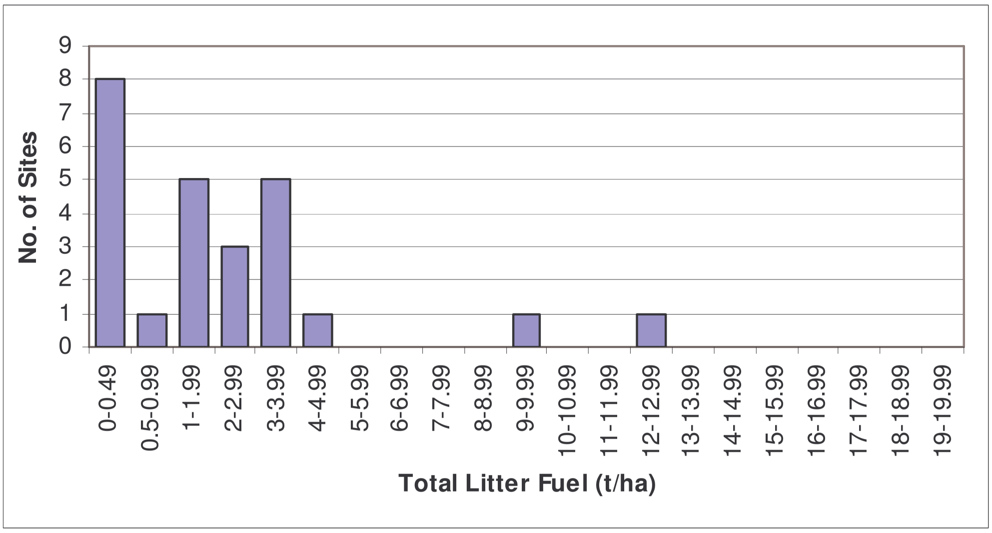
Source	DF	Sum of Squares	Mean Square	F Ratio	Prob>F
Veg Type	5	58.03	11.61	10.81	<0.0001
Error	144	154.56	1.07		
Total	149	212.59			

(e)

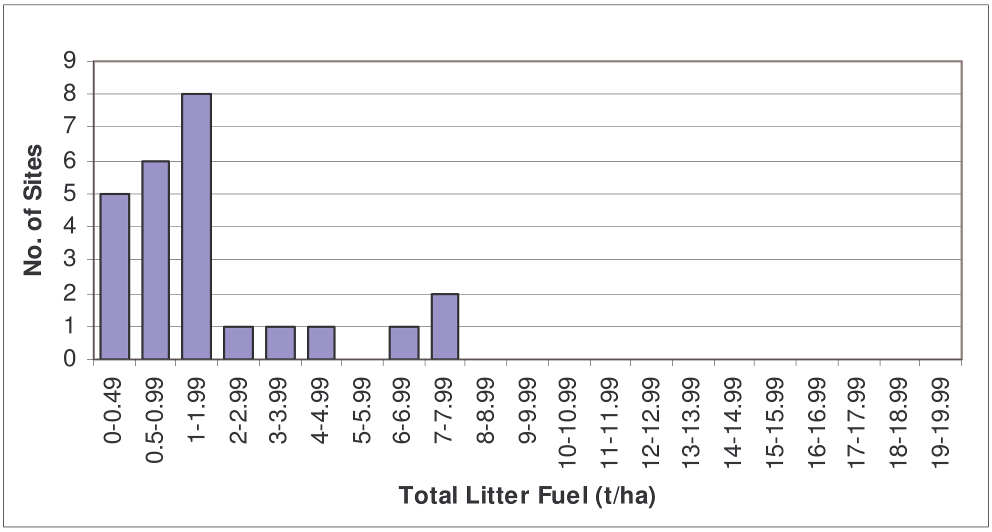
Source	DF	Sum of Squares	Mean Square	F Ratio	Prob>F
Veg Type	5	98.53	19.71	11.23	<0.0001
Error	144	525.80	1.76		
Total	149	351.33			

Appendix 5: Litter Fuel Loads (t/ha) for all Sites in Vegetation Types (a) 138, (b) 140, (c)159, (d) 167, (e) SB and (f) Creek.

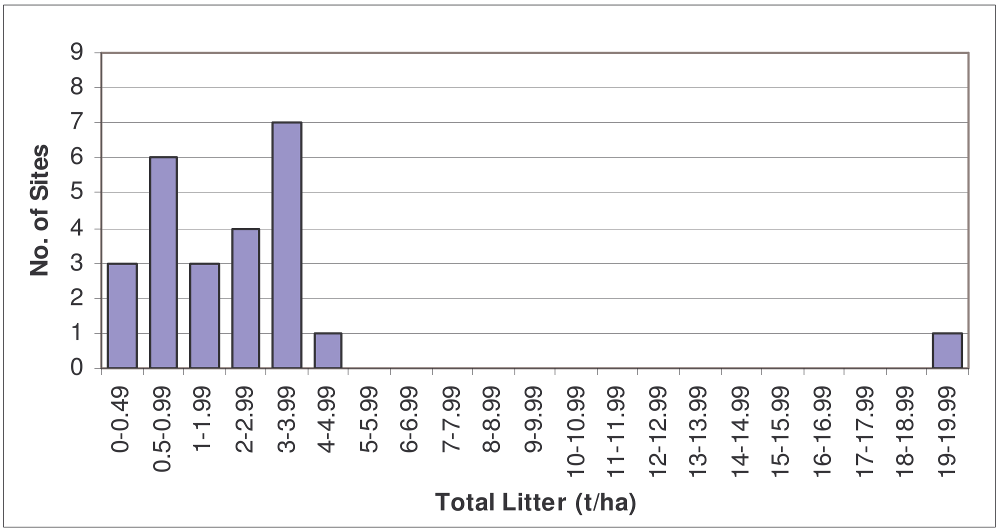
(a)



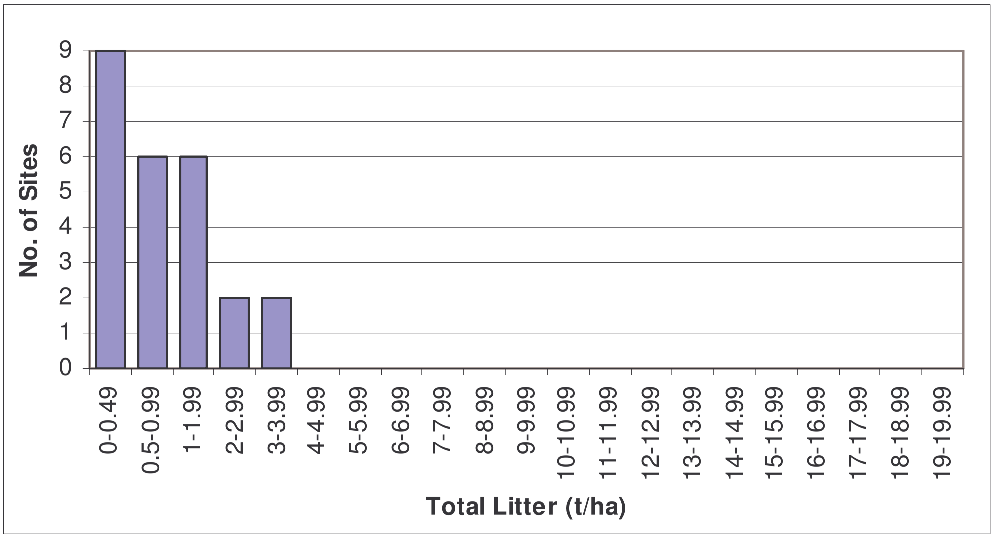
(b)



(c)

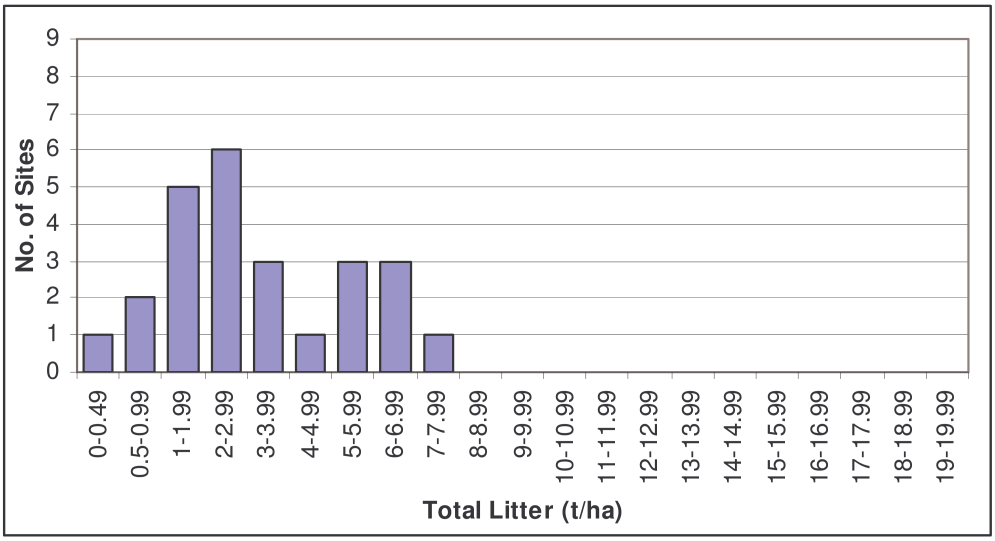


(d)



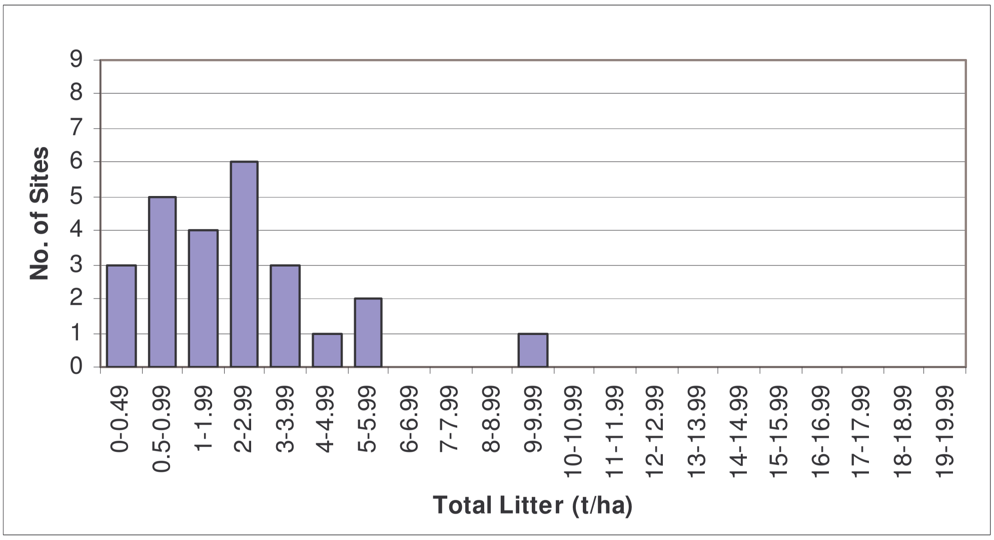
No. of Sites
0
1
2
3
4
5
6
7
8
9
0-0.49
0.5-0.99
1-1.99
2-2.99
3-3.99
4-4.99
5-5.99
6-6.99
7-7.99
8-8.99
9-9.99
10-10.99
11-11.99
12-12.99
13-13.99
14-14.99
15-15.99
16-16.99
17-17.99
18-18.99
19-19.99
Total Litter (t/ha)

(e)



No. of Sites
0
1
2
3
4
5
6
7
8
9
0-0.49
0.5-0.99
1-1.99
2-2.99
3-3.99
4-4.99
5-5.99
6-6.99
7-7.99
8-8.99
9-9.99
10-10.99
11-11.99
12-12.99
13-13.99
14-14.99
15-15.99
16-16.99
17-17.99
18-18.99
19-19.99
Total Litter (t/ha)

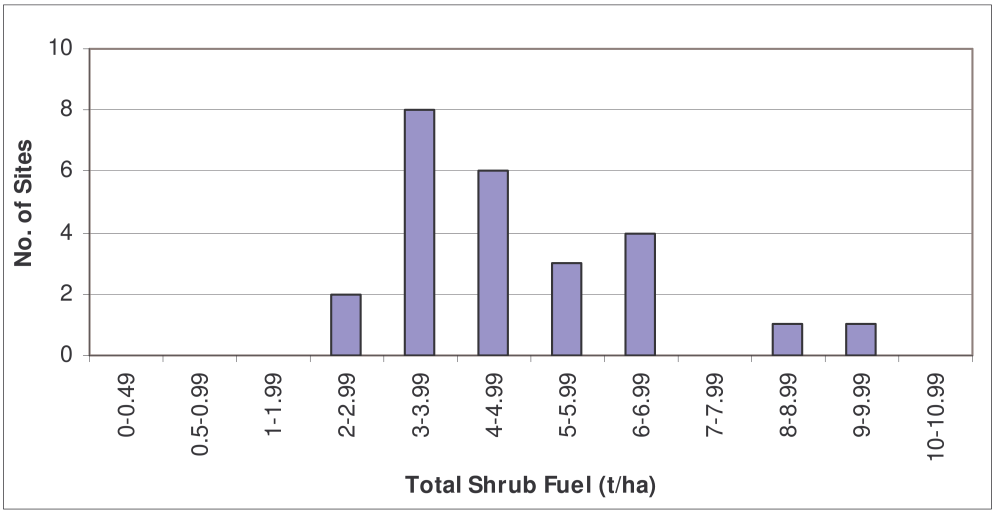
(f)



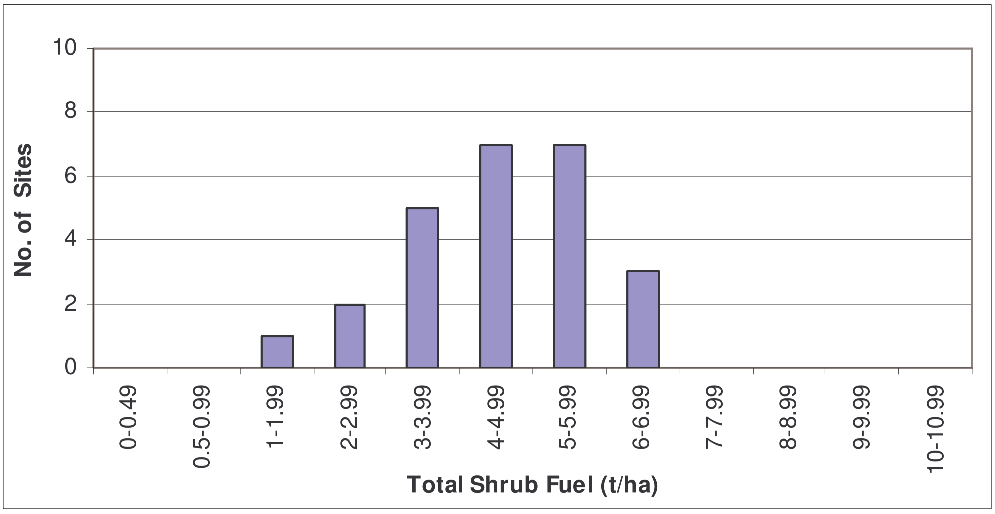
No. of Sites
0
1
2
3
4
5
6
7
8
9
0-0.49
0.5-0.99
1-1.99
2-2.99
3-3.99
4-4.99
5-5.99
6-6.99
7-7.99
8-8.99
9-9.99
10-10.99
11-11.99
12-12.99
13-13.99
14-14.99
15-15.99
16-16.99
17-17.99
18-18.99
19-19.99
Total Litter (t/ha)

Appendix 6: Shrub Fuel Loads (t/ha) for all Sites in Vegetation Types (a) 138, (b) 140, (c)159, (d) 167, (e) SB and (f) Creek.

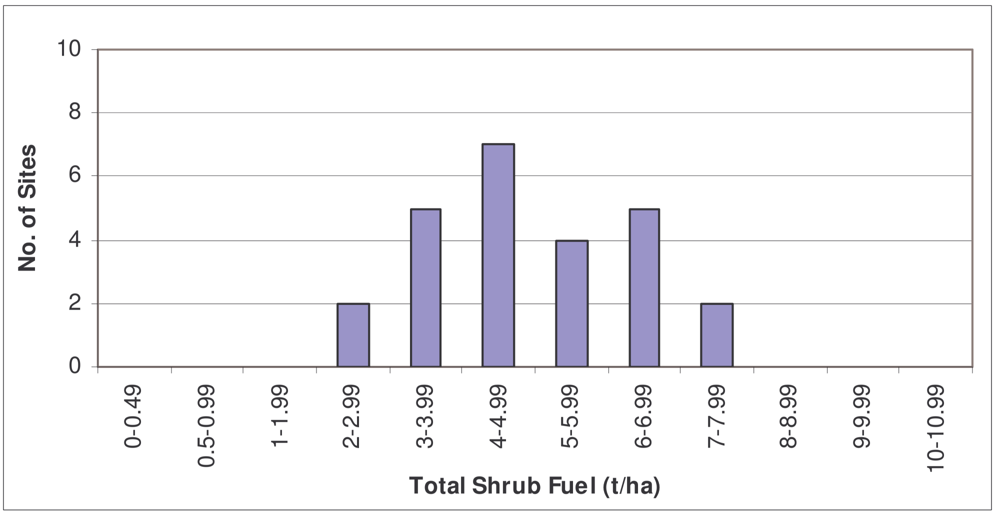
(a)



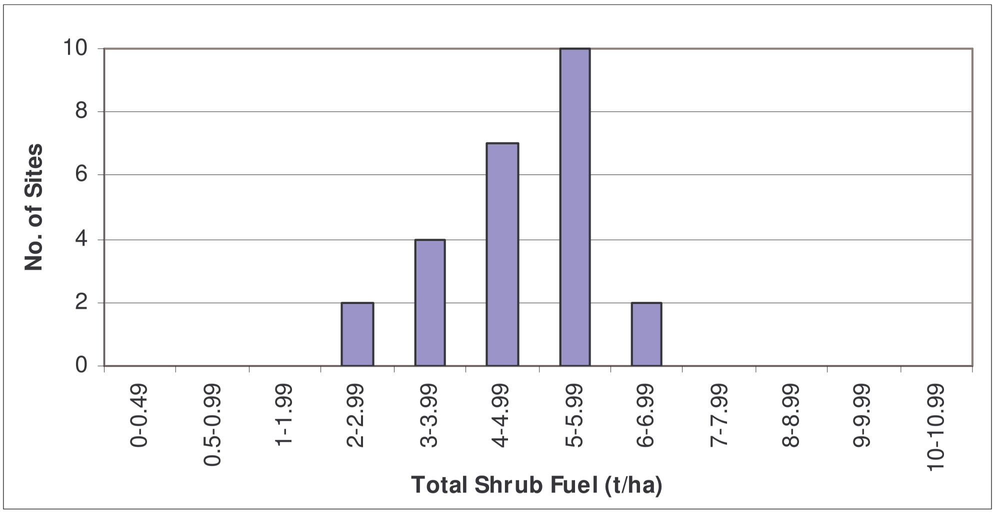
(b)



(c)

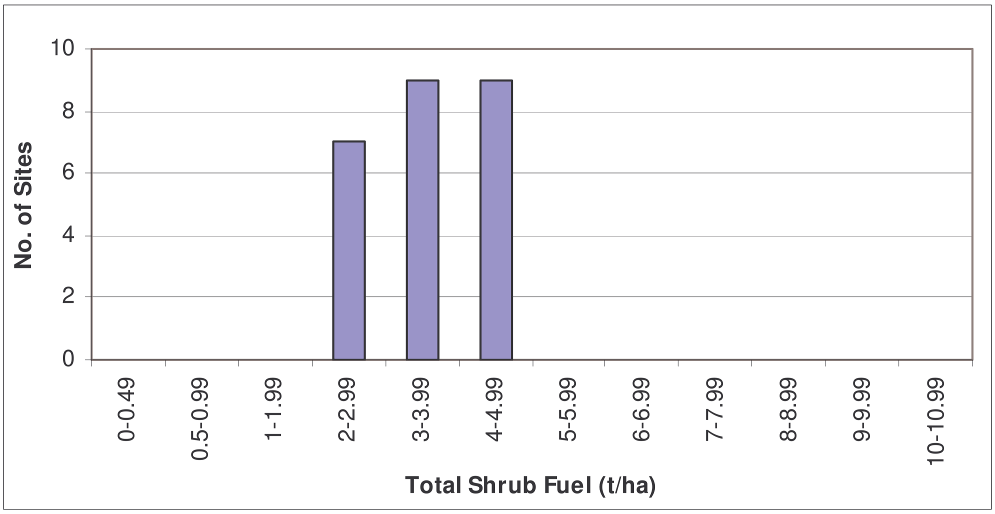


(d)



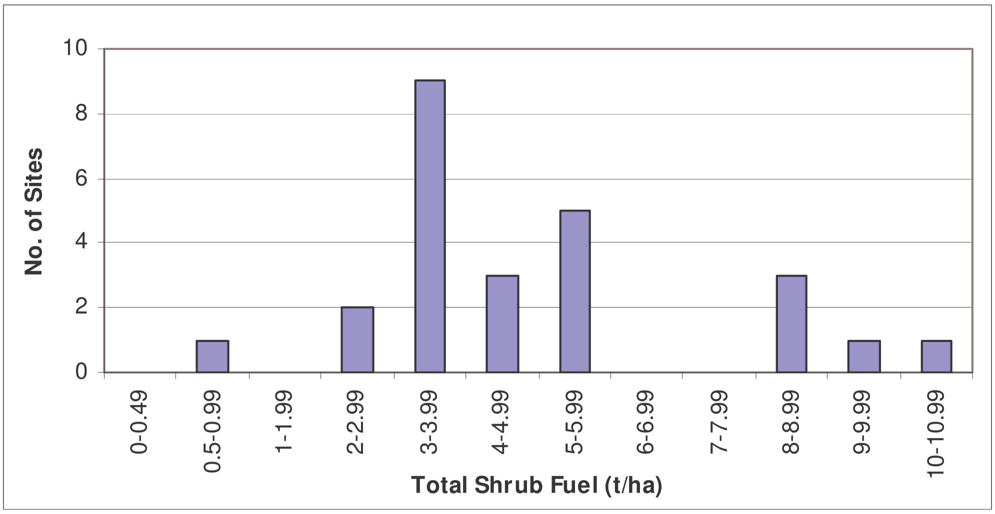
No. of Sites
10
8
6
4
2
0
0-0.49
0.5-0.99
1-1.99
2-2.99
3-3.99
4-4.99
5-5.99
6-6.99
7-7.99
8-8.99
9-9.99
10-10.99
Total Shrub Fuel (t/ha)

(e)



No. of Sites
10
8
6
4
2
0
0-0.49
0.5-0.99
1-1.99
2-2.99
3-3.99
4-4.99
5-5.99
6-6.99
7-7.99
8-8.99
9-9.99
10-10.99
Total Shrub Fuel (t/ha)

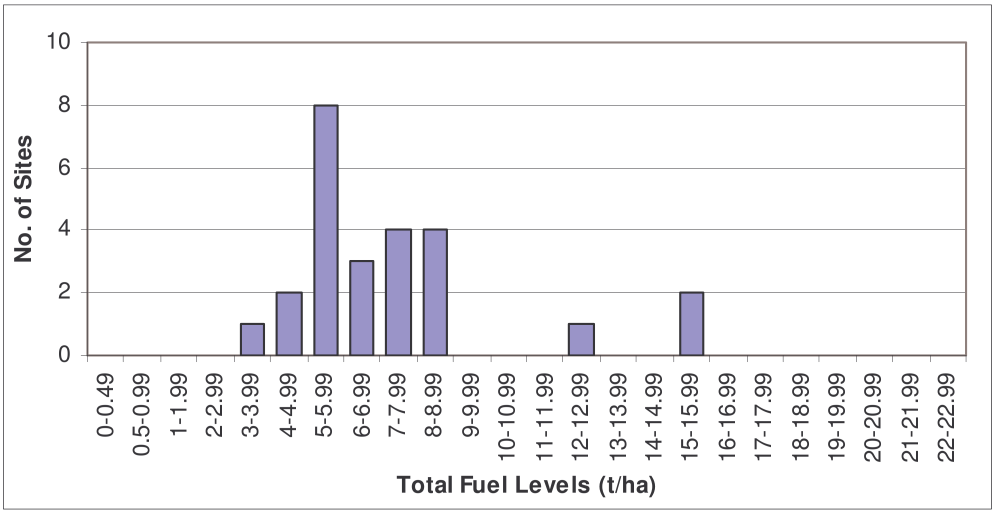
(f)



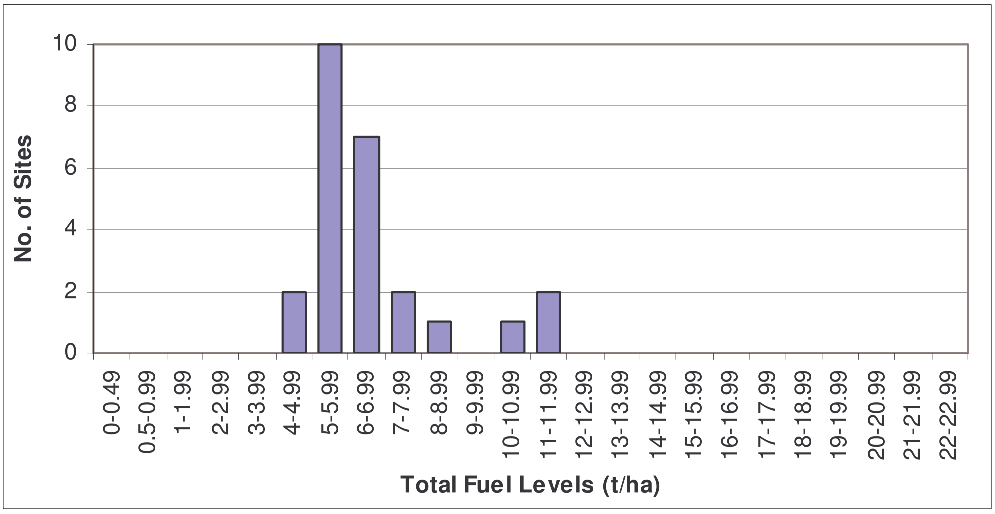
No. of Sites
10
8
6
4
2
0
0-0.49
0.5-0.99
1-1.99
2-2.99
3-3.99
4-4.99
5-5.99
6-6.99
7-7.99
8-8.99
9-9.99
10-10.99
Total Shrub Fuel (t/ha)

Appendix 7: Total Fuel Loads (t/ha) for all Sites in Vegetation Types (a) 138, (b) 140, (c)159, (d) 167, (e) SB and (f) Creek.

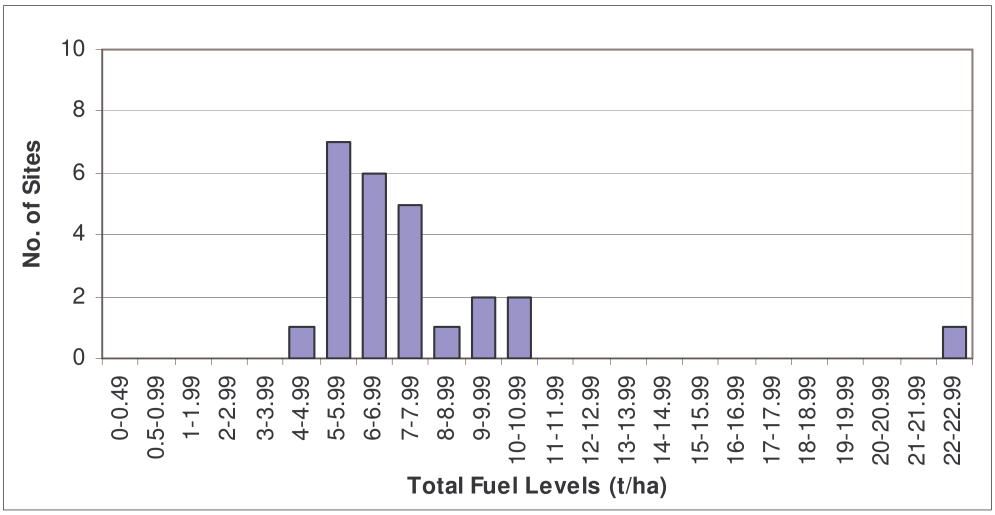
(a)



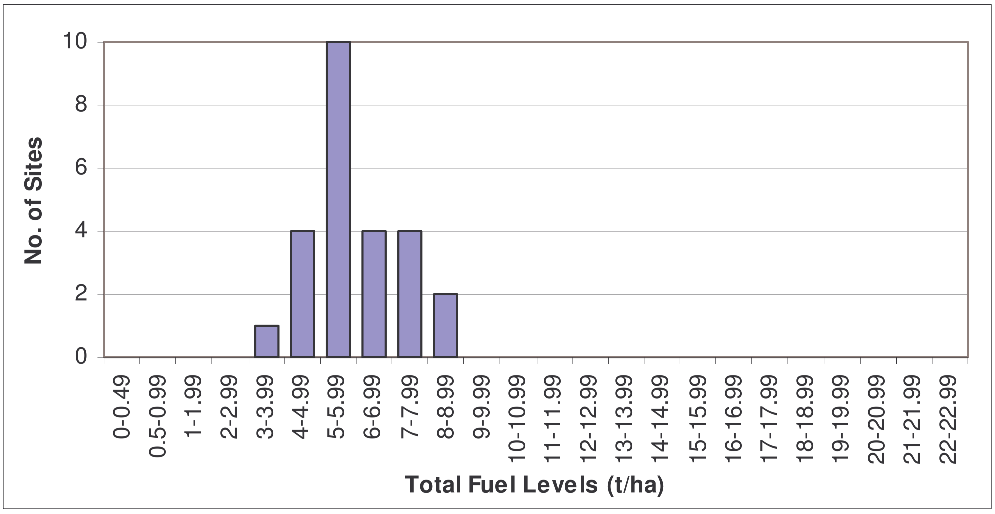
(b)



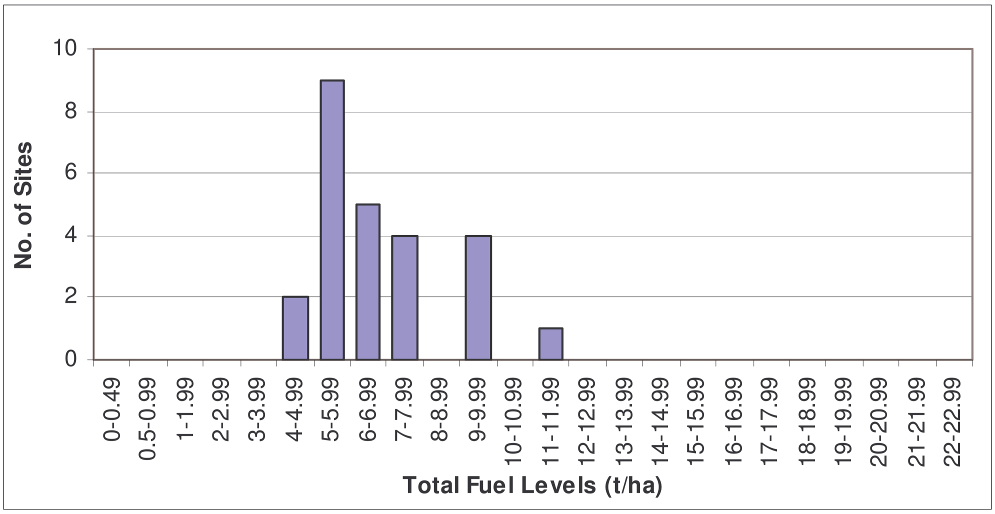
(c)



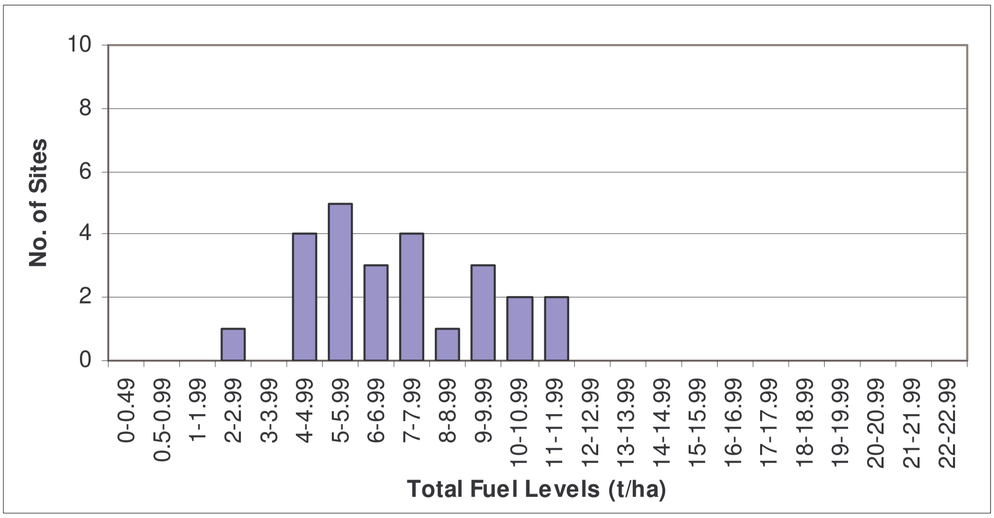
(d)


No. of Sites
Total Fuel Levels (t/ha)
0
2
4
6
8
10
0-0.49
0.5-0.99
1-1.99
2-2.99
3-3.99
4-4.99
5-5.99
6-6.99
7-7.99
8-8.99
9-9.99
10-10.99
11-11.99
12-12.99
13-13.99
14-14.99
15-15.99
16-16.99
17-17.99
18-18.99
19-19.99
20-20.99
21-21.99
22-22.99

(e)

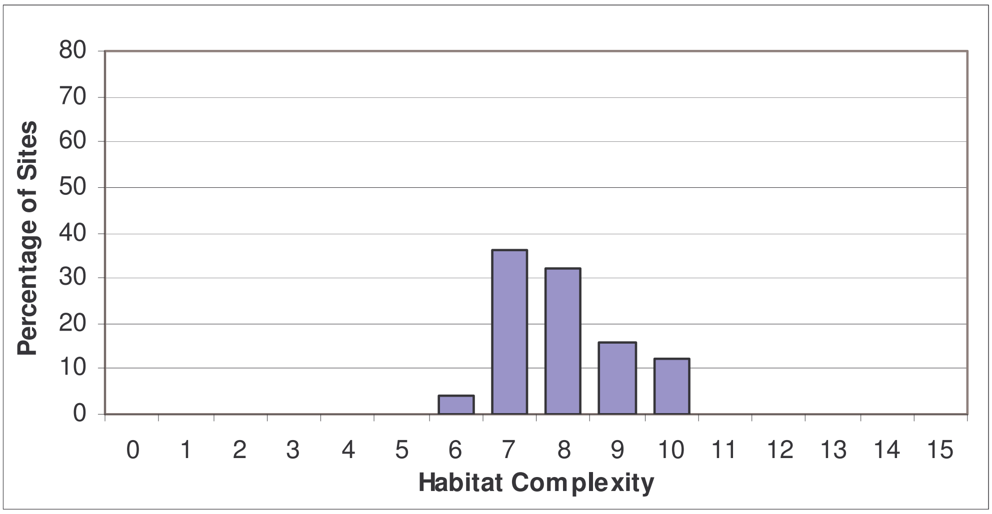

No. of Sites
Total Fuel Levels (t/ha)
0
2
4
6
8
10
0-0.49
0.5-0.99
1-1.99
2-2.99
3-3.99
4-4.99
5-5.99
6-6.99
7-7.99
8-8.99
9-9.99
10-10.99
11-11.99
12-12.99
13-13.99
14-14.99
15-15.99
16-16.99
17-17.99
18-18.99
19-19.99
20-20.99
21-21.99
22-22.99

(f)

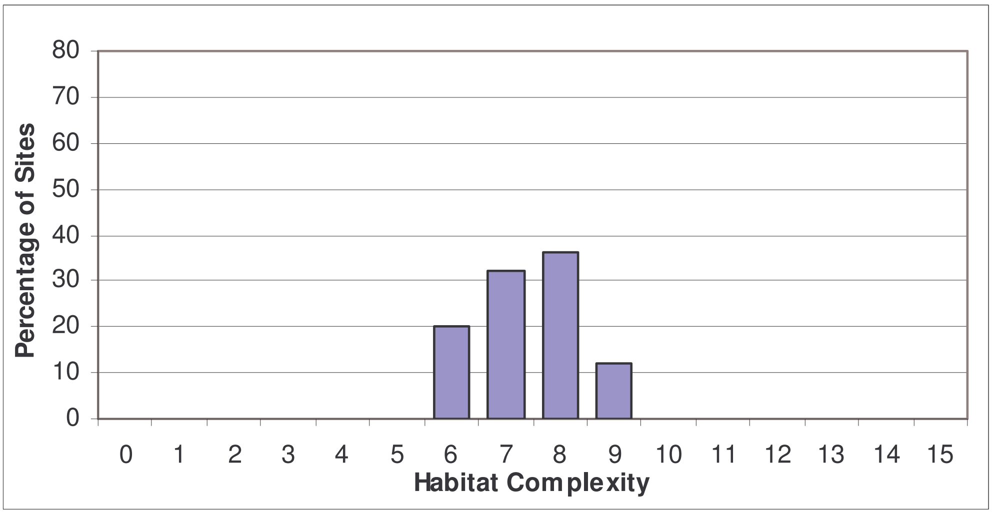

No. of Sites
Total Fuel Levels (t/ha)
0
2
4
6
8
10
0-0.49
0.5-0.99
1-1.99
2-2.99
3-3.99
4-4.99
5-5.99
6-6.99
7-7.99
8-8.99
9-9.99
10-10.99
11-11.99
12-12.99
13-13.99
14-14.99
15-15.99
16-16.99
17-17.99
18-18.99
19-19.99
20-20.99
21-21.99
22-22.99

Appendix 8: Percentage of Sites with Mammal Habitat Complexity Scores Ranging Between 0 and 15 for Vegetation Type (a) 138, (b) 140, (c) 159, (d) 167 (e) SB and (f) Creek.

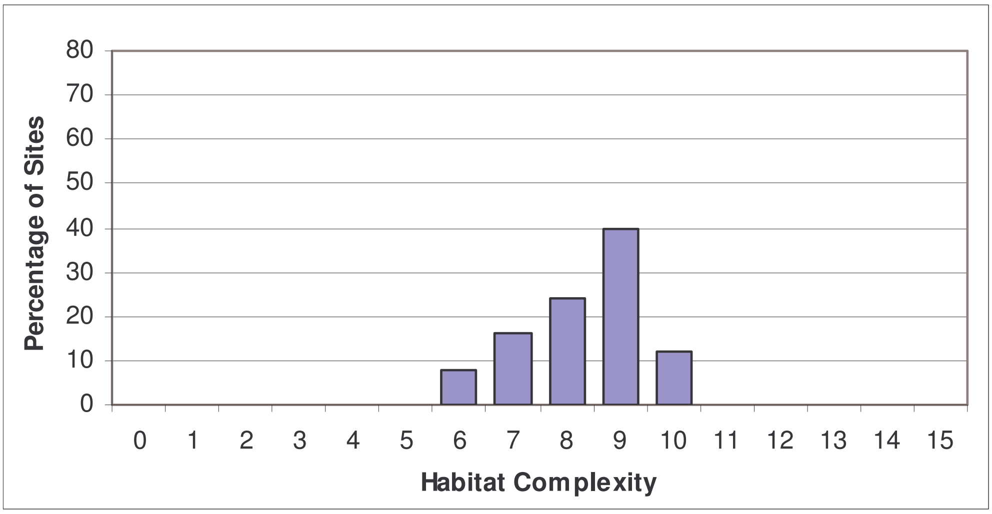
(a)



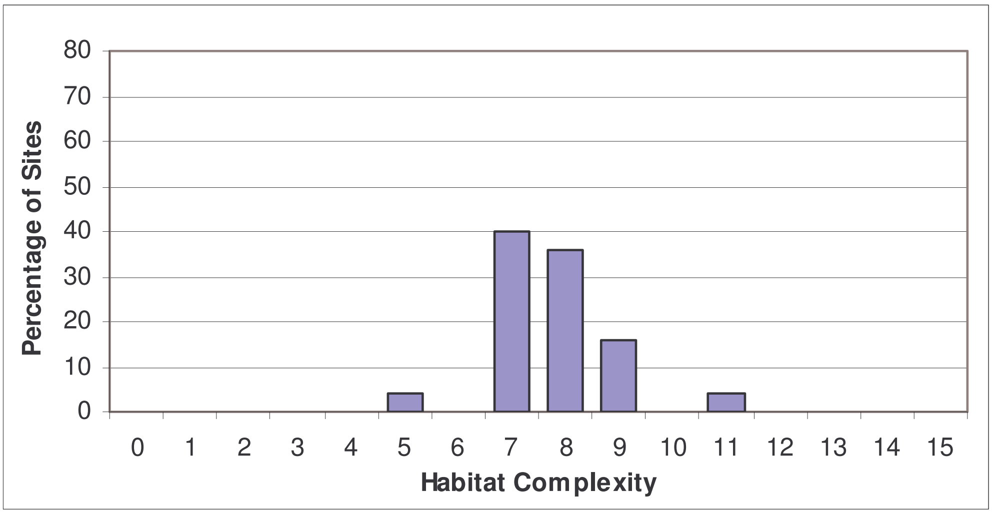
(b)



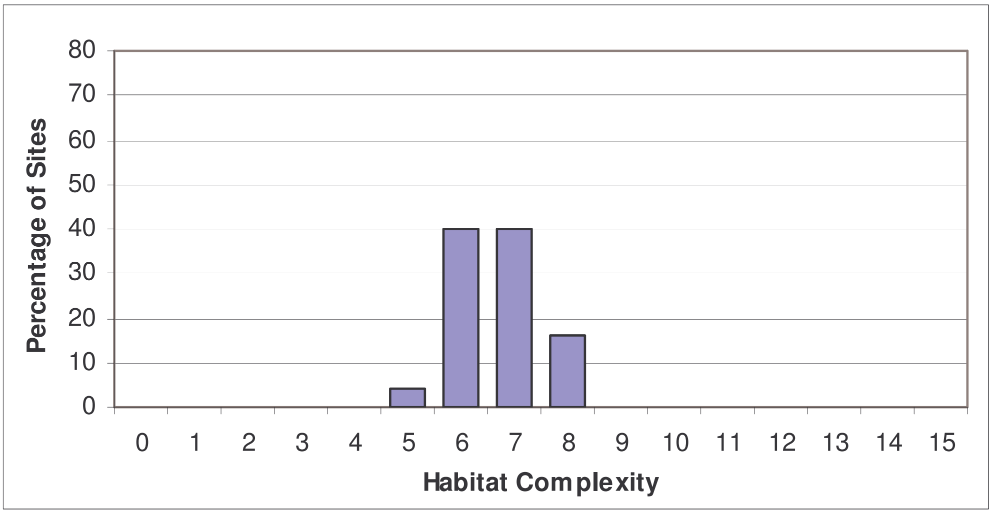
(c)



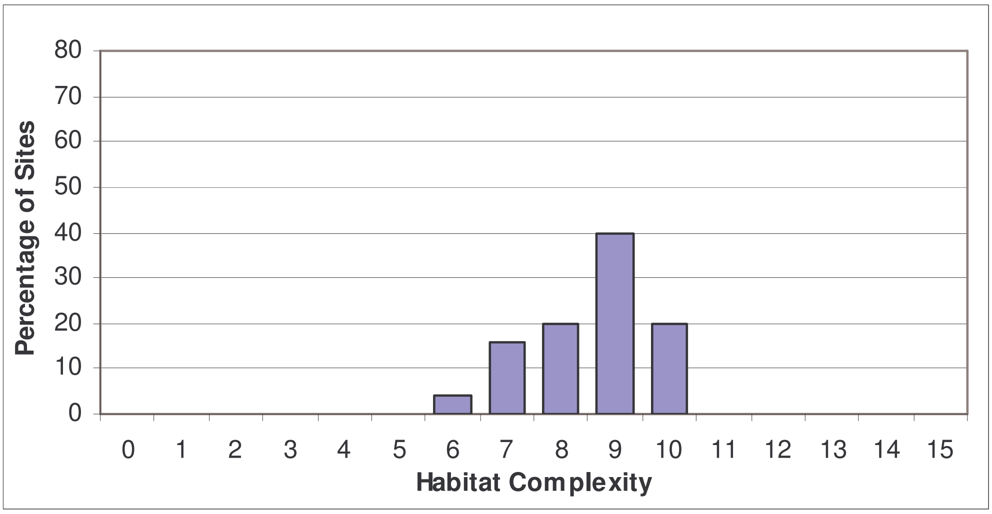
(d)


Percentage of Sites
80
70
60
50
40
30
20
10
0
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15
Habitat Complexity

(e)

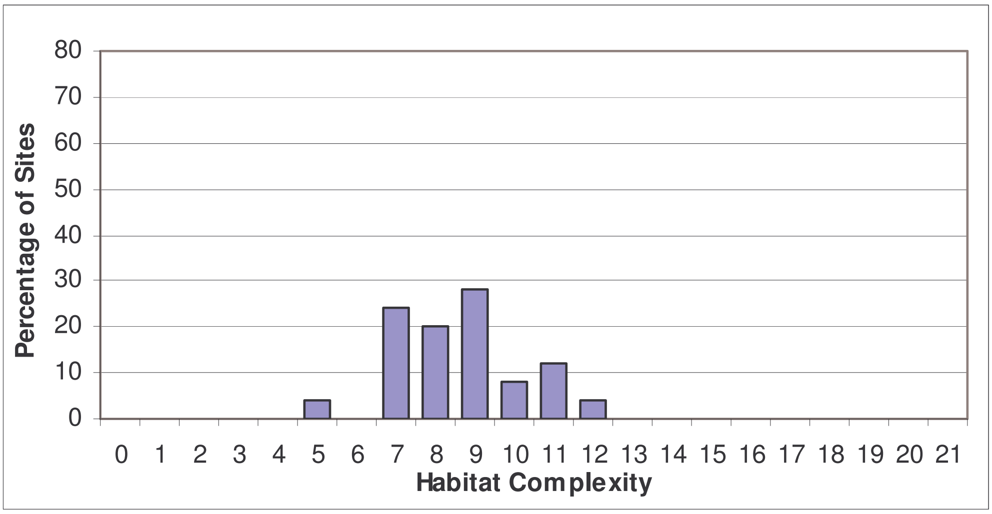

Percentage of Sites
80
70
60
50
40
30
20
10
0
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15
Habitat Complexity

(f)

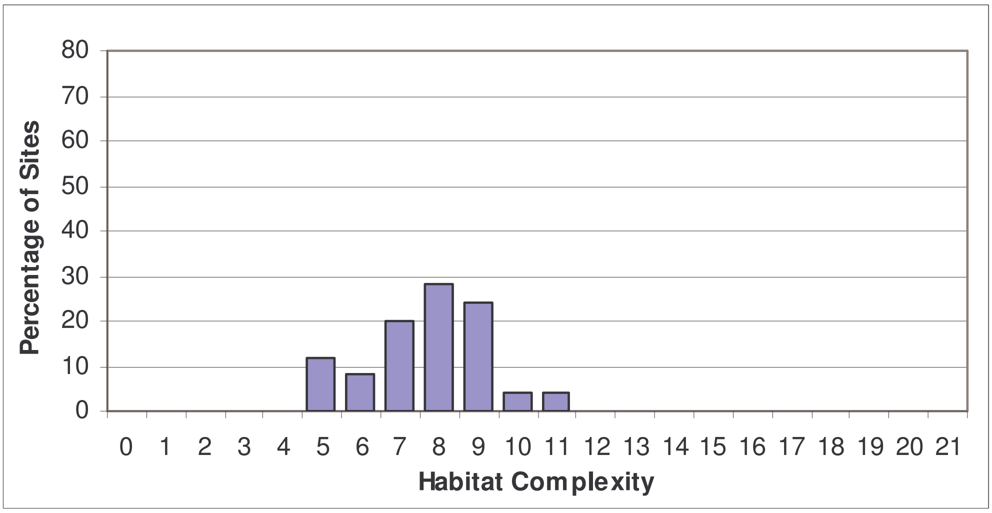

Percentage of Sites
80
70
60
50
40
30
20
10
0
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15
Habitat Complexity

Appendix 9: Percentage of Sites with Bird Habitat Complexity Scores Ranging Between 0 and 21 for Vegetation Type (a) 138, (b) 140, (c) 159, (d) 167 (e) SB and (f) Creek.

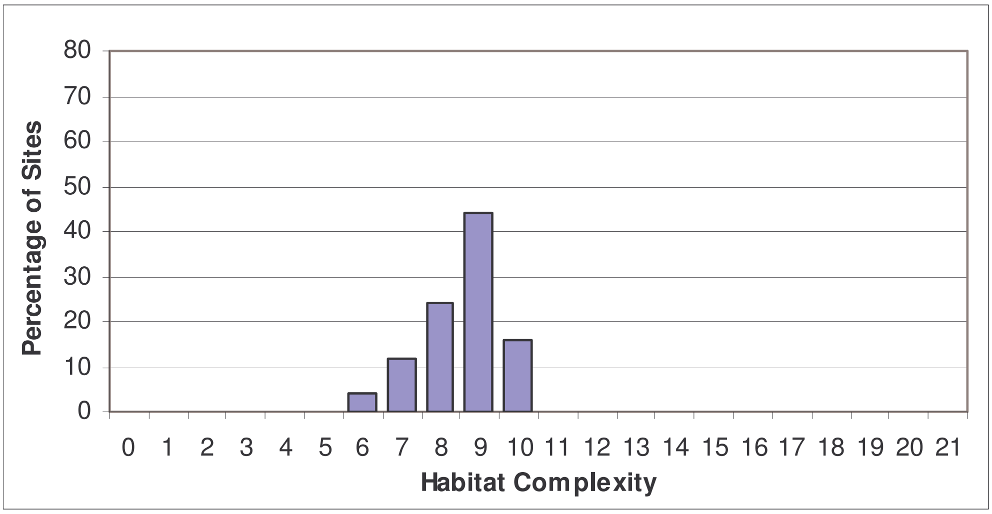
(a)



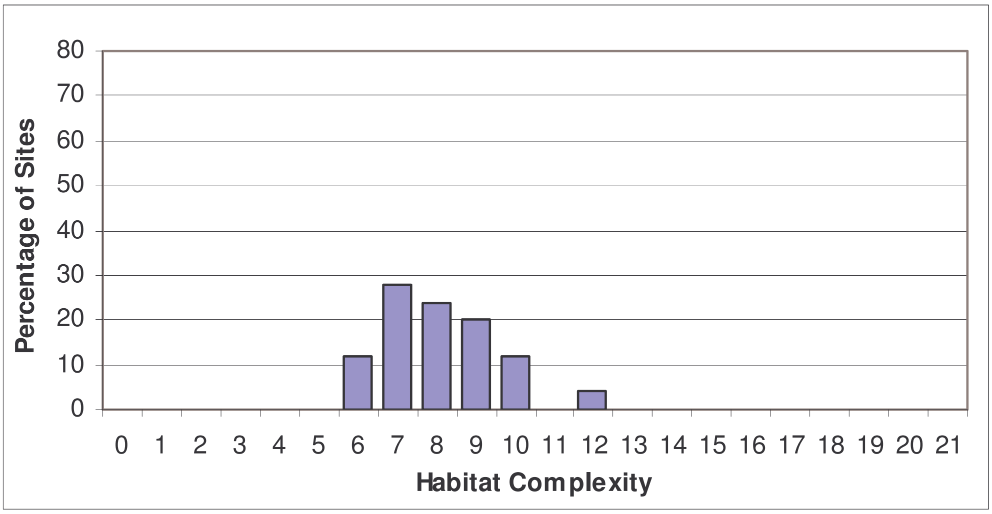
(b)



(c)

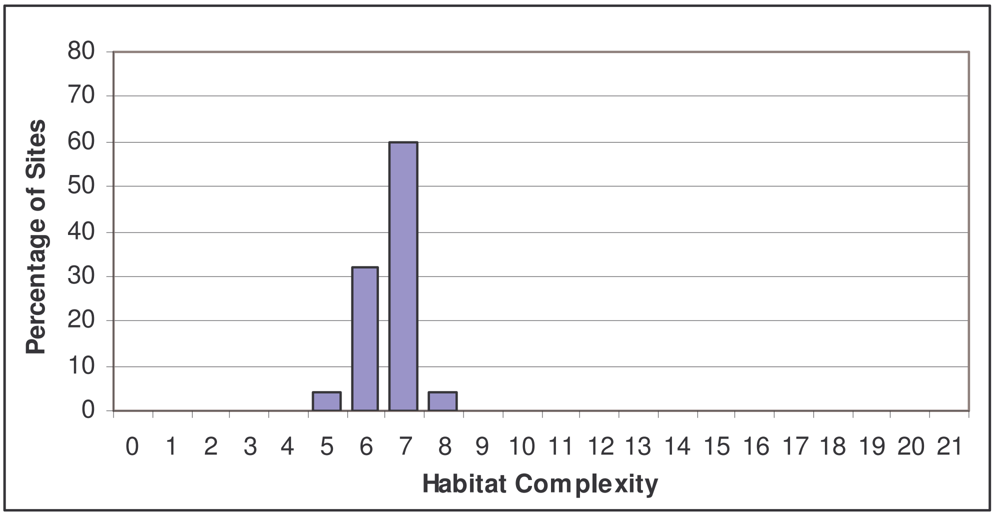


(d)



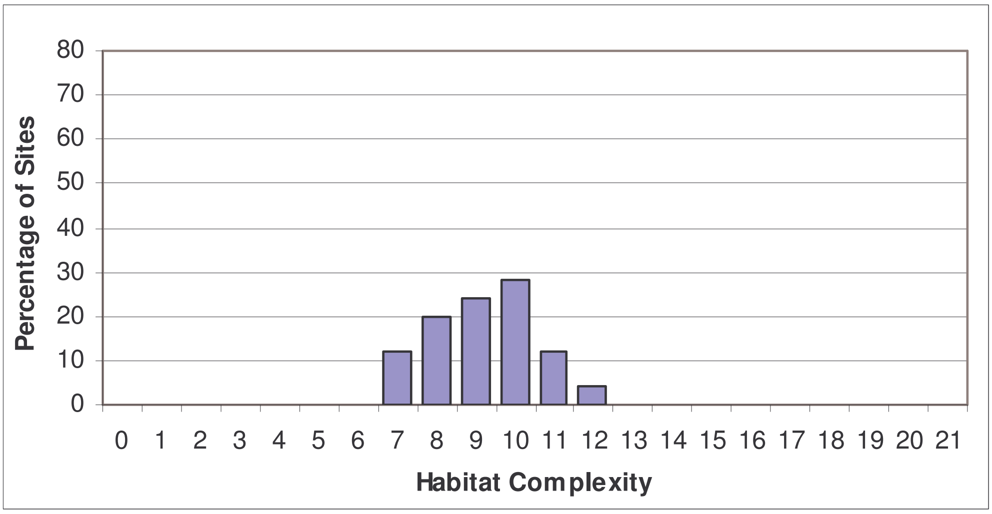
80
70
60
50
40
30
20
10
0
Percentage of Sites
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21
Habitat Complexity

(e)



80
70
60
50
40
30
20
10
0
Percentage of Sites
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21
Habitat Complexity

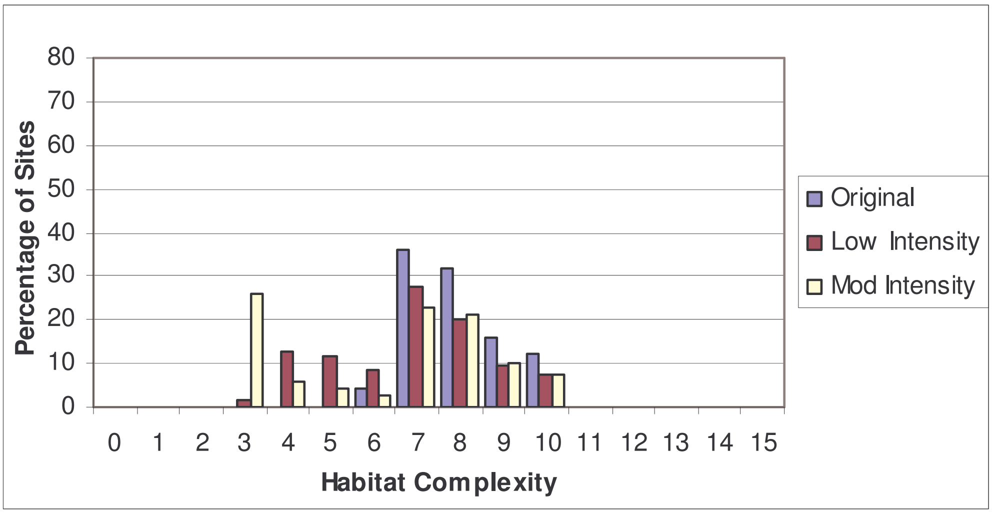
(f)



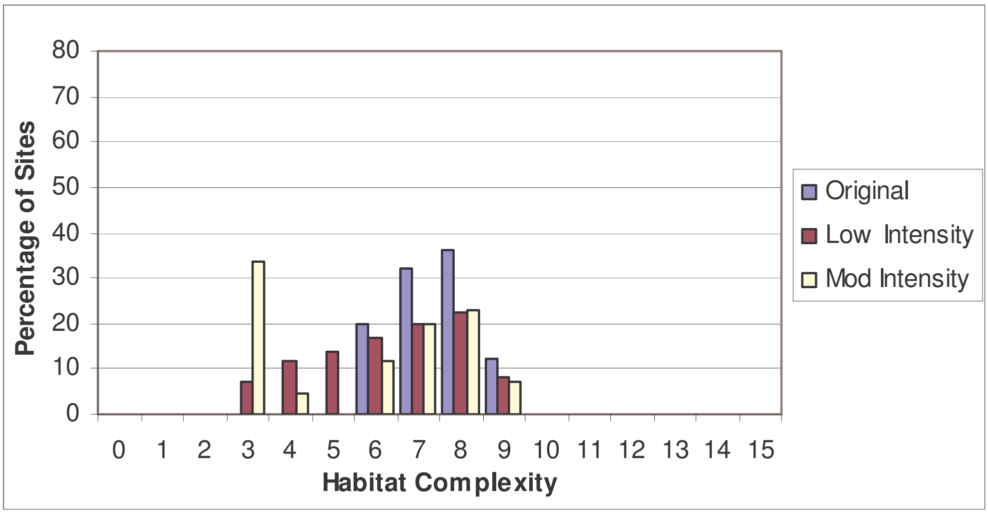
80
70
60
50
40
30
20
10
0
Percentage of Sites
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21
Habitat Complexity

Appendix 10: Mammal Habitat Complexity Before & After Computer Modelled Low & Moderate Intensity 40% Fuel Reduction Burns in vegetation type (a) 138, (b) 140, (c) 159, (d) 167, (e) SB, (f) Creek.

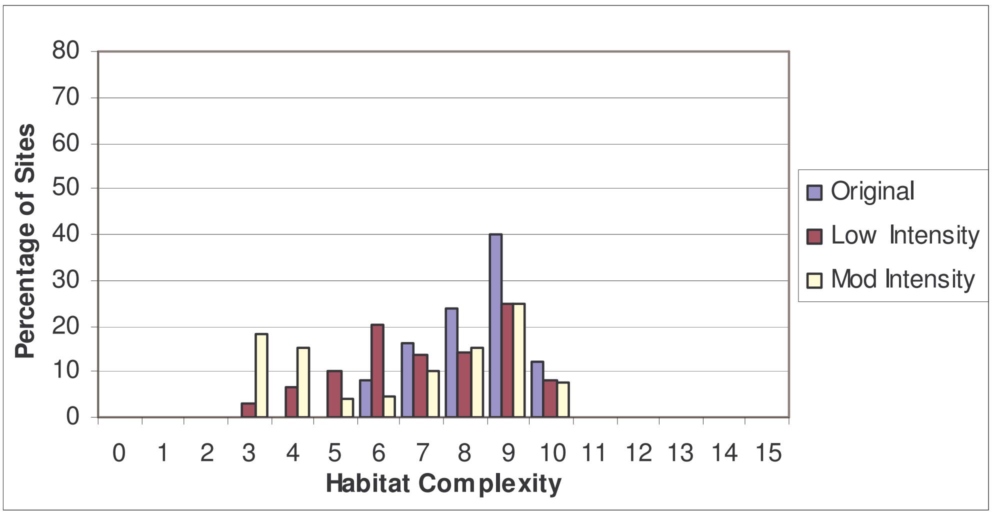
(a)



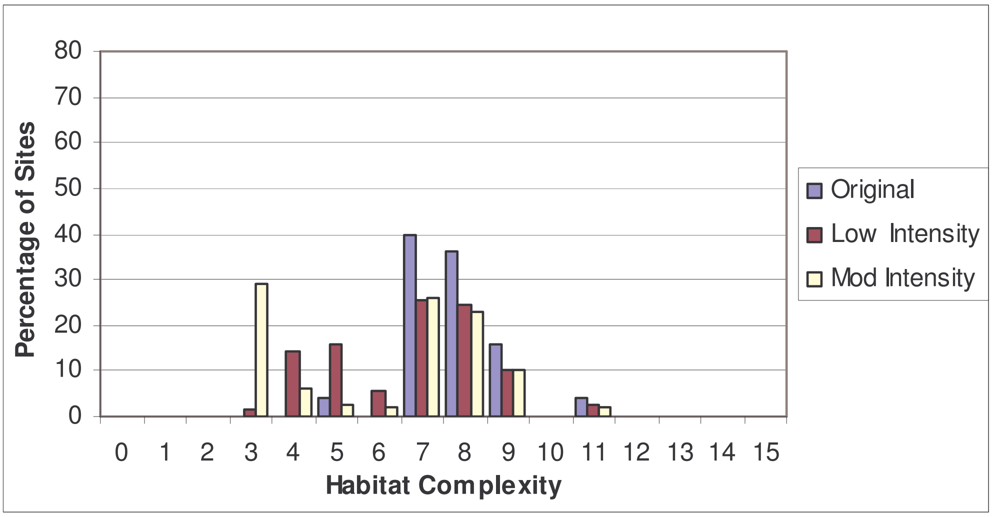
(b)



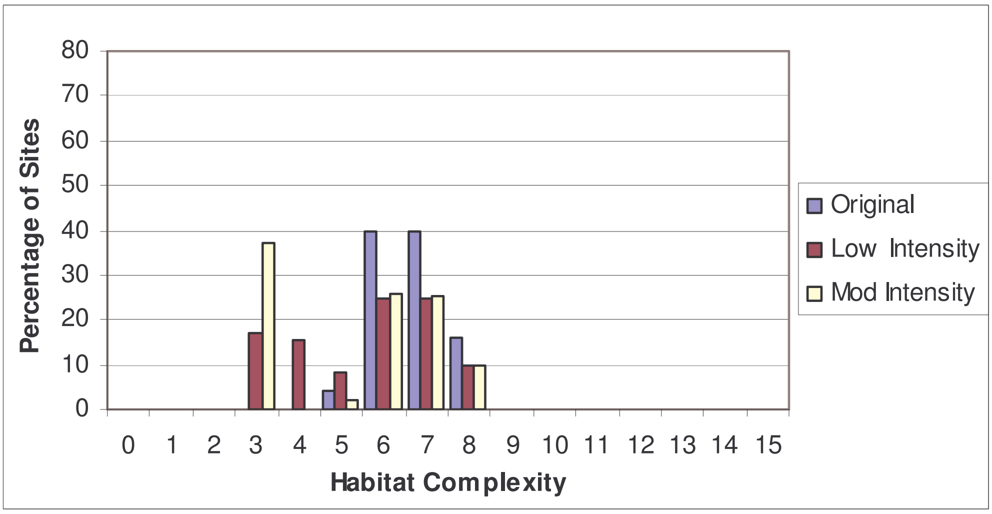
(c)



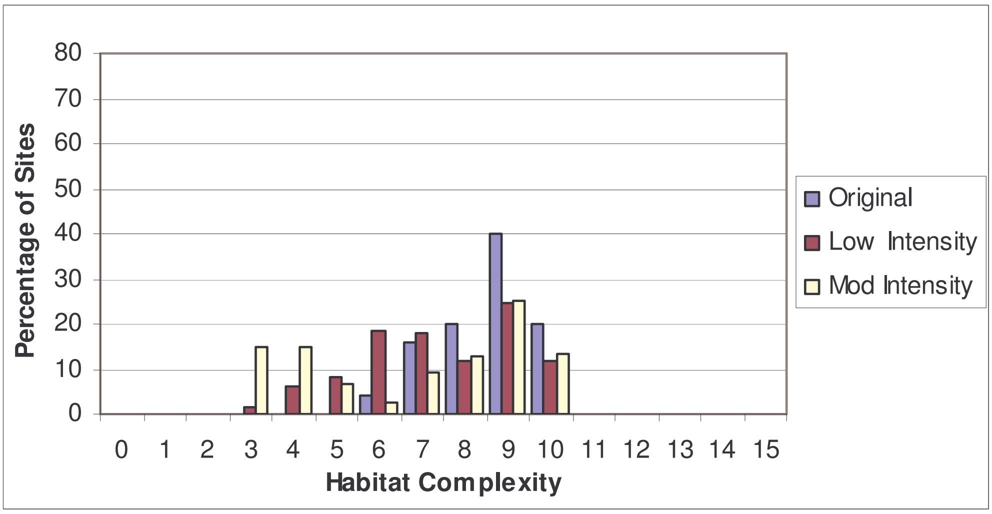
(d)


80
70
60
50
40
30
20
10
0
Percentage of Sites
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15
Habitat Complexity
Original
Low Intensity
Mod Intensity

(e)

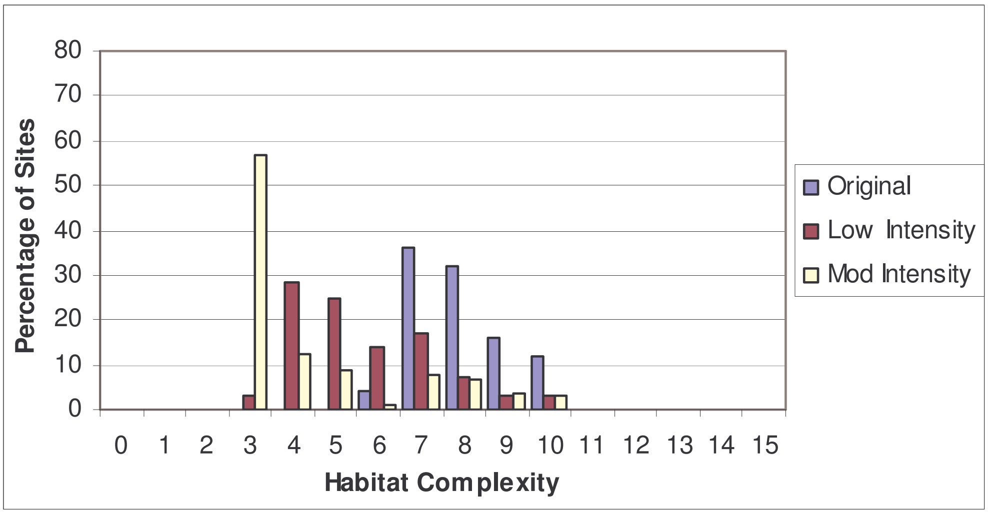

80
70
60
50
40
30
20
10
0
Percentage of Sites
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15
Habitat Complexity
Original
Low Intensity
Mod Intensity

(f)

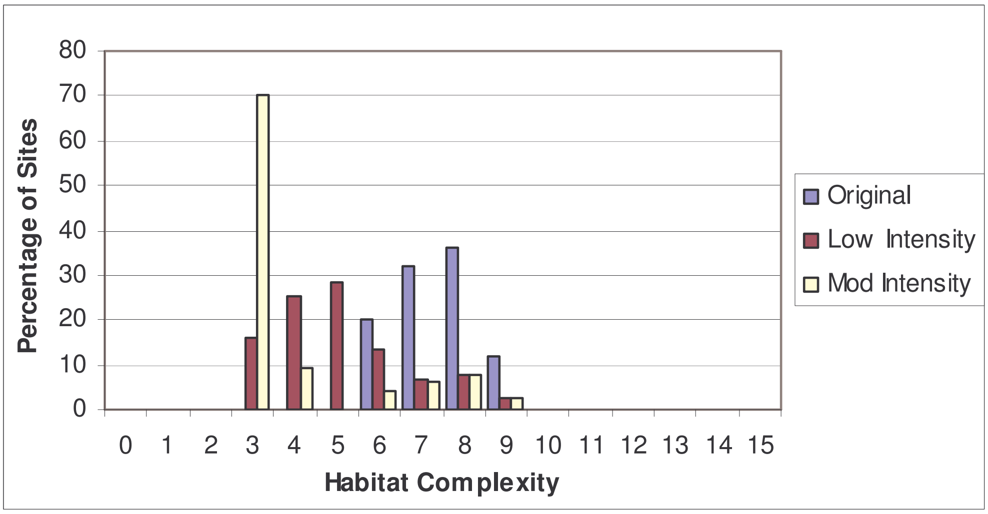

80
70
60
50
40
30
20
10
0
Percentage of Sites
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15
Habitat Complexity
Original
Low Intensity
Mod Intensity

Appendix 11: Mammal Habitat Complexity Before & After Computer Modelled Low & Moderate Intensity 80% Fuel Reduction Burns in vegetation type (a) 138, (b) 140, (c) 159, (d) 167, (e) SB, (f) Creek.

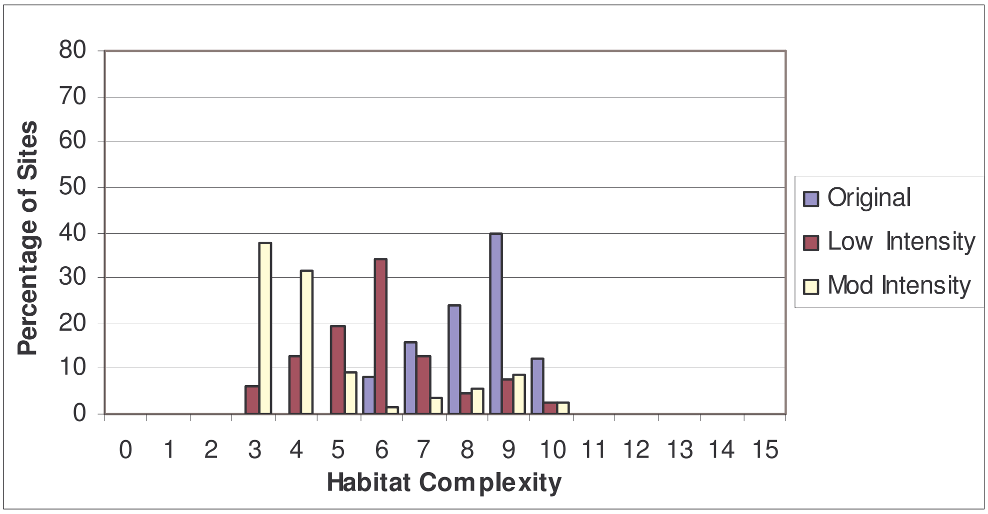
(a)



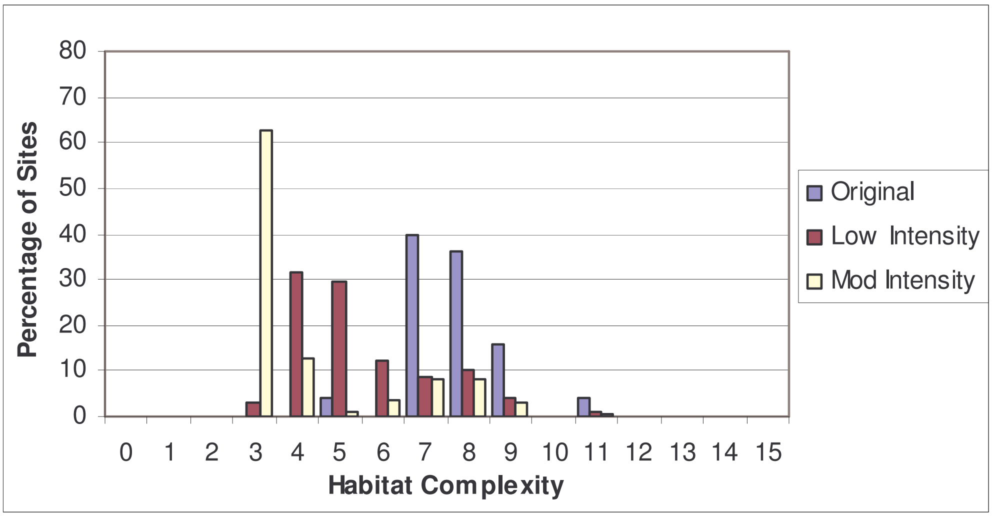
(b)



(c)

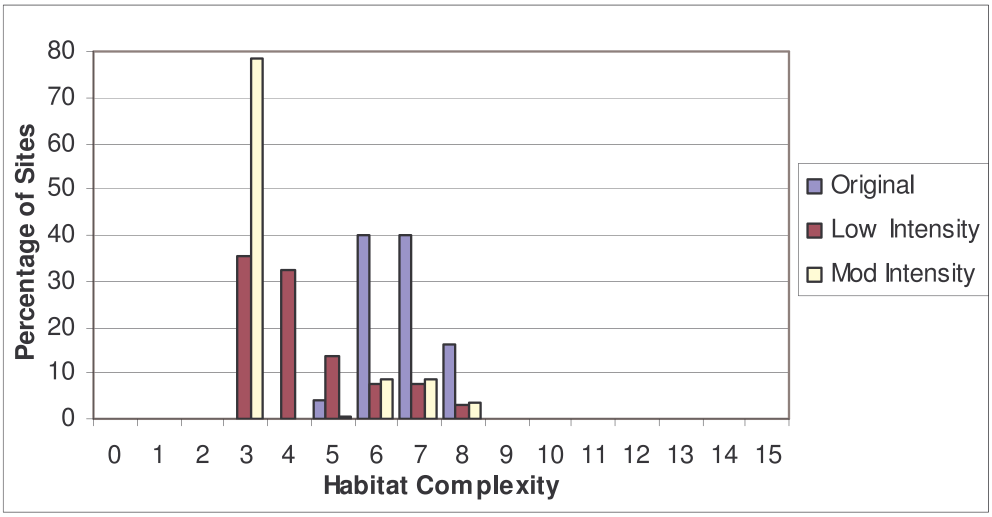


(d)



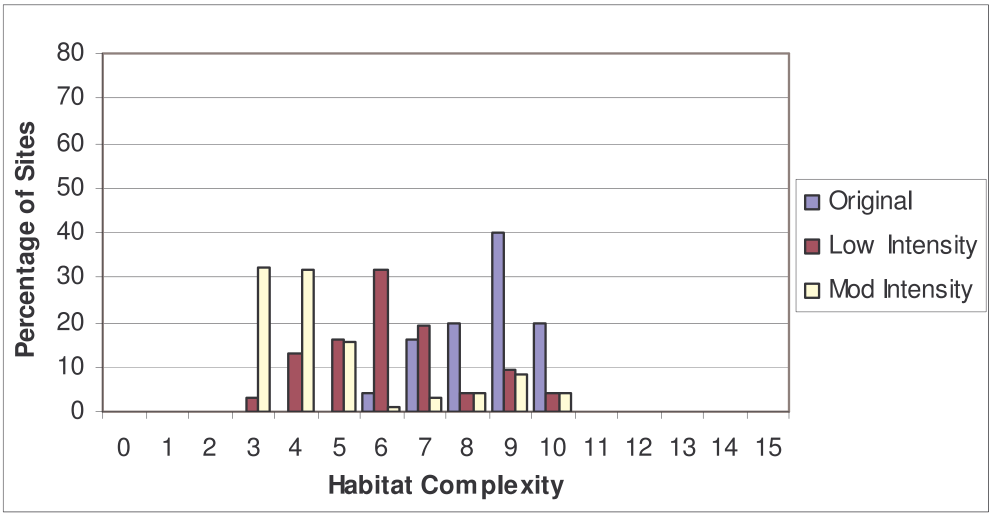
Percentage of Sites
80
70
60
50
40
30
20
10
0
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15
Habitat Complexity
Original
Low Intensity
Mod Intensity

(e)



Percentage of Sites
80
70
60
50
40
30
20
10
0
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15
Habitat Complexity
Original
Low Intensity
Mod Intensity

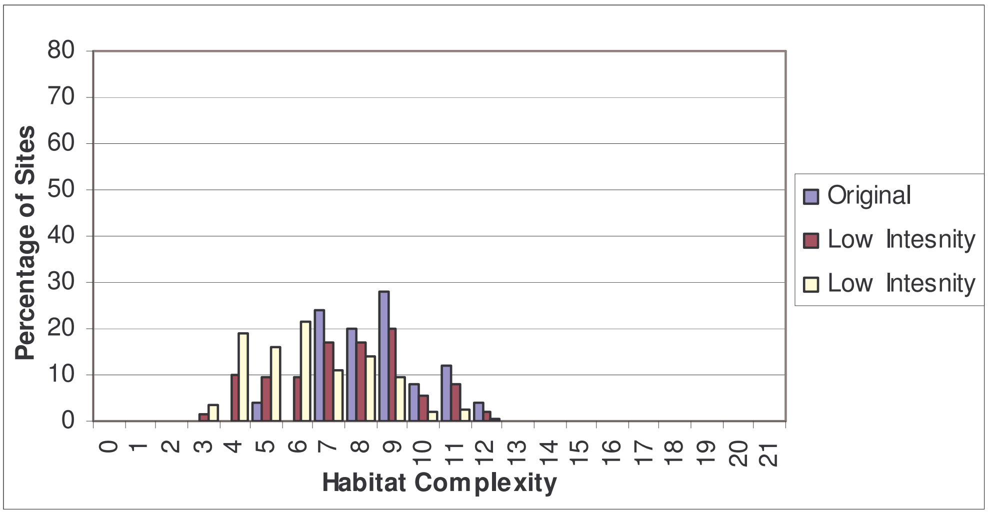
(f)



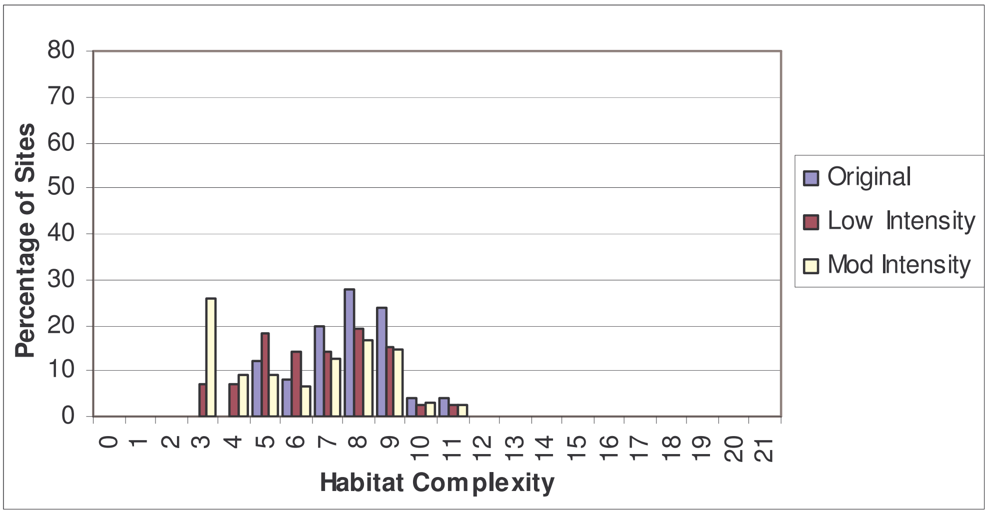
Percentage of Sites
80
70
60
50
40
30
20
10
0
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15
Habitat Complexity
Original
Low Intensity
Mod Intensity

Appendix 12: Bird Habitat Complexity Before and After Computer Modelled Low and Moderate Intensity 40% Fuel Reduction Burns in vegetation type (a) 138, (b) 140, (c) 159, (d) 167, (e) SB (f) Creek.

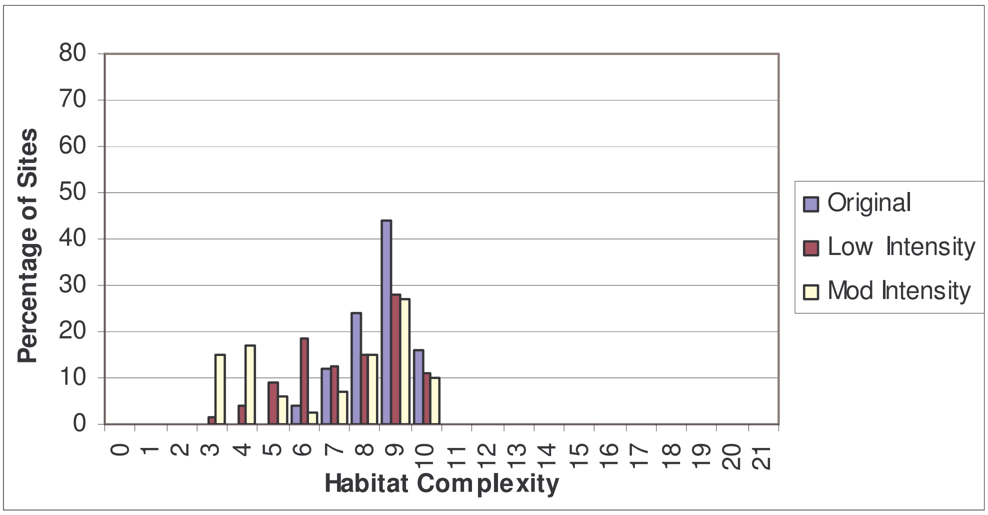
(a)



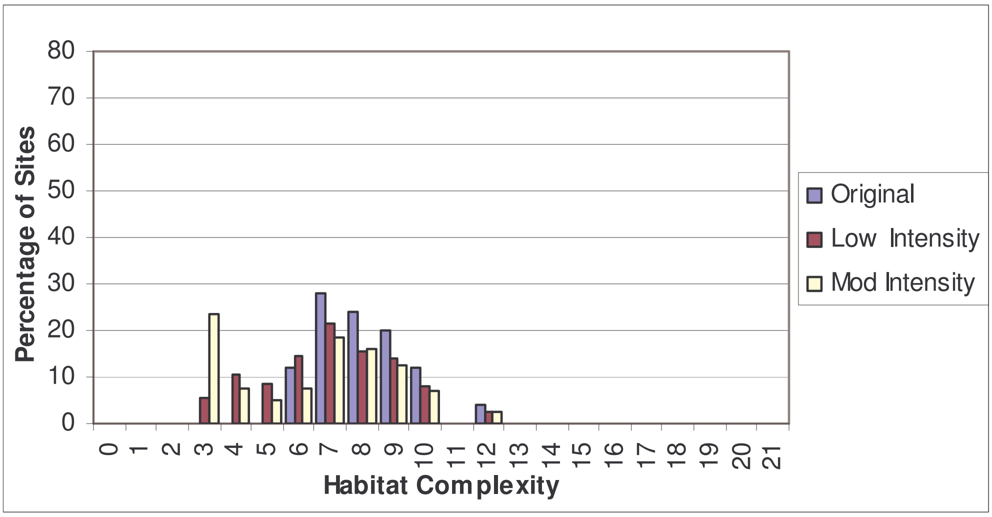
(b)



(c)

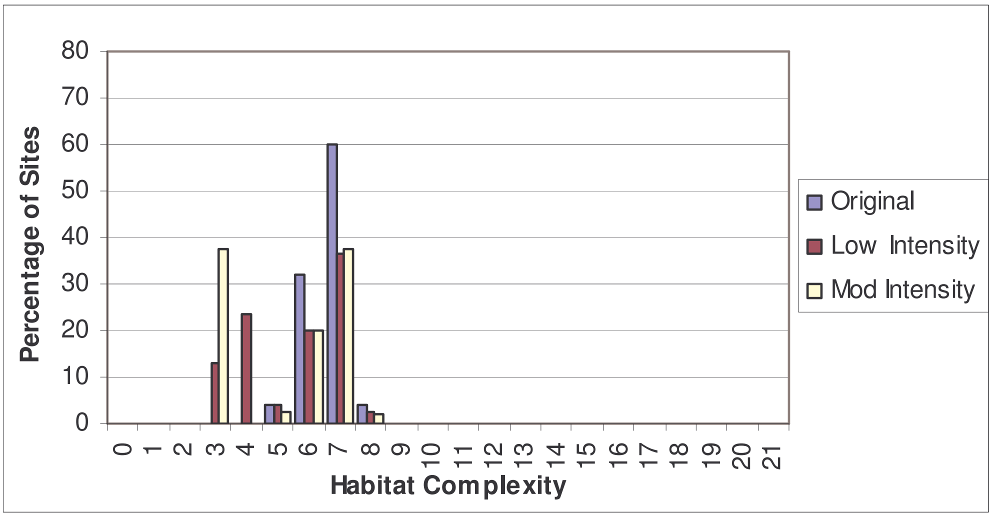


(d)



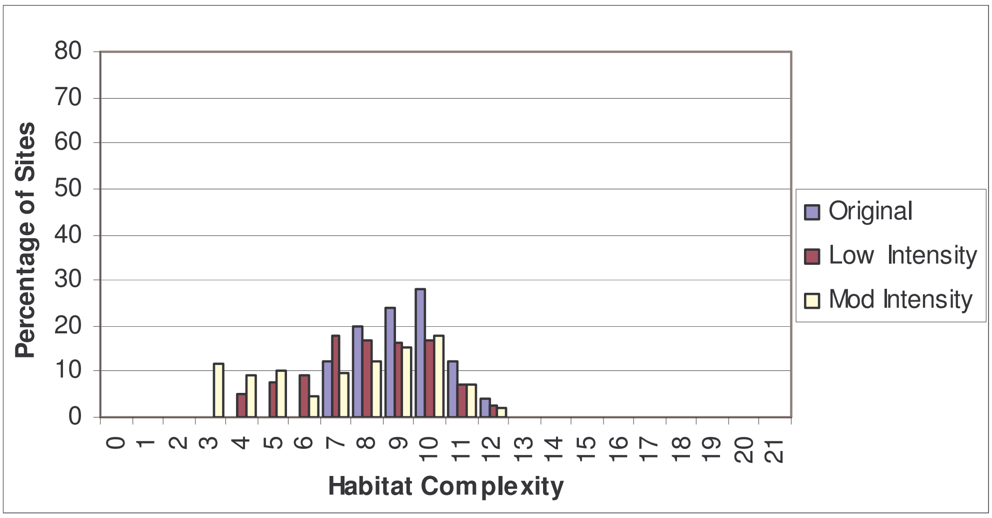
Percentage of Sites
Habitat Complexity
Original
Low Intensity
Mod Intensity

(e)



Percentage of Sites
Habitat Complexity
Original
Low Intensity
Mod Intensity

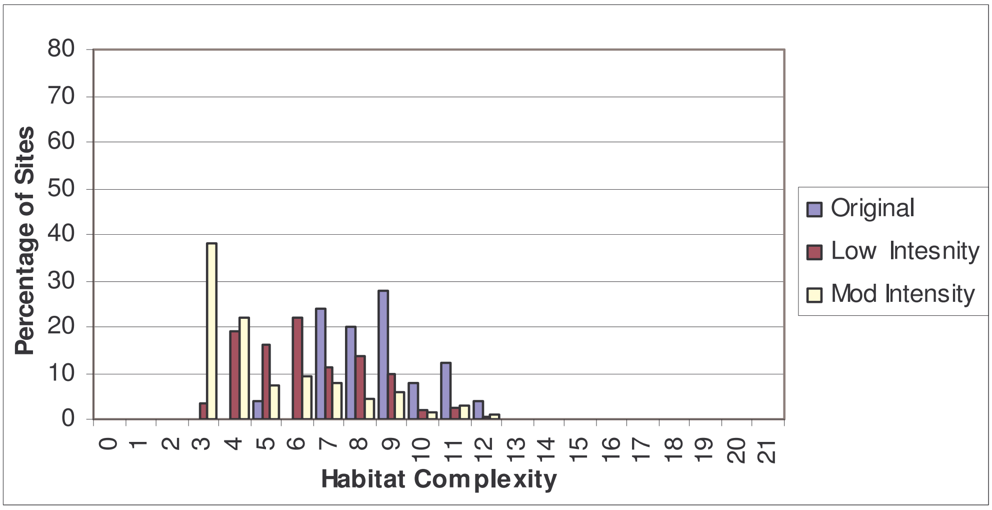
(f)



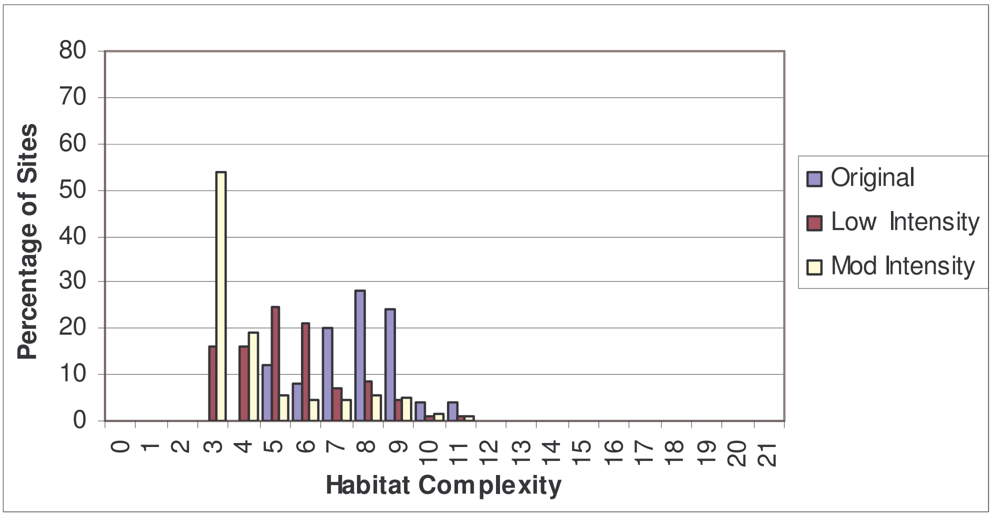
Percentage of Sites
Habitat Complexity
Original
Low Intensity
Mod Intensity

Appendix 13: Bird Habitat Complexity Before and After Computer Modelled Low and Moderate Intensity 80% Fuel Reduction Burns in vegetation type (a) 138, (b) 140, (c) 159, (d) 167, (e) SB (f) Creek.

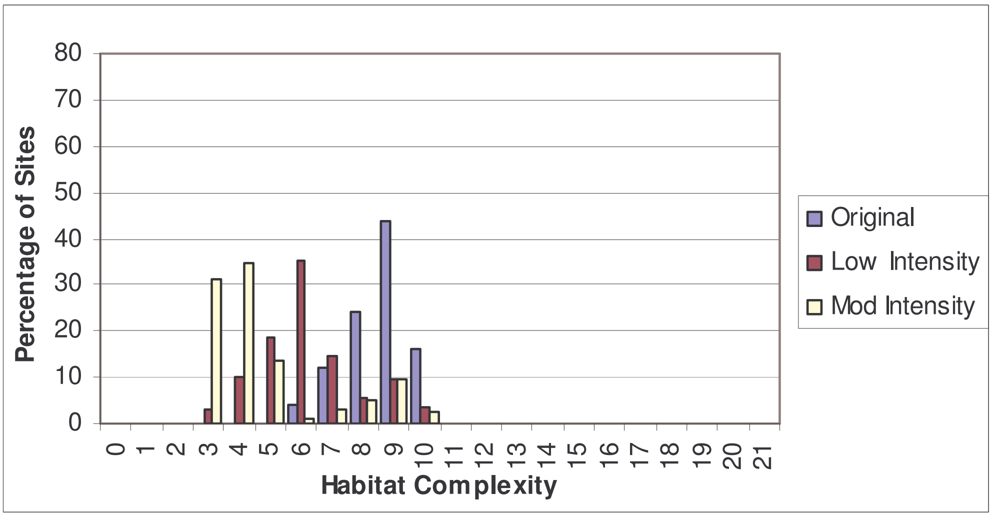
(a)



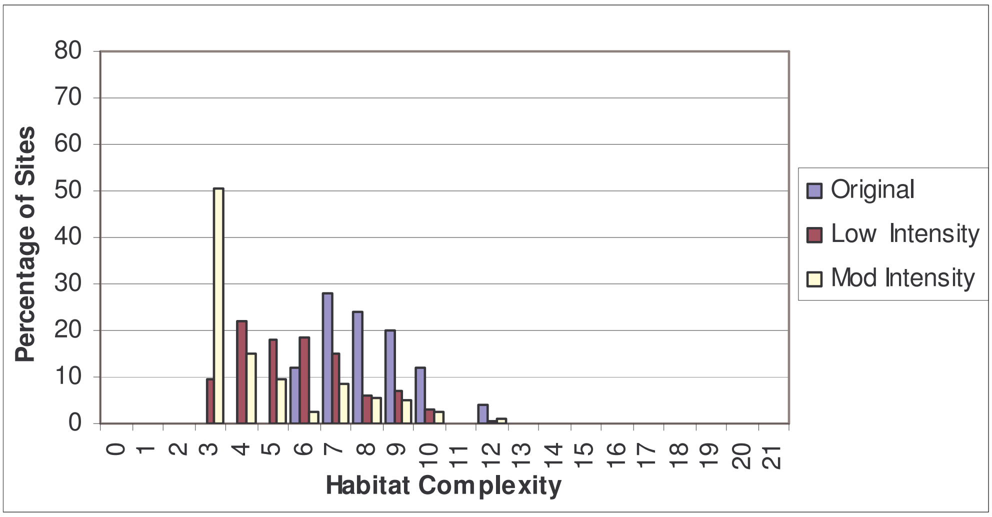
(b)



(c)

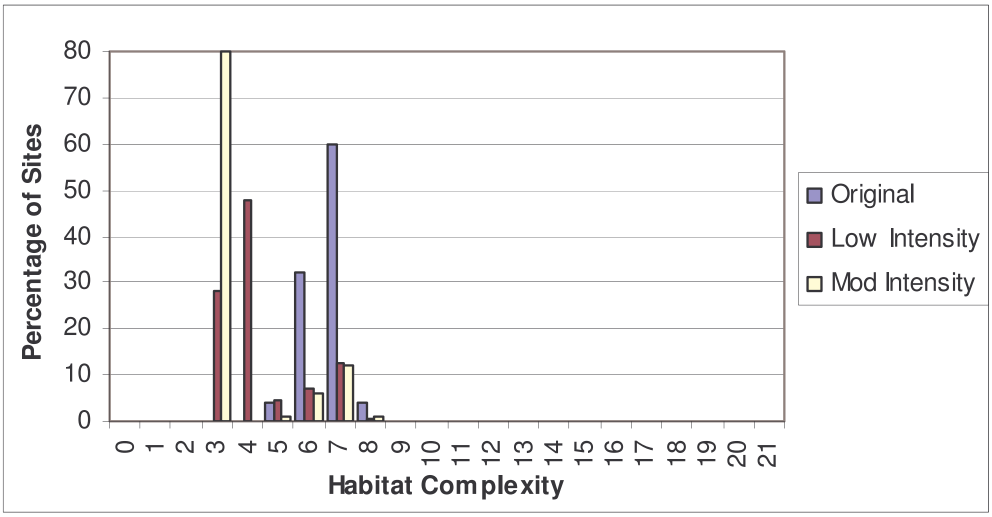


(d)



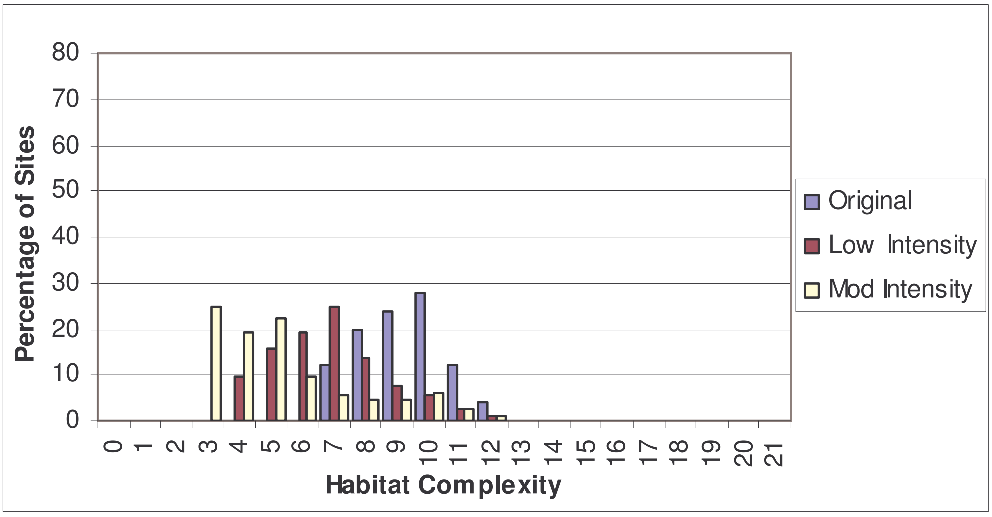
Percentage of Sites
80
70
60
50
40
30
20
10
0
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21
Habitat Complexity
Original
Low Intensity
Mod Intensity

(e)



Percentage of Sites
80
70
60
50
40
30
20
10
0
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21
Habitat Complexity
Original
Low Intensity
Mod Intensity

(f)



Percentage of Sites
80
70
60
50
40
30
20
10
0
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21
Habitat Complexity
Original
Low Intensity
Mod Intensity

Appendix 14: Sites with High Habitat Complexity Scores (circles) and Low Habitat Complexity Scores (squares).

Please see print copy for Appendix 14

Appendix 15: Photographs from Coolah Tops National Park of (a) Vegetation Type 138, (b) Vegetation Type 140, (c) Vegetation type 167, (d) Vegetation Type 159 (Lomatia thicket), (e) Vegetation Type SB, (f) Vegetation Type Creek, (g) A Track Bordering the Site, and (h) Thick Leaf Litter under Lomatia.

(a)

Please see print copy for Appendix 15