



**Exotic Plants in the Australian Alps Including a Case Study of the Ecology of Achillea Millefolium, in Kosciuszko National Park**

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**EXOTIC PLANTS IN THE AUSTRALIAN  
ALPS INCLUDING A CASE STUDY OF THE  
ECOLOGY OF *ACHILLEA MILLEFOLIUM*,  
IN KOSCIUSZKO NATIONAL PARK**

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**A thesis submitted in fulfilment of the requirements of the Degree of  
Doctor of Philosophy**

**School of Environmental and Applied Sciences**

**Faculty of Environmental Sciences**

**Griffith University**

**Gold Coast**

**August 2005**



## **DECLARATION OF ORIGINALITY**

This work has not previously been submitted for a degree or diploma in any university. To the best of my knowledge and belief, this thesis represents my original research except where otherwise acknowledged in the text.

Frances Johnston

August 2005



## FORWARD

*“In a small section of the garden a tiny weed spoke to the blooms that grew there.*

*‘Why,’ he asked, ‘does the gardener seek to kill me? Do I not have a right to life? Are my leaves not green, as yours are? Is it too much to ask that I be allowed to grow and see the sun?’*

*The blooms pondered on this, and decided to ask the gardener to spare the weed. He did so. Day by day the weed grew, stronger and stronger, taller and taller, its leaves covering the other plants, its roots spreading. One by one the flowers died, until only a rose was left.*

*It gazed up at the enormous weed and asked: ‘Why do you seek to kill me? Do I not have a right to life? Are my leaves not green, as yours? Is it too much to ask that I be allowed to grow and see the sun?’*

*‘Yes, it is too much to ask,’ said the weed” (Gemmell 1995 page 57).*



*Achillea millefolium* growing in subalpine native *Poa* grassland, Kosciuszko National Park, New South Wales (Photo: F. Johnston).



## ABSTRACT

Exotic plants are a threat to natural areas world wide including the Australian Alps, one of the largest relatively undisturbed natural areas remaining in Australia. This thesis examines the diversity, abundance and distribution of exotic plants in the Australian Alps, including Kosciuszko National Park and then focuses on *Achillea millefolium* (L.) (Asteraceae) as a case study of the biology and ecology of an important environmental weed.

To determine the diversity and abundance of exotics in the Australian Alps published records of exotic species were reviewed. A total of 175 exotic taxa were recorded in the alpine and subalpine areas representing 41 families and 122 genera. The distribution of exotics was associated with human activities with 80% of exotic taxa found along roads and tracks and nearly 60% around ski resorts. Just over 20% of exotic species were naturalised with some species presenting an environmental threat to the region.

To examine the relationship between human disturbance and exotics, vegetation was surveyed and soil analysed on road verges, in runoff areas and in adjacent vegetation along a gravel road in the subalpine zone of Kosciuszko National Park. The road verge was dominated by exotics, the area 10 m from the road verge was dominated by natives and the road drainage areas were dominated by the exotic, *A. millefolium*. There were also clear differences in the soils, with coarse nutrient poor soils on the road verge, highly organic fine soils in the areas 10 m from the road, and soils with high nutrients and water content in the road drainage areas.

The potential for exotics to colonise areas adjacent to roads after disturbance was examined in an experiment conducted along a subalpine road. The composition of plants colonising small gaps created in the existing vegetation (50 cm x 100 cm) was dependant on the distance from the road. In general, gaps one metre from the road verge were recolonised by exotic species while gaps five or ten metres from the road verge were predominantly recolonised by native early succession species. However the exotics *A. millefolium* and *Acetosella vulgaris* were present in many sites prior to disturbance, and were the major exotics to recolonise gaps five and ten metres from

the road. Therefore disturbance of natural areas where there are exotic propagules present may not necessarily result in a native climax community, but in a community with an even higher cover of exotics than prior to disturbance.

These initial studies highlighted the importance of *A. millefolium* as an environmental weed in the Australian Alps. Therefore further research was carried out on this species. A review of literature highlighted the capacity of this species to colonise and invade both disturbed and natural habitats. Based on current weed risk assessment methodologies this species presents a serious threat to both agricultural and natural environments in Australia. Data on the distribution of *A. millefolium* was used to develop a CLIMEX<sup>®</sup> model of its distribution worldwide and in Australia under current and changing climatic conditions. The models indicate that cool, temperate and Mediterranean climates are suitable for this species, while deserts and tropics are unsuitable. Under climate warming scenarios, there would be an overall reduction in the area suitable for *A. millefolium*, including within Australia, but an increase in suitable sites at higher altitudes.

Field and glasshouse experiments were conducted examining the distribution, phenology, resource allocation, seed ecology and competitive abilities of *A. millefolium*, including any variation in these characteristics associated with increasing altitude. Field surveys and published records of *A. millefolium* indicate that *A. millefolium* populations are primarily associated with disturbance, with some limited spread into native vegetation. It occurs along more than 100 km of walking tracks, roads and trails within the Park. *Achillea millefolium* populations were observed growing between 800 m and 2100 m a.s.l., with the majority of populations occurring in areas above 1200 m a.s.l.

The vegetative and flowering phenology studies of *A. millefolium* confirm that it is able to grow and flower from the tableland to high subalpine with flowering commencing earlier and lasting longer at lower altitude sites. However, even at sites 1760 m altitude, flowering occurred for approximately 80 days with large numbers of inflorescences (19 per m<sup>2</sup>) at the peak of flowering in early March.

The effect of altitude on the allocation of biomass in *A. millefolium* between above ground, below ground and reproductive structures indicates that with increasing

altitude there was a decrease in the relative and absolute allocation of biomass to reproductive structures (average 2.7 kg/m<sup>2</sup>), although the total number of flower heads was not affected (average 129 flowering heads/inflorescence). There was no effect of altitude on the absolute allocation to below ground (average 3.1 kg/m<sup>2</sup>) and above ground vegetative structures (average 0.7 kg/m<sup>2</sup>).

The seed ecology of *A. millefolium* was examined including estimating the potential maximum seed production (51400 seeds/m<sup>2</sup>), seed rain, and seed viability. There was 60% viability of seed remaining after three years dry storage and 16% viability of seed remaining after three years of burial in the field. All these seed characteristics were highly variable among sites, with either no, or limited effect of increasing altitude.

In a glasshouse competition experiment between *A. millefolium* and the dominant native snowgrass *Poa fawcettiae*, the weed produced four times as much biomass as the native grass at the end of the 12 week experiment. As a result, when grown together, *A. millefolium* significantly decreased the root and shoot biomass of *P. fawcettiae* while *P. fawcettiae* had no effect on the biomass of *A. millefolium*. Root interaction from the weed on the grass appeared to be the primary source of competition.

Population dynamics modelling using data from this research and from the literature indicated that without human induced control this species has the potential to continue to spread from current populations in subalpine and alpine areas. Therefore a strategy to effectively control this species must include the removal of flowers to decrease the input of seed into the seed bank, limiting the establishment of seedlings and removal of the underground rhizome system.

This study has shown that the high altitude areas of the Australian Alps are susceptible to exotic plant invasions. The results also highlight the importance of human induced disturbance in the introduction and distribution of exotics, including the case study species *A. millefolium*. Increasing severity of conditions with increasing altitude does not appear to be limiting the establishment, growth and reproduction of *A. millefolium*, even though altitude did affect some components of the ecology of this species in Kosciuszko National Park.



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## GLOSSARY

**Anthropological disturbance** - disturbance that is not natural to an area but is caused by humans, for example the construction of roads through natural vegetation.

**Biomass** - the weight of vegetation per unit area, often measured as dry weight.

**Capitulum (flower head)** - in Asteraceae a group of florets (small flowers) which are sessile on a common receptacle (Harden 1993).

**CLIMEX<sup>®</sup>** - a software program used to model the climatic requirements of a plant species. This allows predictions to be made about the potential geographical distribution (Sutherst *et al.* 2000).

**Community** - all organisms inhabiting a particular area: an assemblage of populations of different species living close enough for potential interaction (Campbell and Reece 2005).

**Disk florets** - usually actinomorphic flowers produced in the central part of the flower head with a tubular corolla of more or less equal lobes, as in most Asteraceae (Duncan 1994).

**DYMEX<sup>™</sup>** - a computer based modelling system combining life stage-based transition matrix with Markov chain population modelling frameworks and individual-based models (Sutherst *et al.* 2000; Kriticos *et al.* 2003).

**Endemic** - taxa that are native and confined naturally to a particular and usually restricted area or region (Costin *et al.* 2000).

**Environmental weed** - a plant species occurring outside its natural geographic range that is capable of replication without direct human intervention in undisturbed, semi disturbed or disturbed indigenous vegetation and that is considered to have adverse impact on the vegetation where it is found (Groves 1999; Sindel 2000; Vranjic *et al.* 2000).

**Established** - a species with a self sustaining population outside of its native range.

**Exotic(s)** - a plant species not native to an area whose presence is due to intentional or accidental introduction. Also can refer to a species, subspecies, or lower taxon occurring outside of its natural range (past or present) and dispersal potential (i.e. outside the range it occupies naturally or could not occupy without direct or indirect introduction or care by humans). Synonyms are non-native, non-indigenous, alien, weed (Booth *et al.* 2003).

**Floret** - a small flower, one of a dense cluster as in Asteraceae (Duncan 1994).

**Flowering head** - is used throughout this thesis and is synonymous with capitulum.

**Inflorescence** - a general term for the flower-bearing system of a plant. In this thesis the term refers to the cluster of flowering heads (capitulum) in Asteraceae. For *Achillea millefolium* each inflorescence consists of a terminal corymb with numerous flowering heads and stems (peduncles) and side corymbs with flowering heads including the stem and associated leaves.

**Interspecific competition** - competition between two or more species relying on similar limiting resources (Booth *et al.* 2003).

**Intraspecific competition** - competition between members of the same species (Booth *et al.* 2003).

**Invasion** - the whole process from the arrival of a new species into a community, its establishment and maintenance in that community, to its further spread into other communities (Priour-Richard and Lavorel 2000).

**Invasive plants** - naturalised plants that produce reproductive offspring, often in high numbers and at considerable distance from the parent plants and thus have the potential to spread (Booth *et al.* 2003).

**Invasiveness** - the capacity for a species to successfully invade communities from which it was previously absent (Prieur-Richard and Lavorel 2000).

**Naturalised weed** – a non native plant that forms self sustaining population but does not necessarily invade natural, managed or human made ecosystems (Groves 1999; Sindel 2000; Vranjic *et al.* 2000).

**Ordination** - a type of multivariate statistical analysis that can be used to examine how species abundances vary within the environment.

**Phenology** - the timing of seasonal life cycle events; the study of lifecycle events and the environmental conditions that influence them.

**Primary succession** – the establishment of plants on land completely devoid of soil and vegetation e.g. volcanic formations, after the retreat of glaciers (Campbell and Reece 2005).

**Protected area** - refers to nature reserve, nature preserve, national park, managed resource protected area, protected landscape, habitat or species management area, wilderness area, strict nature reserve or refuge or other terms (Usher *et al.* 1988).

**Radiate head** - has both disk and ray florets. The disk florets are at the centre of the receptacle with the ray florets arranged in one or more rows around the edge of the receptacle (Duncan 1994).

**Ray floret** - (also called ligulate floret) zygomorphic flower in many Asteraceae, usually formed toward the periphery of the head and with the corolla extended into a strap-shaped ligule (Duncan 1994).

**Receptacle** - the often more or less expanded top of the stalk on which a flower or flower head arises (Duncan 1994).

**Relative abundance** - is a measure of the proportion of species in the community as a whole (Campbell and Reece 2005).

**Secondary succession** - occurs if an existing community has been cleared by some disturbance that leaves the soil intact (e.g. abandoned agricultural fields). If the disturbance stops, the community will begin a secondary succession, changes in the vegetation that will lead back to a climax community. If a plant community is significantly disturbed, the loss of the vegetation may change the biotic and abiotic conditions. If this occurs and the habitat has changed, secondary succession may lead to a different climax community (Campbell and Reece 2005).

**Site led weed control strategy** – protection of the natural flora at a particular place through managing buffer zones and potential corridors for invasion and controlling of sources of propagules (Owen 1998).

**Sleeper weed** - the name given for a weed species whose invasion is characterised by a lag between the time the species is first found in an area to when the population increases rapidly (Kowarik 1995; Booth *et al.* 2003).

**sp.** - refers to a particular but unidentified species within a genus.

**Species diversity** - the number and relative abundance of species in a biological community (Campbell and Reece 2005).

**Species richness** - is the number of species in a community or given area (Campbell and Reece 2005).

**spp.** - refers to more than one unidentified species from the same genus.

**Succession** - a process of change that results from disturbance in communities and includes the transition in species composition over time (Campbell and Reece 2005).

**Undisturbed** – an area that has been subjected to only natural disturbance.

**Weed led weed control strategy** - preventing the spread of weed species into high conservation values areas or controlling the spread of weeds beyond their current distribution with the overall aim of eradication or at least containment. Weed led programs usually focus on species with a limited distribution and or low numbers (Owen 1998).



---

# CHAPTER 1

## EXOTIC PLANTS IN NATURAL ECOSYSTEMS

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### 1.1. INTRODUCTION

Worldwide, areas of natural vegetation are declining as a result of human activities (Worboys *et al.* 2005). The biodiversity of natural areas is threatened by fragmentation and destruction of habitat as well as through inappropriate resource use and pollution (Cronk and Fuller 1995). For example, in Australia in 2000 over 564 000 ha of native vegetation were cleared, principally for farming, the highest rate of clearing in any developed nation (ASEC 2001).

An often underestimated threat to the conservation of natural areas is the invasion of exotic species (Cronk and Fuller 1995; Colton and Alpert 1998; Low 1999). In natural ecosystems worldwide there is a trend for an increase in exotic plant diversity and abundance with an accompanying decrease in native species (Adair and Groves 1998; Stohlgren *et al.* 1999). In Australia, exotic plants, particularly environmental weeds, have recently been recognised as a major threat to the biodiversity of the remaining natural areas (Williams and West 2000). Environmental weeds are species which can establish and be maintained in an ecosystem in the absence of human activities and which have the potential to detrimentally affect the ecosystem (Groves 1999). Exotics that become environmental weeds can threaten ecosystem function and processes (e.g. Carr *et al.* 1986; Billings 1994; Schmitz *et al.* 1997; Adair and Groves 1998; Groves and Willis 1999; Humphries *et al.* 1999; Lonsdale 1999; Williams and West 2000).

In view of the serious threat that exotics may present to remaining natural areas this thesis' aims were twofold. Firstly, to determine the diversity, abundance and distribution of exotic plants in protected areas of the Australian Alps, particularly in Kosciuszko National Park. Secondly, to investigate the biology and ecology of *Achillea millefolium* (L.) (Asteraceae) as a case study of an environmental weed in the Australian Alps.

In the first chapter of this thesis, the scope and impacts of exotic plants in natural ecosystems in Australia are reviewed and the process of plant invasions into natural ecosystems described.

## **1.2. EXOTIC SPECIES IN AUSTRALIA**

### **1.2.1. Scope of the problem**

Despite the irreversible and cumulative effects of exotic plant invasion into natural areas this threat has not received much public attention (Low 1999). Few Australians are aware that environmental weeds are an important threat to natural biodiversity (Temple 1990; Muyt 2001). Almost all of Australia's native vegetation has been, or is likely to be, invaded by exotic plant species (Adamson and Fox 1982; Carr *et al.* 1986; Groves 1986; Michael 1994; Fox and Adamson 1999). It has been suggested that no other continent has experienced such rapid change in the last 200 years with human activities being the most important factors in the introduction and spread of exotics including environmental weeds (Adamson and Fox 1982; Vranjic *et al.* 2000; Williams and West 2000; Muyt 2001).

The introduction and spread of exotics in natural ecosystems in Australia appears to be neither a problem of the past nor a diminishing problem (Scott 2000; Vranjic *et al.* 2000; Williams and West 2000). For example Hooker (1860) listed 139 naturalised plants in Australia. In a recent compilation of herbaria data in 2001, 2700 exotics were recorded as naturalised with half of these found in natural ecosystems and several hundred species posing a serious threat to native vegetation (Muyt 2001).

### **1.2.2. Sources of exotic species**

Exotic species have been deliberately and accidentally introduced to Australia. Intentional introductions include plants imported for agronomic, agricultural, silvicultural or aesthetic planting (Low 1999; Williams and West 2000). In a survey of 220 exotic plants declared noxious in Australia, 46% were introduced intentionally (Panetta 1993). Many exotics have spread from gardens or agricultural land into natural environments (Low 1999; Williams and West 2000). For example Broom (*Cytisus scoparius*) was deliberately introduced into Australia as a garden

plant but has become a major environmental weed of the southeast of Australia, competing with native shrubs and other understorey vegetation in wet and dry sclerophyll forests, grasslands and alpine heaths (Csurhes and Edwards 1998; McArthur 2000; Vranjic *et al.* 2000). A study of 463 exotic grasses and legumes introduced as pasture species to northern Australia between 1947 and 1985 reported that less than 1% of species were recommended as useful without being potential weeds, the remaining 99% were classed as either of no pasture value or as possible weeds (Lonsdale 1994). Many other exotics have been brought to Australia unintentionally. For example, Siam Weed (*Chromolaena odorata*) and Golden Dodder (*Cuscuta campestris*) arrived as contaminants of pasture and horticultural seed stock (Low 1999).

Exotic pasture and garden plants have unintentionally been introduced into natural areas by a number of vectors. Seed and other propagules become attached to vehicles, machinery, shoes or clothing. Animals (domestic, feral and native) have also acted as vectors through seed attached externally or transported internally in their digestive tracts. Seed and other propagules have also been transported into natural areas as contaminants in construction materials, for example during the construction of roads (Hodkinson and Thompson 1997; Fox and Adamson 1999; Low 1999).

### **1.3. IMPACTS OF EXOTICS IN NATURAL ECOSYSTEMS IN AUSTRALIA**

Ecological consequences of environmental weeds, such as changes to ecosystem structure, processes and functions have been demonstrated in a number of environmental weed invasions in Australia (e.g. Amor and Piggin 1977; Buckley 1981; Carr *et al.* 1986; Groves 1986; Willis 1994; Adair and Groves 1998; Mack and D'Antonio 1998; Groves and Willis 1999; Low 1999; Costello *et al.* 2000; Williams and West 2000). Changes in ecosystem function or structure may adversely affect some native species and favour others resulting in changes to vegetation communities (Carr *et al.* 1986; Adair and Groves 1998). For instance, *Mimosa pigra* invasion in northern Australia has caused changes to the structure and function of the original ecosystem by converting the aquatic grassland or sedgeland ecosystems to

shrublands (Lonsdale 1993). Other general ecosystem level changes due to environmental weeds include changes to fire intensity and frequency, altered successional pathways, altered habitat structure and availability for fauna, altered spatial distribution of nutrients, changed hydrological patterns and chemistry, reduced native plant species richness, cover and abundance and changes to the number and distribution of faunal species (Adair and Groves 1998 and references therein; Williams and West 2000). In all cases, however, the degree of impact is rarely quantified (Adair and Groves 1998).

#### **1.4. EXOTIC PLANT INVASION INTO NATURAL ECOSYSTEMS**

There are five stages that can be distinguished during the invasion of plants into natural environments; introduction, establishment, survival, production of numerous propagules and widespread dispersal (Humphries *et al.* 1991; Scott 2000; Kolar and Lodge 2001; Booth *et al.* 2003). Each phase can be complex in terms of the space, time and biotic features of the invasive species and the environment (Groves 1986). Each stage or transition must be completed for the plant to become invasive. If any of the first four stages are not completed the invasion will fail. If the last does not occur, the invasion may remain localized or eventually fail (Booth *et al.* 2003). Most species of plants do not become invasive. For example, in a study of biological invasion in Germany less than 10% of introduced species begin to invade, 2% become established and only 1% successfully invaded the natural vegetation (Kowarik 1995). Generally it is thought that 80-95% of species are lost at each transition stage: however, while a species may fail at some stage at a particular location it may re-enter the invasion cycle later at the same site or at other sites (Hobbs 1989; Booth *et al.* 2003).

Predicting the invasive potential of an exotic species into native ecosystems still remains largely guesswork (Mack *et al.* 1999; Scott 2000; Lockwood *et al.* 2001; Booth *et al.* 2003; Heger and Trepl 2003). The invasion outcome depends on many factors such as the habitat characteristics (e.g. Swincer 1986; Crawley 1987; 1989; Mooney and Drake 1989; Henneke *et al.* 1990; Mallen-Cooper 1990; McIntyre and Lavorel 1994; Burke and Grime 1996; Gilfedder and Kirkpatrick 1998; Davis *et al.* 2000; Dupre and Ehrlén 2002), native species diversity (e.g. Fox and Fox 1986;

Rejmanek 1989; Case 1990; Crawley *et al.* 1999; Lonsdale 1999; Mack *et al.* 1999; Stohlgren *et al.* 1999), the traits of the exotic species (e.g. Baker 1975; Timmins and Williams 1987; Roy 1990; Thompson *et al.* 1995; Goodwin *et al.* 1999; Muylt 2001), and the disturbance regime (e.g. Forcella and Harvey 1983; Fox and Fox 1986; Hobbs 1987,1989; Rejmanek 1989; Humphries *et al.* 1991; Hobbs and Huenneke 1992; McIntyre *et al.* 1995; Fox and Adamson 1999; McIntyre *et al.* 1999 a,b; Stohlgren *et al.* 1999; Almasi 2000; Hobbs 2000; Trombulak and Frissell 2000; Frenot *et al.* 2001; Laska 2001). The complexity of each of these factors and the interaction between them make predictions about specific introductions difficult. Although general predictions have been listed (Table 1.1) it is still not possible to tell whether a specific species will invade a specific habitat (Booth *et al.* 2003).

Table 1.1. Ten general predictions about plant invasions (Rejmanek 1999, 2000, adapted from Booth *et al.* 2000).

- 
1. Invasive species are more likely to be able to maintain fitness over a range of environments using phenotypic plasticity.
  2. Invasive species are more likely to have small genome size with the corresponding small seed size and high leaf area ratio.
  3. Woody species are more likely to invade disturbed areas if they have small seeds, a short juvenile period and short time span between large seed production years.
  4. Seeds of woody species that invade disturbed and undisturbed habitats are more likely to be vertebrate dispersed.
  5. Invasive herbaceous species often have large native latitudinal ranges.
  6. Invasive species often reproduce vegetatively especially at higher latitudes.
  7. Exotic species are more likely to be successful if they are from an exotic genus that is not represented in the native flora.
  8. Invasive species are less likely to be dependent on specific mutualisms (pollinators, mycorrhizal fungi) and will be able to overcome the abiotic and biotic filters in a new environment.
  9. Tall plants often invade both disturbed and undisturbed herbaceous communities especially in mesic habitats.
  10. Exotic species are often spread by human activities.
- 

### **1.5. EXOTIC SPECIES IN PROTECTED AREAS IN AUSTRALIA**

In Australia there are over 4100 protected areas, 12 declared as biosphere reserves, with a total area managed for conservation at 60 500 000 ha or 7.9% of the landmass (Worboys *et al.* 2005). These areas are set aside due to their high conservation value containing important reservoirs of native species (Worboys *et al.* 2005). Within Australian protected areas the integrity of natural vegetation is threatened by habitat disturbance, visitor use, pest animals, pollution etc. (Leaver and Turner 1983;

McIntyre 1990; Worboys *et al.* 2005). Many of these conservation areas contain large numbers of exotic plants, with the number and individual species varying with the biophysical characteristics of the individual park, the period of declaration as a park and past and present land use within and surrounding the park (Benson 1991).

The presence of exotic plants within protected areas is a major conservation issue and management problem (Williams and West 2000; Harmon and Worboys 2004). This is reflected in the legislative objectives for national parks. For New South Wales this is "...to preserve and protect the unique or outstanding scenery or natural feature..." and fulfilment of this objective includes the control of exotic plant species (Good 1987; ISC 2004).

### **1.5.1. Exotic taxa in the Australian Alps**

The alpine and subalpine areas of southeast Australia, the Australian Alps, contain a significant component of Australia's floral biodiversity and of the diversity of alpine floras worldwide (Costin 1989; Good 1992a; Körner 1999). The alpine and subalpine areas above 1500 m in Kosciuszko National Park, the largest protected area in the Australian Alps, contain around 204 flowering plant species including 21 endemic species (Good 1992a; Costin *et al.* 2004).

The native flora of the Australian Alps is considered to derive from three sources; Australian lowland species adapted to alpine conditions, species from other alpine regions, and cosmopolitan species (Barlow 1988). A fourth more recent source is exotic plants (Mallen 1986; Johnston and Pickering 2001a). Some of these species are environmental weeds and pose a serious threat to the ecology of the Australian Alps (Carr *et al.* 1992). The introduction and spread of exotics including environmental weeds in the Australian Alps and in particular, Kosciuszko National Park, illustrates the process by which plant invasions can occur in protected areas.

## **1.6. RATIONALE**

This thesis examines the status of exotic plants in one of the largest protected areas in the Australian Alps, Kosciuszko National Park. This was accomplished by first examining the diversity of exotics and their association with particular types of

disturbance. This included examining the impacts of road disturbance on plant assemblages and soil characteristics and the colonisation of areas adjacent to roads. Then the research focuses on the ecology of a specific environmental weed, *Achillea millefolium*, to illustrate; (1) the characteristics of exotics that may become environmental weeds in a mountain protected area; (2) how exotics respond to the specific environmental conditions in a protected area; and (3) the issues that arise when attempting to control environmental weeds in protected areas.

For many natural areas, including those in Kosciuszko National Park, there is little detailed or quantitative information on the distribution of exotic species generally or for specific taxa. Nor is there detailed information on the impact of environmental weeds on biodiversity or ecological functions (Adair and Groves 1998; Prieur-Richard and Lavorel 2000).

One of the most important steps in assessing the threat posed by exotic plants to the biodiversity of a protected area is to obtain an estimate of the diversity and distribution of the exotic plants. For Kosciuszko National Park this was done by analysing vegetation surveys conducted over the past 100 years. In addition, the origin and biology of exotic species were reviewed and management issues were examined.

This highlighted, as have other studies, that roads are a major type of disturbance and that there is often a high diversity of exotics along road verges. However, a lot of the research into the environmental impacts of roads, including provision of habitat for exotic taxa, comes from Europe and North America with very little data available for natural environments, including those in protected areas in Australia (Donaldson and Bennett 2004). In addition only limited studies have been conducted in Australia on the impacts of roads on soil characteristics and how that relates to colonisation by exotic plants (Donaldson and Bennett 2004). In order to address the lack of research in Australia the effects of roads on plant assemblages and soil in the subalpine area of Kosciuszko National Park was examined.

Following on from this research, an experiment was conducted to understand the role of disturbance in the potential spread of exotic taxa from roadsides into adjacent natural vegetation. To identify the roadside exotics that may pose a threat to adjacent

native vegetation this research determined which exotic species were present above ground and in the seed bank prior to creating small gaps in the vegetation, and then examining which species colonised the gaps over time.

Of the exotics found along roadsides in Kosciuszko National Park, one, *Achillea millefolium* was of particular concern. This species has been present in the Park for over 50 years but in the last decade the density of existing populations and the number of sites where it has been recorded appear to have increased (Johnston and Pickering 2001b). Based on existing overseas research it was possible to assess the risk of the species as an environmental weed. To then understand how this species is responding to the specific environment where it is occurring, the distribution, phenology, resource allocation, seed ecology and the competitive ability of *A. millefolium* were examined in Kosciuszko National Park.

Environmental conditions vary within mountain regions which affects the ecology of plants. For example, climatic conditions (which vary with altitude) affect how species grow and establish, when they flower, how resources are allocated to different functions (growth vs. reproduction, above vs. below ground structures) and the amount of flowers and seed produced. All of these factors affect the success of the species, including environmental weeds. Therefore the distribution of *A. millefolium* was related to disturbance and climate.

There have been few studies of the phenology of plants in the Australian Alps with most examining native species in the alpine zone (Inouye and Pyke 1988; Pickering 1994, 1995, 2000). To assist in understanding the timing and extent of seed production of plants growing at disturbed sites over an altitudinal range the phenology of *A. millefolium* was examined at a range of sites within Kosciuszko National Park and surrounding areas. The effect of altitude was explored by examining changes in resource allocation over an altitudinal gradient including allocation of biomass to vegetative, flowering and rhizome structures. Seed production and seed viability are examined further in a series of experiments including whether altitudinal factors affect seed production and viability of this exotic. The competitive interactions of *A. millefolium* with the dominant native grass *Poa fawcettiae* in the Australian Alps were examined in glasshouse experiments. The

interaction between these two taxa was particularly important as the extensive bushfires that occurred during the study increased the threat of exotic invasion due to the removal of natural vegetation over large areas, while many of populations of exotic species survived along road verges.

Information on the ecology of *A. millefolium*, including data in this thesis, were used to develop a population model. This allowed the effect of different control strategies for *A. millefolium* to be evaluated.

## RESEARCH QUESTIONS

To investigate the diversity and distribution of exotic species in the Australian Alps and the ecology and management of the environmental weed *A. millefolium* particularly in Kosciuszko National Park the following research questions were posed:

1. Which exotic plants occur in subalpine and alpine areas of the Australian Alps including Kosciuszko National Park (Chapter 3)?
2. Is their distribution associated with particular types of human disturbance (Chapters 3, 4, 5 and 7)?
3. What is the distribution of *A. millefolium* in Kosciuszko National Park (Chapters 3, 4, 5, 7, 8, 9, and 10)?
4. What are the effects of disturbance on *A. millefolium* (Chapters 3, 4, 5 and 8)?
5. What is the effect of altitude/climate on *A. millefolium* (Chapters 7, 8, 9 and 10)?
6. What other factors influence the distribution and ecology of *A. millefolium* (Chapters 3, 4, 7, 8 and 10)?
7. What are the effects of *A. millefolium* on native vegetation (Chapters 4, 5 and 10)?
8. How can *A. millefolium* be controlled (Chapters 12 and 13)?
9. Do environmental weeds, and in particular, *A. millefolium*, threaten the native biodiversity in the alpine and subalpine zones of the Australian Alps (Chapters 3 and 13).

## 1.7. THESIS OUTLINE

The thesis is written as a single document comprising three sections, with chapters written in the form of research papers each with their own summary, introduction, methods, results, discussion and conclusions. The results of several chapters have been published.

**Section One.** This section reviews exotic species in protected areas, with a focus on the Australian Alps particularly Kosciuszko National Park. The association between human disturbances such as roads and exotic species is also examined.

*Chapter 1* provides a general introduction to the process of exotic plant invasions and the factors which may affect the outcome. The scope of the exotics in Australia, particularly in protected areas is reviewed.

*Chapter 2* summarises the importance of the Australian Alps and Kosciuszko National Park as protected areas. This chapter includes a description of the environment and native flora of Kosciuszko National Park, where this research was conducted.

*Chapter 3* reviews the extent of exotics in the alpine and subalpine areas of the Australian Alps, particularly in Kosciuszko National Park, including the history of introductions and the association between particular types of human disturbances and exotics. This review of exotics highlights the importance of some specific weeds including *A. millefolium*.

*Chapter 4* examines the composition and extent of vegetation cover and soil types associated with roads, a major type of human disturbance in the Australian Alps.

*Chapter 5* reports on a manipulative field experiment examining vegetation colonisation following disturbance in a subalpine woodland area of Kosciuszko National Park adjacent to a road verge. This includes examining the diversity of pre and post disturbance above ground vegetation and the composition of the soil seed bank.

**Section Two.** This section examines the ecology of the case study environmental weed *A. millefolium*.

*Chapter 6* is a general review of the biology of *A. millefolium* and determines the priority for the control of this particular weed under current systems for evaluating weeds in Australia. In addition, the present distribution of *A. millefolium* and the potential future distribution under climate change worldwide and in Australia is explored using the CLIMEX modelling program.

*Chapter 7* examines the current distribution of *A. millefolium* in Kosciuszko National Park, including its association with disturbance and altitude/climate.

*Chapter 8* reports on the phenology of *A. millefolium* (vegetative and flowering) at a range of altitudes and types of disturbance in the Park.

*Chapter 9* examines the allocation of resources by *A. millefolium* along an altitudinal transect in the Park to examine the species' response to increasing severity of conditions.

*Chapter 10* examines the seed ecology of *A. millefolium* including the potential number of seeds produced per inflorescence, seed rain, and seed viability post harvest and post soil burial over a range of altitudes.

*Chapter 11* reports on the results of a glasshouse experiment examining the effect of competition between *A. millefolium* and the dominant native grass in the Australian Alps, *Poa fawcettiae*.

**Section Three** The final section of the thesis brings together the results from the field and glasshouse work with previous research on *A. millefolium* to generate a life stage transition matrix population model of *A. millefolium* in the Australian Alps. Then the overall results of the research are discussed.

*Chapter 12* reports the results of life stage modelling to explore management strategies for this particular weed species in the Australian Alps.

*Chapter 13* provides a general discussion of the research findings reported in the previous sections, and the conclusions reached by this research including a discussion of possible management of *A. millefolium* and exotics in general in the Australian Alps and particularly in Kosciuszko National Park.



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## CHAPTER 2

### THE AUSTRALIAN ALPS AND KOSCIUSZKO NATIONAL PARK<sup>1</sup>

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#### 2.1. THE AUSTRALIAN ALPS

The Australian Alps form the southern section of the Great Dividing Range, extending north from Victoria through the Snowy Mountains of New South Wales and into the Brindabella Range near Canberra in the Australian Capital Territory (Good 1992a; Green 1998).

The landscape and soil of the Australian Alps is the product of hundreds of millions of years of geological and geomorphological processes, including deposition, sedimentation, metamorphism and vulcanicity, differential weathering of these rock types, extensive faulting and uplift. More recent geological features include karst formations and glacial and periglacial landscapes (Worboys 1982; Costin 1989; Galloway 1989; Good 1992a,b; Costin *et al.* 2000; Costin *et al.* 2004).

The Australian Alps are recognised by the World Conservation Monitoring Centre as one of the world centres of biodiversity (ISC 2004). The area is significant for its physical, cultural, historical and economic features, encompassing a wide range of landforms, soils, vegetation types and fauna habitats (Davey 1989; Good 1992a,b; Costin *et al.* 2000; Costin 2004; Costin *et al.* 2004). The absence of severe and extensive glaciation has led to the development of a deep organic soil which in turn provides the substrate for an almost complete vegetative cover in many areas of the Australian Alps, including the alpine zone (Costin 1954; McDougall 1982; Good 1992b). The Australian Alps with its wide elevation range contains a diverse and complex flora (McDougall 1982; Good 1992b; Kirkpatrick 1994; Costin *et al.* 2000;

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<sup>1</sup>Johnston, F. M. and Pickering, C. M. (2001a) Alien plants in the Australian Alps. *Mountain Research and Development* **21**, 284–291.  
Johnston, F. M. and Johnston, S. W. (2003) Weeds set to plume following fires. *Victorian Naturalist* **120** (5), 194-197.

Kirkpatrick 2003; Costin *et al.* 2004) which differs from mountain floras in other parts of the world in botanical composition, level of species richness and botanical zonation (Barlow 1988; Wardle 1989; Good 1992b; Kirkpatrick 2003; Costin *et al.* 2004).

Different vegetation communities are associated with altitudinal, latitudinal, climatic and edaphic factors and provide habitat for many species of animals, birds and insects (Costin 1954; Good 1992a; Green and Osborne 1994). The climate, soils and vegetation have been divided into four zones: alpine, subalpine, montane and tableland (Costin 1954; Costin *et al.* 2000). Detailed information on the landscape features, climate, soils, plant and animal communities is provided by Costin (1954, 2004); McDougall (1982); Barlow (1988); Ollier and Wyborn (1989); Good (1992a,b); Green and Osborne (1994); Kirkpatrick (1994); Costin *et al.* (2000); Kirkpatrick (2004); Galloway (2004); Costin *et al.* (2004); and Spate (2004).

## **2.2. KOSCIUSZKO NATIONAL PARK**

Most of the Australian Alps are conserved within a contiguous series of reserves collectively known as the Australian Alps National Parks (Figure 2.1). Kosciuszko National Park, in southeast New South Wales, is the largest and best known of these, encompassing more than 690 000 ha. The Park contains the most extensive contiguous alpine area on the continent as well as the highest mountain, Mt Kosciuszko at 2228 m (Good 1992a,b; Cairnes 2004a).

Kosciuszko National Park is internationally recognised under the UNESCO Man and the Biosphere Program as a World Biosphere Reserve (in 1977) with Blue Lake protected under the RAMSAR convention (ISC 2004). Few large natural protected areas, such as Kosciuszko National Park, are present in temperate Australia (Cairnes 2004a). The Park contains six wilderness areas and its alpine and subalpine areas contain unique plant and animal species (Good 1992a,b; Green and Osborne 1994; Costin *et al.* 2000; ISC 2004).

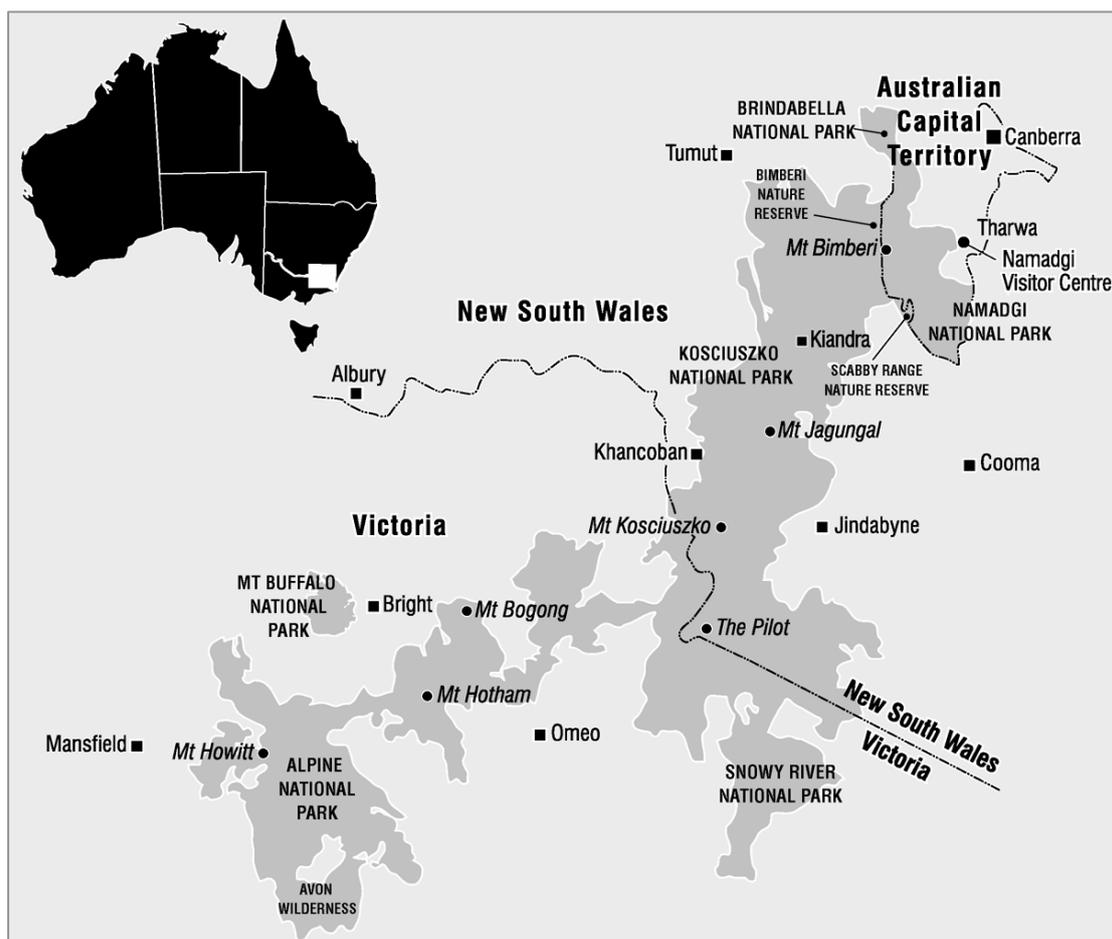


Figure 2.1. Location of the Australian Alps National Parks (modified from AALC 1999).

### 2.2.1. Vegetation, climate and soils of Kosciuszko National Park

The vegetation communities of Kosciuszko National Park strongly reflect altitudinal and climatic gradients. There are distinct floristic zones with discrete boundaries between dominant vegetation associations (Good 1992a; Costin *et al.* 2000). The alpine zone is dominated by tall alpine herbfield and heath with other communities occurring where soil moisture, aspect, drainage or temperature limit the growth of the tall alpine herbfield. The subalpine vegetation is principally *Eucalyptus niphophila* alliance (Snowgums) woodland (Costin *et al.* 2004). The montane zone is dominated by *E. pauciflora* woodlands with *E. delegatensis* occurring in wetter southerly and southeasterly aspects. The tablelands zone within the Park is relatively small but includes a wide range of soils, slopes and aspects. This provides for many vegetation associations chiefly woodlands and forests of *Eucalyptus* spp. woodlands as well as grasslands (Good 1992a; Costin *et al.* 2004).

### *Alpine zone*

The alpine area of Kosciuszko National Park is of international and national significance (Costin *et al.* 2004). The alpine tract occurs between ~1850 m to 2228 m elevation and covers an area of approximately 100 km<sup>2</sup>. Two hundred and four species of flowering plants from 94 genera and 38 families comprise the Kosciuszko alpine flora: 30 are exclusively alpine species and 21 are endemic (Costin *et al.* 2000; Costin *et al.* 2004). Plant communities include heath, sod tussock grassland, tall and short alpine herbfield, bog, fen, and wind exposed and snow patch fieldmark.

The climate of the alpine zone usually confines the plant growth season to December to March (Green and Osborne 1994; Costin *et al.* 2004). Mean monthly temperatures fall below 0°C for 4-6 months with the average maximum for the warmest month of 10°C. Annual precipitation is approximately 1780 mm to 3040 mm mainly falling as snow in the winter months. Precipitation peaks in winter-spring with minimum falls from summer to autumn (Green and Osborne 1994). Winds in the areas can commonly be 75 km/hr reaching 150 km/hr (Green and Osborne 1994). Snow is persistent, generally for four months of the year but can persist in sheltered leeward sites for much longer. This extensive and relatively long lasting snow cover insulates the natural deep alpine humus topsoil from freezing so protecting the soil flora and fauna and ensuring the continuous decomposition of soil organic matter (Brown and Millner 1989; Costin 1989; Good 1992a,b; Costin *et al.* 2000).

### *Subalpine zone*

The subalpine tract lies between 1500 m and ~1850 m. The lower level of this tract corresponds to the lower limit of the winter snowline. This area marks a transition zone in vegetation type as it is also the upper limit of the tree line. The wooded areas are dominated by the *Eucalyptus niphophila* (Snowgums) alliance (Costin *et al.* 2000) with an understorey of heath, bog or grassland vegetation. The majority of the subalpine woodland has been burnt by wildfire and grazing management fires. Treeless plains occur in valley floors where cold air drains at night. The valley floors and plains vegetation consists of wet tussock grasslands and shrubby heath lands and bogs (Worboys 1982; Costin 1989; Mallen-Cooper 1990; Good 1992a,b; Costin *et al.* 2000; Costin 2004).

The subalpine zone receives less precipitation than the alpine: annual rainfall is 760-2030 mm. Snow provides ground cover for 1-4 months of the year. Mean monthly temperatures fall below 0°C for 1-4 months a year with the warmest month at mean temperature of 15°C (Green and Osborne 1994). Soil types are similar to those in the alpine tract with transitional alpine humus soils and meadow gley podsolic soils forming the dominant groups for the subalpine and lower subalpine regions respectively (Costin 1989; Costin *et al.* 2000).

#### *Montane and tableland zones*

The montane zone occurs between 500 m and 1500 m. The associated vegetation communities include tall open sclerophyll forests in wet areas and open forest in dry areas. The dominant species are *E. pauciflora* with *E. delegatenis*, *E. bicostata*, *E. glaucescens* and *E. fastigata* occurring in specialized sites. Other species of remnant rainforest from past climatic regimes exist in the Geehi montane zone (Good 1992a).

The annual precipitation is between 600 mm to 1500 mm with intermittent snow cover depending on specific year conditions. The temperature does not often fall below 0°C with the temperature of the warmest month from 15° to 25°C (Good 1992a; Green and Osborne 1994; Costin *et al.* 2000).

The tablelands and lower slopes support mixed open woodland including *Eucalyptus* spp. woodlands and grasslands on duplex soil group. The woodlands are interspersed with small but significant areas of *Poa* and *Stipa* spp. grasslands. In the lower tableland rain shadow areas, woodlands, heath and grasslands communities are found on grey-brown podsolics and brown soils of light texture. These regions lie beneath 500 m with rainfall usually less than 600 mm per year (Good 1992a; Costin *et al.* 2004).

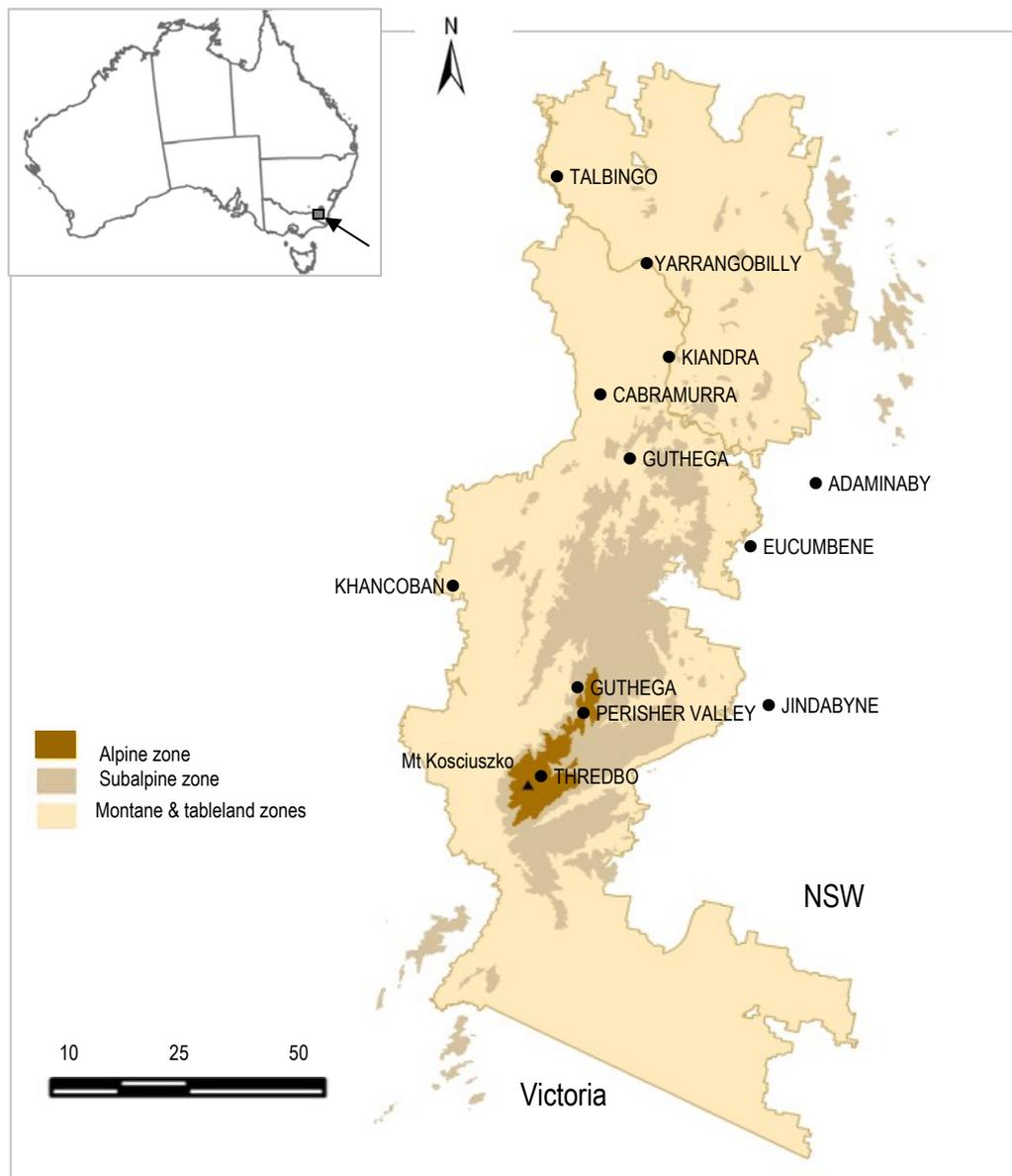


Figure 2.2. Kosciuszko National Park showing floristic zones (Source: NSW National Parks and Wildlife Service GIS database).

### 2.3. HUMAN ASSOCIATION WITH KOSCIUSZKO NATIONAL PARK

Human association with the area began with Aborigines, who are thought to have mainly used the high country in summer and had minimal effect (ISC 2004). Dramatic changes have occurred as a result of human use in the last 200 years from activities such as burning, grazing, clearing and removal of trees, road making, damming and diversion of water sources, buildings and animal and plant introduction (Costin 1954; Good 1992a; ISC 2004).

The Monaro tablelands and the Snowy Mountains region of New South Wales were officially ‘discovered’ by Europeans in 1823, and by 1831 the Monaro was

extensively settled (Good 1992a). The first European visit to the Kosciuszko area is credited to Strzelecki in 1840 with the naming of Mount Kosciuszko. In the mid 1840s James Spencer began grazing sheep and cattle in the subalpine and alpine areas (1300-1600 m) during summer. The main attraction for graziers was the 700 km<sup>2</sup> of treeless plains in the northern area of what is now Kosciuszko National Park. Between 1880 and 1940 permanent settlement of the high country occurred with the development of homestead complexes (Good 1992a; Hamilton-Smith 2004; Sullivan and Lennon 2004). With these settlements came the first introduction of exotic plants and animals to the high altitude areas of the Australian Alps (Maiden 1898; Maiden 1899; Costin 1954; Thompson and Gray 1981; Mallen-Cooper 1990).

Scientific interest in the areas' flora began with the arrival of Baron Von Mueller, the Victorian Government Botanist, in 1853. He collected and catalogued botanical samples of the area between 1853 and 1897 (Good 1992a). Overseas scientists of the time were excited by the Australian flora, however, in Australia the main interest was the use of native plants for livestock feed. By the end of the 19<sup>th</sup> century summer grazing and burning the vegetation to promote new regrowth were well established practices in areas now contained within Kosciuszko National Park. However concern over the effects of grazing on the vegetation, soils and waterways also began (Costin 1954; Good 1992a). At the same time other uses for the Kosciuszko region were developing. Tourism and recreational interest increased with the completion of a road from Jindabyne to Mount Kosciuszko in 1909. By 1932 widespread damage to the vegetation and soils in the area had been described and protection measures commenced (Worboys and Pickering 2004). At this time the New South Wales Soil Conservation Service documented damage to the water catchments and increasing levels of soil erosion due to grazing. In 1944 the Kosciuszko State Park (about 5000 km<sup>2</sup>) was created and grazing excluded from 4000 hectares around Mount Kosciuszko (ISC 2004). By 1958 grazing was withdrawn from all areas of the Park above 1370 m (Costin *et al.* 2000; Cairnes 2004a).

The Snowy Mountain Hydroelectric Scheme, 1948-1972, had large and irreversible effects on the region (Costin *et al.* 2000). The Scheme diverts the eastern-flowing Snowy River westward to the Murray and Murrumbidgee rivers. The water falls

through shafts, tunnels and power stations to generate electricity. The Scheme built seven power stations, 16 major dams, 140 km of tunnels, 80 km of aqueducts and many kilometres of roads and access trails (Mallen-Cooper 1990; Costin *et al.* 2000).

In 1963 the Kosciuszko State Park Trust declared the alpine area around Mt Kosciuszko a Primitive Area to be excluded from further major human disturbances. In 1987 Kosciuszko State Park became a National Park under the control of the National Parks and Wildlife Service of New South Wales (ISC 2004).

The greatest human pressures today in the Australian Alps, including Kosciuszko National Park is tourism connected with the ski industry (Green 1998; Sun and Walsh 1998; Pickering *et al.* 2003a; Worboys and Pickering 2004) and more recently the increased numbers of summer visitors particularly to the alpine area (Johnston and Growcock 2005). Winter tourism includes downhill skiing, cross-country skiing with or without the use of accommodation and associated facilities. Summer mountain tourism includes walking, horse riding, mountain biking, sightseeing, golf, tennis and fishing (Worboys and Pickering 2004).

### **2.3.1. 2003 fires in the Australian Alps**

In January-February 2003, the most extensive fires in 60 years occurred in the Australian Alps, including Kosciuszko National Park (Worboys 2003). Over 1.73 million hectares burnt, including 70% of the area above 1500 m in Kosciuszko National Park (Worboys 2003). The impact of the fires varied, ranging from low intensity fires where the effects were only a partial burn of the undergrowth to high intensity fires, where everything including the organic topsoil has been burnt (Johnston and Johnston 2003). In less severely affected areas regeneration of the native flora had started within a month of the fires (Johnston and Johnston 2003).

A survey of road verges in the Snowy Mountains from Jindabyne to Tumut in March 2003 found that exotic species often survived the fires along roads with road verges containing Clover (*Trifolium* spp.), Sweet Vernal Grass (*Anthoxanthum odoratum*), Brown Top Bent (*Agrostis capillaris*), Sheep Sorrel (*Acetosella vulgaris*), Dandelion (*Taraxacum officinale*) and Yarrow (*Achillea millefolium*) (Johnston and Johnston 2003).

With the removal or reduction of native vegetation and exposure of bare soil in fire affected areas adjacent to unburnt exotic road verges, there is the potential for the spread of exotics into areas that previously had near complete native vegetation cover (Johnston and Johnston 2003). This process has been noted in the past in the Australian Alps after much smaller fire events (Morgan and Lunt 1999; Maret and Wilson 2000; Wahren *et al.* 2001). In the next couple of years the rapid germination and growth of the many exotics may further limit the germination and establishment of early successional native species in bare areas created by the fires (Morgan and Lunt 1999; Maret and Wilson 2000; Wahren *et al.* 2001). This threat could be even more pronounced in areas which were burnt to a higher intensity, as competition for the exotic species is even less. The organic topsoils have been (partially) lost making establishment of natives even slower in these areas (Johnston and Johnston 2003).

### **2.3.2. Exotic plants in the Australian Alps**

Human activities have had a range of impacts on the unique biodiversity and natural ecological processes of the Australian Alps (Cairnes 2004b). For example, as a result of past and current land use there are a large number of exotic plant species, including environmental weeds in the Australian Alps including Kosciuszko National Park (McDougall 1982; Mallen-Cooper 1990; Good 1992a; McDougall and Appleby 2000; Johnston and Pickering 2001a). Some of these species are threatening the natural values of the area. The significance of this threat is increasingly being recognised, with the current draft Plan of Management for Kosciuszko National Park listing weeds as a priority (NSW NPWS 2003; Cairnes 2004b).

Although surveys of vegetation including exotics have been undertaken for over 100 years, until recently these data have not been collated to provide an estimate of the diversity of exotic plants and their associations with human activities in the Australian Alps overall, and in Kosciuszko National Park in particular. The next chapter of this thesis reviews published records of exotic plants in the Australian Alps, with a focus on the alpine and subalpine regions of Kosciuszko National Park. It also describes the distribution of these plants including their association with different types of human activities, their origins and biology.

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## CHAPTER 3

### EXOTICS IN THE AUSTRALIAN ALPS<sup>2</sup>

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#### 3.1. INTRODUCTION

For the Australian Alps, as for other protected areas, exotic plants including environmental weeds are an increasing threat. It is therefore important to determine the diversity of exotic plants present and the types of disturbance and other environmental factors associated with them. This chapter reviews the diversity of exotic plants recorded in the Australian Alps, with a focus on Kosciuszko National Park, the characteristics of these plants, the types of human activities they are associated with and the issues they raise for protected area managers.

##### 3.1.1. Information sources

Records of exotic species occurrences in the alpine and subalpine regions of the Australian Alps were compiled from just over one hundred years of published and unpublished vascular plant records (Maiden 1898, 1899; Costin 1954; Thompson and Gray 1981; McDougall 1982; Walsh *et al.* 1984; Mallen 1986; Mallen-Cooper 1990; Robinson and EcoPlan Pty Ltd 1996; Pearson 1997; Duncan 1998; Sainty *et al.* 1998; CSIRO 1999; Ingwersen 1999; McDougall and Appleby 2000). Records of the exotic species were entered into a database, and the taxonomy revised according to the Flora of New South Wales (Harden 1993). Information on the location, habitat, form, dispersal mechanism, family, origin, environmental tolerances and flowering

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<sup>2</sup>Johnston, F. M. and Pickering, C. M. (2001a) Alien plants in the Australian Alps. *Mountain Research and Development* **21**, 284-291.

Johnston, F., Pickering, C.M. and Enders, G. (2001) Alien Plants in the Australian Alps. Cooperative Research Centre for Sustainable Tourism. Griffith University, Gold Coast. Fact Sheet.

Johnston, F. (2002) Alien Plants in the Australian Alps. In: Research on Australia's High Country 1999-2001. (eds. Pickering, C.M., Green, K. and Bridle, K.). Research Report. Cooperative Research Centre for Sustainable Tourism. p 34.

Pickering, C.M., Hill, W. and Johnston, F. (2003) Ecology of disturbance: the effect of tourism infrastructure on weeds in the Australian Alps. In: Celebrating Mountains. Proceedings of an International Year of the Mountains Conference. (ed. Janet Mackay and Associates). Jindabyne, Australia, November 25-28 2002. Australian Alps Liaison Committee, Canberra. pp. 213-21.

Pickering, C.M., Hill, W. and Johnston, F. (2005) Snapshot 14.13 Weeds, tourism, and climate change. In: Protected Area Management: Principles and Practice, Second Edition. (eds. G. Worboys, T. DeLacy, and M. Lockwood). Cambridge University Press, Cambridge. pp. 399-400.

period of the species were added from the original references and other texts (Auld and Medd 1992; Bodkin 1992; Harden 1993; Lazarides *et al.* 1997). Estimates of the total and regional diversity of exotics were then obtained from the database. Location data were used to identify the type of land use that may favour particular species.

### 3.2. HISTORY OF EXOTIC PLANT INTRODUCTIONS

One of the first records of exotics in the Australian Alps was the result of a survey of New South Wales vegetation by Maiden (1898, 1899, Table 3.1). Sheep and cattle grazing were already common in much of the Australian Alps at this time, with thousands of cattle and sheep pastured in the region (Good 1992a; Johnston 1993). Only one species (*Alchemilla xanthochlora*) was recorded as exotic in the alpine area (Maiden 1898; 1899), although its status as introduced is doubtful (Costin *et al.* 2000). *Alchemilla xanthochlora*, *Acetosella vulgaris*, *Hypochaeris radiata*, and *Taraxacum officinale* were recorded in subalpine areas and *Vulpia bromoides*, *Hordeum murinum*, *Lotus corniculatus* and *Picris hieracioides* (now known as *Helminthotheca echioides*<sup>3</sup>) were recorded in the montane area (Maiden 1898; 1899).

Table 3.1. Exotic plant species recorded in surveys in subalpine and alpine areas of the Australian Alps between 1898 and 1999.

Species	NSW					ACT		Victoria		
	1898 <sup>1</sup>	1954 <sup>2</sup>	1981 <sup>3</sup>	1986 <sup>4</sup>	1997 <sup>5</sup>	1998 <sup>6</sup>	1999 <sup>7</sup>	1982 <sup>8</sup>	1984 <sup>9</sup>	1999 <sup>10</sup>
<b>Total</b>	6	44	76	135	67	144	10	41	9	102
<i>Acetosella vulgaris</i> Fourr.	x	x	x	x		x	x	x	x	x
<i>Achillea millefolium</i> L.		x	x	x	x	x		x		
<i>Agrostis capillaris</i> L.		x	x	x	x	x		x		x
<i>Agrostis gigantea</i> Roth						x				
<i>Agrostis stolonifera</i> L.			x	x		x		x		x
<i>Aira caryophylla</i> L.			x	x	x	x				x
<i>Aira praecox</i> L.			x							
<i>Alchemilla xanthochlora</i> Roth.	x		x	x		x			x	
<i>Allium schoenoprasum</i> L.										x
<i>Alnus glutinosa</i> (L.) Gaertn.						x				
<i>Alstroemeria</i> I Graham			x	x		x				x
<i>Amsinckia calycina</i> (Moris) Chater		x		x		x				
<i>Anagallis arvensis</i> L.		x		x	x	x				x
<i>Anthemis arvensis</i> L.				x	x	x				
<i>Anthoxanthum odoratum</i> L.		x	x	x	x	x		x		x

<sup>3</sup> In Costin *et al.* 2000 (page 41) *Picris hieracioides* is considered a native species.

Species	NSW					ACT		Victoria		
	1898 <sup>1</sup>	1954 <sup>2</sup>	1981 <sup>3</sup>	1986 <sup>4</sup>	1997 <sup>5</sup>	1998 <sup>6</sup>	1999 <sup>7</sup>	1982 <sup>8</sup>	1984 <sup>9</sup>	1999 <sup>10</sup>
<i>Aphanes arvensis</i> L.			x	x	x	x			x	x
<i>Aquilegia vulgaris</i> L.										x
<i>Arenaria serpyllifolia</i> L.			x	x		x				
<i>Arrhenatherum elatius</i> var <i>elatius</i> JS & C Presl			x	x		x				x
<i>Avena sativa</i> L.										x
<i>Barbarea verna</i> (Miller) Asch.						x				
<i>Bellis perennis</i> L.										x
<i>Borago officinalis</i> L.						x				
<i>Bromus diandrus</i> Roth			x	x		x				x
<i>Bromus hordeaceus</i> L.		x	x	x	x	x		x		x
<i>Bromus madritensis</i> L.				x		x				
<i>Bromus sterilis</i> L.				x	x	x				x
<i>Bromus tectorum</i> L.				x	x	x				
<i>Callitriche stagnalis</i> Scop.				x		x				x
<i>Campanula rapunculoides</i> L.		x								
<i>Capsella bursa-pastoris</i> L. Medikus		x	x		x				x	
<i>Centaurium erythraea</i> Rafn				x	x	x	x			
<i>Centipeda cunninghamii</i> DC.										x
<i>Cerastium fontanum</i> Brama. ssp. <i>triviale</i> (Murb.) Jalas	x	x	x	x	x		x	x	x	
<i>Cerastium glomeratum</i> Thuill.		x		x	x	x		x	x	x
<i>Chenopodium album</i> L.				x	x	x	x	x		x
<i>Chenopodium murale</i> L.		x		x	x	x				
<i>Chondrilla juncea</i> L.			x	x		x				
<i>Chrysanthemum parthenium</i> (L.) Pers.										x
<i>Cirsium lanceolatum</i> Scop		x								
<i>Cirsium vulgare</i> (Savi) Ten			x	x	x	x	x	x		x
<i>Clinopodium vulgare</i> L.				x						x
<i>Conium maculatum</i> L.				x		x				
<i>Conyza bonariensis</i> (L.) Cronq.				x		x				x
<i>Cotoneaster microphyllus</i> Wallich ex Lindl.									x	
<i>Cotoneaster</i> sp.				x		x				x
<i>Crepis capillaris</i> (L.) Wallr			x	x	x	x	x			x
<i>Crepis setosa</i> Hallier f.										x
<i>Crepis virens</i> L.		x								
<i>Crococsmia x crocosmiliflora</i> (Lemoineex Morren) N.E.Br.								x		
<i>Cytisus scoparius</i> (L.) Link ssp. <i>scoparius</i>			x		x	x	x		x	
<i>Dactylis glomerata</i> L.		x	x	x	x	x		x		x
<i>Dianthus barbatus</i> L.						x				x
<i>Diplotaxis tenuifolia</i> DC		x		x		x				
<i>Echium plantagineum</i> L.						x				x
<i>Echium vulgare</i> L.			x	x	x	x				
<i>Elytrigia repens</i> L. Nevski					x					
<i>Epilobium ciliatum</i> Rafn			x	x		x		x		x
<i>Erodium cicutarium</i> (L.) L'Her. Ex Aiton	x		x	x	x					

Species	NSW					ACT		Victoria		
	1898 <sup>1</sup>	1954 <sup>2</sup>	1981 <sup>3</sup>	1986 <sup>4</sup>	1997 <sup>5</sup>	1998 <sup>6</sup>	1999 <sup>7</sup>	1982 <sup>8</sup>	1984 <sup>9</sup>	1999 <sup>10</sup>
<i>Erophila verna</i> L. Chevall ssp. <i>verna</i>		x	x	x	x					
<i>Euphorbia peplus</i> L.				x						x
<i>Festuca arundinacea</i> Schreb.				x				x		x
<i>Festuca rubra</i> L. ssp. <i>rubra</i>		x	x	x	x	x		x		
<i>Fumaria</i> sp.				x		x				x
<i>Gnaphalium coarctatum</i> Willd.						x				x
<i>Helminthotheca echioides</i> (L.) Holub	x	x	x	x	x					
<i>Hirschfeldia incana</i> (L.) Lagreze- Fassett	x			x	x					
<i>Holcus lanatus</i> L.			x	x	x	x		x		x
<i>Hordeum glaucum</i> Steudel		x	x	x	x	x				
<i>Hordeum leporinum</i> Link			x	x	x	x		x		
<i>Hordeum marinum</i> L.		x			x	x				
<i>Hyacinthoides hispanica</i> (Mill) Rothm		x								x
<i>Hypericum perforatum</i> L.				x				x		x
<i>Hypochaeris glabra</i> L.				x						
<i>Hypochaeris radicata</i> L.	x	x	x	x		x		x	x	x
<i>Ilex aquifolium</i> L.		x	x	x	x	x				x
<i>Iris germanica</i> L.				x						x
<i>Juncus acutifolius</i> Ehrh. ex Hoffm.									x	
<i>Juncus articulatus</i> L.			x	x	x	x		x		x
<i>Juncus bufonius</i> L.			x	x	x	x				x
<i>Juncus effusus</i> L.			x	x		x		x		x
<i>Juncus tenuis</i> Willd.			x	x		x		x		x
<i>Lamiastrum gemeobdolen</i> (L.) Ehrend. & Polatschek			x	x		x				
<i>Lepidium campestre</i> (L.) R Br.		x	x	x						x
<i>Leucanthemum maximum</i> (Ramond) DC	x	x	x		x				x	
<i>Leucanthemum vulgare</i> Lam.				x		x				x
<i>Linaria arvensis</i> (L.) Desf.				x		x				
<i>Lolium perenne</i> L.		x	x	x	x			x		x
<i>Lotus corniculatus</i> L.		x	x	x	x	x		x		x
<i>Lotus uliginosus</i> Schkuhr.				x		x				
<i>Lupinus incanus</i> (Lindl.) Anderson			x		x				x	
<i>Malus domestica</i> Borkh.				x	x	x		x		x
<i>Malva neglecta</i> Wallr.		x		x	x	x				x
<i>Malva nicaeensis</i> All.		x		x		x				
<i>Marrubium vulgare</i> L.		x	x	x		x				
<i>Medicago lupulina</i> L.		x		x	x	x				
<i>Medicago sativa</i> L.		x	x	x	x	x				
<i>Melilotus albus</i> Medik.			x	x	x	x		x		
<i>Mentha spicata</i> L.			x	x		x				x
<i>Mimulus moschatus</i> Douglas ex Lindl.				x		x				x
<i>Moenchia erecta</i> (L.) Gaertn., Meyer & Scherb.			x	x		x				x
<i>Muscari armeniacum</i> Leichtlin ex Baker				x		x				x
<i>Myosotis discolor</i> Pers.				x	x					x
<i>Narcissus</i> sp.			x	x		x				

Species	NSW					ACT		Victoria		
	1898 <sup>1</sup>	1954 <sup>2</sup>	1981 <sup>3</sup>	1986 <sup>4</sup>	1997 <sup>5</sup>	1998 <sup>6</sup>	1999 <sup>7</sup>	1982 <sup>8</sup>	1984 <sup>9</sup>	1999 <sup>10</sup>
<i>Nassella trichotoma</i> (Nees) Hack. Ex Arechav.				x		x				
<i>Oenothera glazioviana</i> M.Micheli			x	x	x					
<i>Onopordum acanthium</i> L.		x	x	x	x					
<i>Oxalis corniculata</i> L.		x	x	x		x	x			
<i>Pastinaca sativa</i> L. ssp. <i>sativa</i>						x				x
<i>Penstemon</i> sp.				x		x				x
<i>Petrorhagia nanteuillii</i> (Burnat) P.W. Ball & Heyw.					x					
<i>Phleum pratense</i> L.			x	x	x	x		x		x
<i>Pinus contorta</i> Douglas ex Loundon				x		x				
<i>Pinus jeffreyi</i> Grev. & Balf.				x		x				
<i>Pinus mugo</i> Turra				x		x				
<i>Pinus radiata</i> D.Don										x
<i>Pinus sylvestris</i> L.				x		x				
<i>Plantago lanceolata</i> L.		x	x	x	x	x		x		x
<i>Plantago major</i> L.										x
<i>Poa annua</i> L.		x	x	x	x	x		x		x
<i>Poa pratensis</i> L.			x	x	x	x		x		x
<i>Polygonum arenastrum</i> Jordan ex Boreau			x	x	x	x				
<i>Polygonum aviculare</i> L.		x		x	x	x		x		x
<i>Populus alba</i> L.				x		x				
<i>Potentilla recta</i> L.			x	x		x			x	x
<i>Prunella vulgaris</i> L.				x		x				x
<i>Prunus cerasifera</i> Ehrh.				x						x
<i>Quercus</i> sp.				x		x				
<i>Ranunculus muricatus</i> L.				x		x				x
<i>Ranunculus repens</i> L.				x		x		x		x
<i>Raphanus raphanistrum</i> L.				x		x				x
<i>Reseda luteola</i> L.			x	x		x				
<i>Ribes uva-crispa</i> L.		x								
<i>Rorippa palustris</i> (L.) Besser				x		x				
<i>Rosa rubiginosa</i> L.			x		x	x		x		x
<i>Rubus discolor</i> Weihe & Nees						x				
<i>Rubus fruticosus</i> spp. agg. L. s. lat.				x			x	x		x
<i>Rubus idaeus</i> L.										x
<i>Rumex conglomeratus</i> Murray										x
<i>Rumex crispus</i> L.		x	x	x	x	x		x		x
<i>Rumex obtusifolia</i> ssp. <i>obtusifolia</i> L.						x				
<i>Sagina procumbens</i> L.			x	x		x				
<i>Salix cinerea</i> L.						x				x
<i>Salix</i> spp.				x		x				
<i>Salvia verbenaca</i> L.			x	x		x				
<i>Silene vulgaris</i> (Moench) Garcke			x	x						
<i>Sisymbrium officinale</i> (L.) Scop.		x		x		x				
<i>Solanum tuberosum</i> L.										x
<i>Sonchus asper</i> (L.) Hill			x	x	x	x				x
<i>Sonchus oleraceus</i> L.				x		x				x
<i>Spergularia rubra</i> (L.) J&C Prest			x	x	x	x		x		x
<i>Spiraea alba</i> Du Roi										x

Species	NSW					ACT		Victoria		
	1898 <sup>1</sup>	1954 <sup>2</sup>	1981 <sup>3</sup>	1986 <sup>4</sup>	1997 <sup>5</sup>	1998 <sup>6</sup>	1999 <sup>7</sup>	1982 <sup>8</sup>	1984 <sup>9</sup>	1999 <sup>10</sup>
<i>Stellaria graminea</i> L.			x	x						
<i>Stellaria media</i> (L.) Villars				x		x				
<i>Taraxacum officinale</i> Weber x Wiggers s. lat.	x	x	x	x	x	x	x	x	x	x
<i>Tragopogon dubius</i> Scop.			x	x	x	x				
<i>Trifolium ambiguum</i> M. Bieb			x	x	x	x				
<i>Trifolium arvense</i> L.			x	x	x	x				
<i>Trifolium dubium</i> Sibth.				x	x	x		x		x
<i>Trifolium glomeratum</i> L.				x	x	x				x
<i>Trifolium hybridum</i> L.			x	x	x	x				
<i>Trifolium pratense</i> L.			x	x	x	x				x
<i>Trifolium repens</i> L.		x	x	x	x	x	x	x	x	x
<i>Verbascum thapsus</i> L.			x	x	x	x				
<i>Verbascum virgatum</i> Stokes		x	x	x	x	x		x		
<i>Veronica arvensis</i> L.			x	x	x	x				x
<i>Veronica peregrina</i> L.						x				x
<i>Veronica persica</i> Poir.										x
<i>Veronica serpyllifolia</i> L.				x		x				
<i>Vinca major</i> L.				x		x				
<i>Vinca minor</i> L.				x						x
<i>Vinca sativa</i> ssp. <i>nigra</i>						x				x
<i>Viola arvensis</i> Murr.		x	x	x	x	x				x
<i>Vulpia bromoides</i> (L.) Gray	x		x	x	x	x		x		x
<i>Vulpia myuros</i> (L.) Gmel			x	x	x	x				x

<sup>1</sup>Maiden, J. H. (1898) A contribution towards a flora of Mount Kosciusko. *Agricultural Gazette of N.S.W.* **9**, 720-740. Maiden, J.H., (1899) A second contribution towards a flora of Mount Kosciusko. *Agricultural Gazette of N.S.W.* **10**, 1001-1042.

<sup>2</sup>Costin, A. B. (1954) *A Study of the Ecosystems of the Monaro Region of New South Wales*. Government Printer, Sydney, pp. 860.

<sup>3</sup>Thompson, J. and Gray, M. (1981) A check list of subalpine and alpine plant species found in the Kosciusko region of New South Wales. *Telopea* **2**, 299-346.

<sup>4</sup>Mallen-Cooper, J. (1990) *Introduced Plants in the High Altitude Environments of Kosciusko National Park, South-Eastern Australia*. PhD Thesis, Australian National University. List based on field work conducted in 1986.

<sup>5</sup>Pearson, (1997) unpublished data resampling Mallen-Coopers plots in Kosciuszko National Park.

<sup>6</sup>Duncan, A. (1998) *Weed Species List for Kosciuszko National Park*. Compiled by Michael Doherty, CSIRO and Division of Wildlife and Ecology. Canberra 1993, updated by Ann Duncan 1998.

<sup>7</sup>Ingwersen, F. (1999) *Study of the Vascular Plants in Treeless and Timbered Sites Naas-Gudgenby Catchment, ACT*. Unpublished report.

<sup>8</sup>Walsh, N. G., Barley, R. H. and Gullen, P. K. (1984) *The Alpine Vegetation of Victoria (excluding the Bogong High Plains Region)*. Department of Conservation, Forests and Lands. ESP Number 376

<sup>9</sup>McDougall, K. (1982) *The Alpine Vegetation of the Bogong High Plains*. Environmental Studies Publication Number 357 Environmental Studies Division. Ministry of Conservation. pp. 1-162.10

<sup>10</sup>McDougall, K. L. and Appleby, M. L. (2000) *Plant Invasions in the High Mountains of North-eastern Victoria*. *Victorian Naturalist*. **117**, 52-59.

By the 1950s exotic plant diversity had increased (Table 3.1). Costin (1954) recorded six exotic species in the alpine area of the New South Wales section of the Australian Alps (*Acetosella vulgaris*, *Hypochaeris radicata*, *Taraxacum officinale*, *Poa annua*, *P. pratensis*, and *Cerastium fontanum* subsp. *triviale*). A further 38 species were found in the subalpine zone and 25 species in the montane zone (Table 3.1). As a result of serious soil erosion and related impacts of cattle and sheep grazing and associated burning practices, grazing was banned from most of the Australian Alps by the 1950s (Good 1992a). Although grazing is still carried out in some alpine areas of Victoria this practice is currently under debate (Alpine Grazing Taskforce 2005). To reduce the impacts of erosion on the Kosciuszko summit area, soil conservation work was undertaken in the 1950s in the alpine and subalpine areas of New South Wales (Johnston 1995). Much of this rehabilitation made use of exotics including *Trifolium arvense*, *T. dubium*, *T. pratense*, *T. repens*, *T. ambiguum*, *T. glomeratum*, *T. hybridum*, *Agrostis capillaris*, *A. stolonifera*, *Dactylis glomerata*, *Festuca rubra*, *Lolium perenne*, *Phleum pratense*, *Poa annua*, *P. pratense*, and *Avena* sp. (Costin and Wimbush 1963; Bryant 1971; Good 1976). Natives have now replaced exotic grasses in rehabilitation work by conservation organisations in much of the Australian Alps (Parr-Smith and Polley 1998).

The construction of the Snowy Mountain Hydroelectric Scheme (1949 to 1972) had large and in some cases, irreversible effects on the topography, hydrology and ecology of the region (Good 1992a). Human settlement associated with the Scheme introduced many exotic garden plants such as *Cytisus scoparius* and *Lupinus incanus*. Large-scale plantings of exotic trees including *Pinus* and *Populus* species also occurred (Good 1992a).

Tourism and recreation have been part of the Australian Alps since the 1860s when the first ski lodge was built at Kiandra, New South Wales (Good 1992a; Johnston 1995; Worboys and Pickering 2004). In the last thirty years this industry has expanded rapidly (Good 1992a; Worboys and Pickering 2004) with a corresponding alteration in soil, hydrology and ecology of the area (Cousins 1998; Growcock 1999). Associated with the expansion of tourism was the rapid expansion of exotics in the area around resorts (McDougall and Appleby 2000; Pickering *et al.* 2003b,

Table 3.1). Some exotic species were planted into gardens including *Lamiastrum gemeobdolen*, *Aquilegia vulgaris*, *Mentha spicata*, *Iris* spp., *Lupinus* spp., *Dianthus barbatus*, *Leucanthemum maximum*, *L. vulgare* and *Vinca minor* (McDougall and Appleby 2000). Park management agencies also introduced exotic species for more practical purposes, such as vigorously growing species used to rehabilitate ski slopes after the winter season. The New South Wales National Parks and Wildlife Service 'Alpine mix' used for soil rehabilitation included the exotic *Agrostis capillaris*, *Dactylis glomerata*, *Festuca rubra*, *Lolium perenne*, *Poa pratensis*, *Trifolium pratense* and *T. repens*. Today only one exotic species, *Festuca rubra* is still used in at higher altitudes in New South Wales by park organisations (Graeme Enders, NSW NPWS, pers. comm., 2000).

Surveys conducted in the early 1980s found 200 exotic species in the New South Wales section of the Australian Alps. Twenty-seven of these were recorded in the alpine area and 70 were recorded in both the alpine and subalpine area (Thompson and Gray 1981, Table 3.1). A study in 1986 examining the distribution of exotic species on roadsides and adjacent natural areas in Kosciuszko National Park, found 48 species in the alpine area, 81 in the alpine and subalpine area, and 215 species in the combined alpine, subalpine and montane areas (Mallen-Cooper 1990). A different alpine and subalpine vegetation study in 1997 found 68 species from 19 families, with 46 in the alpine, and 58 in the subalpine areas (Pearson 1997).

In a snapshot biodiversity survey over two days in January 2002 a 27 square kilometre area from Thredbo Village to the top of Mount Kosciuszko recorded 146 exotic species. The results of the biodiversity study showed that the majority of these species were associated with tourism infrastructure (Pickering *et al.* 2002). Within the garden areas of Thredbo Village 103 exotic taxa were recorded, mostly deliberate plantings in gardens and public places. In the disturbed areas surrounding the resort 49 of the 51 taxa were exotic (Pickering *et al.* 2002; Pickering *et al.* 2003b).

These flora surveys differ in scale, timing and methodology. Although these differences may contribute to the variation seen in exotic plant diversity among the studies, the overall trend is an increase in total exotic diversity with time (Table 3.1). Activities that are associated with exotic plant diversity and abundance such as the

construction of roads, trails and car parks have also increased dramatically, particularly during the last 30 years (Mallen-Cooper 1990; Johnston and Pickering 2001a; Worboys and Pickering 2004).

### 3.2.1. Diversity and distribution of exotic plants

A total of 175 exotic vascular plant species have been recorded in the subalpine and alpine zones (above 1500 m) of the Australian Alps (Table 3.2). Using only those surveys conducted in the five years prior to the 2002 biodiversity survey (Pearson, 1997; Ingwersen 1999; Duncan 1998; McDougall and Appleby 2000), 140 exotic species are present in the Australian Alps.

The total number of species and the number of families and genera have increased over the last hundred years. Only five families were recorded in the 1890s. Currently species representing 41 families and 122 genera are recorded for the area (Table 3.2). The number of species, genera and families varies among the states. New South Wales, with the largest contiguous alpine and subalpine areas, has the largest number of exotic species, 165. Victoria with slightly smaller alpine and subalpine areas has 117 species. Only 10 species were recorded for the small alpine and subalpine areas of the Australian Capital Territory, although this may be an underestimate due to under-sampling of the area (Table 3.2). Around half of the exotic plants in the subalpine region do not currently extend into the alpine zones.

Table 3.2. Number of exotic plant families, genera and species recorded in the Australian Alps above 1500 m. (Information sources as listed in Table 3.1).

<b>Location</b>	<b>Area (km<sup>2</sup>)</b>	<b>Family</b>	<b>Genera</b>	<b>Species</b>
New South Wales	1200	41	117	165
Victoria	1000	29	92	117
Australian Capital Territory	150	8	11	10
Total		41	122	175

Many exotic plants are associated with specific types of land use in the Australian Alps. Based on their location, exotic plants are categorised in this study as ‘grazing exotics’, ‘rehabilitation exotics’, ‘resort exotics’, and ‘roadside and path exotics’ (Table 3.3), with many species associated with more than one type of land use.

Table 3.3. Number of exotic plant families associated with different types of human disturbance within the Australian Alps.

Family	Grazing exotic <sup>1</sup>	Grazing rehab <sup>2</sup>	Naturalised exotic <sup>3</sup>	Roadside/path exotic <sup>4</sup>	Resort exotic <sup>5</sup>	Tourism Rehab <sup>6</sup>
Total	43	19	36	136	102	8
Amaryllidaceae				1		
Apiaceae				1	1	
Apocynaceae				2	1	
Aquifoliaceae	1			1	1	
Asteraceae	8	2	6	16	14	
Boraginaceae	1	2	2	3	2	
Brassicaceae	3	1		8	3	
Callitricheaceae				1	1	
Campanulaceae	1					
Caryophyllaceae	2	1	3	6	5	
Chenopodiaceae	1			6	1	
Eurphoiaceae				1	1	
Fabaceae	4		6	14	7	
Fagaceae				1		
Fumariaceae				1	1	
Gentianaceae			1	1		
Geraniaceae	1			1		
Grossulariaceae	1					
Guttifereae				1	1	
Iridaceae				1	2	
Juncaceae			2	4	5	
Labiatae	1			3	2	
Lamiaceae				2	1	
Liliaceae				2	4	
Malvaceae	2			2	1	
Onagraceae				2	1	
Oxalidaceae	1			1		
Pinaceae				4	1	
Plantaginaceae	1			1	2	
Poaceae	9	10	8	23	18	8
Polygonaceae	3	1	1	4	4	
Primulaceae	1	1		1	1	
Ranunculaceae			1	2	3	
Resedaceae				1		
Rosaceae		1	2	8	10	
Salicaceae				2	1	
Scrophulariaceae	1		4	7	5	
Solaneaceae					1	
Violaceae	1			1	1	

Rehab. = Rehabilitation 1. Costin (1954); 2. Costin and Wimbush (1963); Bryant (1971); Good (1976); 3. McDougall (1982); Walsh et al. (1984); Mallen-Cooper (1990); 4. Mallen-Cooper (1990); Pearson (1997); 5. McDougall and Appleby (2000); 6. Graeme Enders, NSW NPWS pers. comm. (2000).

There are 136 species of exotic plants recorded along roadsides and paths in Kosciuszko National Park alone (Mallen-Cooper 1990; Pearson 1997). This type of disturbance could account for just fewer than 80% of exotic species found in the

Australian Alps (Table 3.3). The next largest group is the ‘resort exotics’ with 58% of species found in and around resort buildings and other infrastructure. Without adequate control, roadside and resort exotics may act as sources of propagules for dispersal into surrounding vegetation (Mallen–Cooper 1990). Just over 20% of exotic species already appear to be independent of human disturbance to provide suitable habitats, having become ‘naturalised exotics’ (Table 3.3).

### **3.2.2. Origin and biology of exotic plants**

A large number of the exotic taxa represent just four families: Poaceae (16.1%), Asteraceae (13.2%), Fabaceae (8.6%) and Rosaceae (6.9%). Many Poaceae species were introduced during the early grazing period (9 species) (Costin 1954), or in revegetation work (10 species, Table 3.3). Some species used in rehabilitation work (*Agrostis capillaris*, *Festuca rubra*, *Phleum pratense* and *Holcus lanatus*) are now considered a threat to the native vegetation (Johnston 1995). The greatest diversity of Poaceae was associated with roadsides (23 species) and resorts (18 species).

Some Asteraceae species have been deliberately introduced, sometimes in gardens from where they have escaped into surrounding native vegetation, for example, *Leucanthemum maximum* and *L. vulgare* (McDougall and Appleby 2000). Other Asteraceae species are common pasture exotics in Australia and overseas such as *Onopordum acanthium*, *Taraxacum officinale*, *Hypochaeris radicata*, and *Achillea millefolium* (Lazarides *et al.* 1997) and are found along roadsides and resorts in the Australian Alps (Table 3.1).

Fabaceae are a relatively uncommon family in native alpine flora in Australia and overseas (Körner 1999; Costin *et al.* 2000). However, non-native species of clovers (*Trifolium* spp., *Medicago* spp. and *Melilotus albus*) have colonised the Australian Alps. They were widely introduced by early graziers and used for rehabilitation work in the Australian Alps (Johnston 1995). The low growing clovers with relatively extensive vegetative spread are very different in their ecological role and life history to the native peas in the alpine and subalpine which are all shrubs (Costin *et al.* 2000). The introduced clovers appear to be successful even at high altitude in the Australian Alps. They are found on the highest peaks with six species having become naturalised weeds (Duncan 1998).

The majority of the exotics in the Australian Alps originate in Europe and Asia (Auld and Medd 1992; Bodkin 1992; Harden 1993; Lazarides *et al.* 1997, Table 3.4). Slightly more than half of the listed species are perennials (54%), with 20% annuals and the remainder biennials. Ninety percent of the exotic species found were herbs, grasses, or rushes, with only 10% shrubs or trees. Many of the taller plants such as the broom (*Cytisus scoparius*) and willows (*Salix* spp.) are receiving attention due to the significant impact they have on the visual environment (Mallen-Cooper 1990). However, many of the smaller stature exotics may also pose an environmental threat in the high altitude areas (Robinson and EcoPlan Pty Ltd 1996). These include highly competitive species such as *Achillea millefolium*, *Dactylis glomerata* and *Hypericum perforatum* that are problem weeds in other national parks in Australia (Sainty *et al.*, 1998; Coyne 2003).

Table 3.4. Origins of exotic species found in the alpine and subalpine areas of the Australian Alps. (Based on surveys by Pearson 1997; Ingwersen 1999; Duncan 1998; McDougall and Appleby 2000).

<b>Origins</b>	<b>% species</b>
Asia only	3.5
Cosmopolitan	1.4
Europe and Asia	17.5
Europe and Mediterranean	2.8
Europe and North America	2.8
Europe only	38.5
Europe, Africa, Mediterranean	2.1
Europe, Asia and Africa	8.4
Europe, Asia, Africa and North America	2.1
Europe, Asia, North America and Mediterranean	0.7
Mediterranean	2.1
North and South America	9.8
Northern Hemisphere	5.6
Other	2.4

Sources: Auld and Medd 1992; Bodkin 1992; Harden 1993; Lazarides *et al.* 1997; Robinson and EcoPlan Pty Ltd 1996; Sainty *et al.* 1998.

The exotic species in the Australian Alps appear to have a range of dispersal mechanisms. Assuming that the dispersal mechanism considered characteristic of each species elsewhere (Auld and Medd 1992; Bodkin 1992; Harden 1993) also applies in the Australian Alps, it would appear that 8.5% of exotic species just spread vegetatively, 59% spread only by seed, while 32.5% spread both vegetatively and by seed dispersal. Seed may be dispersed by animals, both internally and externally, water, wind or a combination of any of these factors (Bodkin 1992). The method of

dispersal is dependent on the type of seed and its characters. For example, many of the berry-producing exotics rely on birds for dispersal. For exotics found near water, such as the willows and rushes, water is often the primary mechanism for seed dispersal (Sainty *et al.* 1998).

As would be expected, many exotic species in the Australian Alps are considered to be frost and drought resistant (47%) (Auld and Medd 1992; Bodkin 1992; Harden 1993). It is interesting to note however, that 11% of the species found in the Alps are considered to be drought and frost-tender in other habitats but are still found in areas subject to freezing temperatures in the Australian Alps. For the frost-tender perennials, survival in the snow country may involve reshooting from underground storage organs (for example, *Solanum tuberosum*, *Alstroemeria aurea*, *Achillea millefolium* and *Ranunculus repens* (Auld and Medd 1992; Bodkin 1992; Harden 1993). Other exotics avoid the cold winters by re-establishing each year from the soil seed bank or seed dispersed from other areas. The exotics of the alpine zone, however, are not annual. Similarly there are low numbers of annuals in the native subalpine and alpine floras of Australia and overseas (Pickering 1995, 1997; Körner 1999; Costin *et al.* 2000).

### **3.3. MANAGEMENT OF EXOTIC PLANTS**

Part of the Australian National Parks Charter is to preserve and protect the natural features and resources of the protected area, which includes the control of exotic plants (Crabb 2003). Current control methods, primarily herbicide applications, are having limited success and those used elsewhere such as large-scale physical removal or broad-spectrum herbicides are often inappropriate for high value conservation areas (Robinson and EcoPlan Pty Ltd 1996; Sanecki 1999; Sanecki *et al.* 2003).

Given the difficulties in controlling plant invasions, such as the problems associated with biological control, expense of herbicides and potential deleterious effects of different control measures, informed management strategies are required. There are at least three key prerequisites for effective weed management strategies: (1) correct identification; (2) understanding the biology and ecology of the exotics and the plant

communities in which they occur; and (3) an assessment of the current and potential impact of the exotic (Sindel 2000).

With limited ecological knowledge on many exotic species in high altitude areas, predicting their effects largely remains guesswork. Research into the ecology of key exotic species in the Australian Alps should be a major priority for conservation organisations. The Australian Alps National Parks are currently developing a list of priority exotic species for research based on the plants' threat status, distribution in the Australian Alps, impact and the potential for management control. The species considered to be a high threat are *Cytisus scoparius*, and the three species of willow, *Salix fragilis*, *S. cinerea* and *S. nigra*. A further five species considered to be a serious threat to the subalpine and alpine floral communities in the Australian Alps are *Rubus discolor*, *Rosa rubiginosa*, *Nassella trichotoma*, *Hypericum perforatum*, and *Achillea millefolium* (Coyne 2003; NSW NPWS 2003).

In addition to understanding the biological characteristics of specific exotics, understanding the ecology of weed invasion is important. This includes determining where the exotics are located and under what conditions they are able to spread into natural vegetation.

The results in this chapter clearly show that in the Australian Alps the greatest diversity of exotics appears to be along roadsides. Therefore the next two chapters further examine the abundance and diversity of roadside exotics in Kosciuszko National Park and identify those species that can invade adjacent native vegetation. In Chapter Four vegetation and soils on road verges, road drainage areas and adjacent natural vegetation in subalpine grasslands are compared. This gives information about: (1) current abundance and diversity of exotics along roads; (2) indicates the impacts road disturbances may have on soils; and (3) if some exotics are restricted to the specific soil types and/or disturbance regimes associated with roads. In Chapter Five vegetation and seed banks from roadsides and adjacent vegetation in subalpine grasslands are again examined, but this time, the study also examines the pattern of colonisation that occurs after small areas of vegetation and top soil were removed. This indicates how exotics are able to recolonise small gaps created in the native vegetation adjacent to road.



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## CHAPTER 4

### IMPACTS OF ROAD DISTURBANCE ON SUBALPINE VEGETATION AND SOILS<sup>4</sup>

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#### 4.1. SUMMARY

The construction and maintenance of roads in Kosciuszko National Park has disturbed the natural vegetation and soils. This study examined vegetation and soils at three microsites associated with roads; road verges, road drainage areas and adjacent natural vegetation. A relationship was found between exotic and native plant species and soil properties. Road verges were dominated by exotics (64% cover), and bare ground (29%) with few natives (two species, 6.8% cover). In contrast adjacent natural vegetation had near complete cover of native vegetation (92% native cover, 6% exotics, 2% bare ground). The soils in natural areas had higher humus levels, less gravel and sand, higher levels of nutrients, and higher pH and electrical conductivity than road verges. In contrast to the road verges, the road drainage microsite had near complete cover of the exotic *Achillea millefolium*. These areas are characterised by high water and sediment washoff and soils had significantly higher pH and higher levels of exchangeable calcium and potassium than both natural and road verge soils. These results confirm that exotics are the dominant vegetation in disturbed road verges and drainage areas and that the soils in these disturbed sites are very different to soils in the adjacent native vegetation.

#### 4.2. INTRODUCTION

Roads are described as specialised ecosystems with unique ecological structure and function (Frenkel 1970; Lugo and Gucinski 2000). When road development occurs in natural areas it can lead to fragmentation of the natural environment by removing the

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<sup>4</sup> Johnston, F.M. and Johnston, S.W. (2001) Relationship between road induced disturbance, soil properties and weed occurrence in Kosciuszko National Park. In: *Ecological Society of Australia*. ESA 2001 Abstract, University of Wollongong. Institute for Conservation Biology.

Johnston, F.M. and Johnston, S.W. (2004) Impacts of road disturbance on soil properties and weed plant occurrence in subalpine areas of the Australian Alps. *Arctic, Antarctic and Alpine Research* **36** (2), 201-207.

original land cover, creating edge habitats, and altering the natural landscape structure, function and spatial patterns (Seiler and Eriksson 1997; Saunders *et al.* 2002).

The primary and secondary ecological effects of roads on a local, regional and landscape scale are summarised in Figure 4.1.

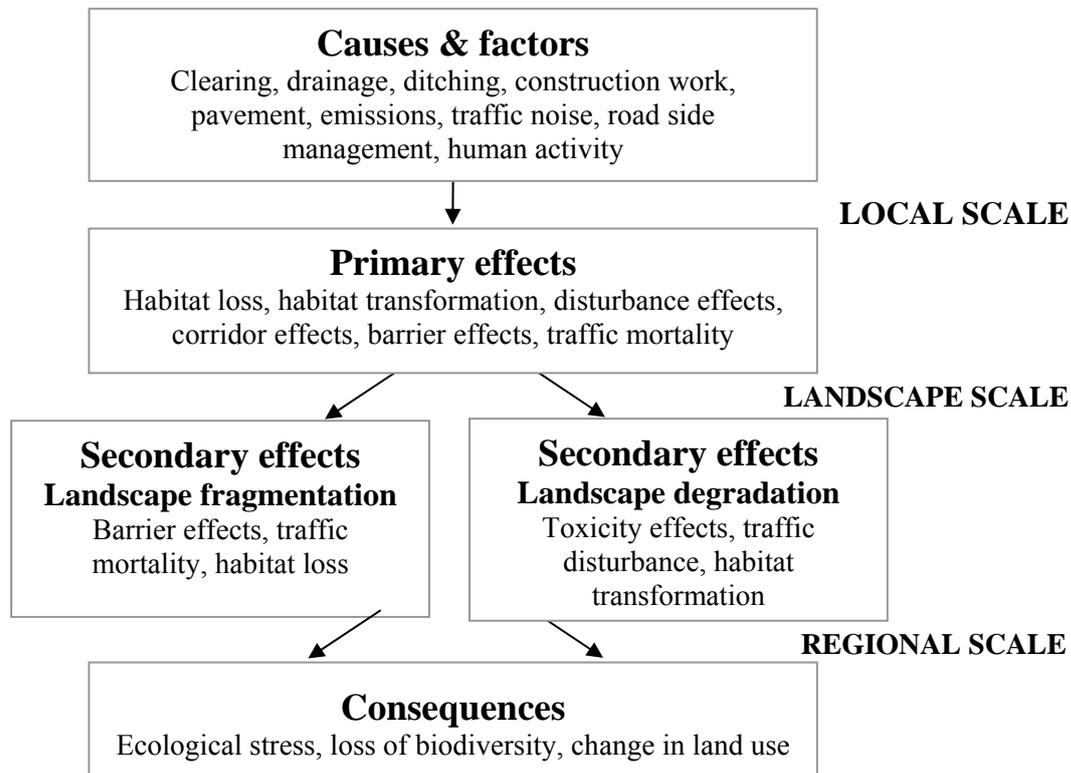


Figure 4.1. Causes, effects and consequences of road construction. Primary and secondary effects occur on different ecological and spatial scales. Primary effects are confined to the single road and nearest surroundings. Primary effects from different roads interact and cause secondary effects such as landscape fragmentation and degradation (adapted from Seiler and Eriksson 1997).

The impact of road disturbance on plant communities is well documented with roads resulting in the introduction, spread and proliferation of exotic plant species (Tyser and Worley 1992; Forman and Alexander 1998; Lugo and Gucinski 2000; Trombulak and Frissell 2000). There have been studies examining roadside vegetation types in many regions including Japan, New Zealand, the Middle East, Czech-Slovakia, Germany, Finland, Sweden, Denmark, France, Great Britain, Belgium, Canada, the United States, Australia and the Netherlands (Forman *et al.* 2003 and references therein). In general, road disturbance increases the numerical abundance of exotic plants (Hobbs 1987,1989; Kotanen 1997; Mack and D'Antonio 1998). Roads have a large boundary to area ratio and consequently create a high

degree of disturbance which is thought to predispose these areas to significant weediness (Panetta and Hopkins 1991). Road disturbance can alter growing conditions favouring exotic over native plant species and provide avenues for exotic propagules (Trombulak and Frissell 2000).

Road disturbance is also known to cause changes to the physical properties of the soil, including its structure, stability, erodibility, porosity and permeability. Road disturbances can also indirectly influence biological and chemical properties of soil, including organic content, soil biota, chemical conditions and soil micro-climatic conditions (Kuss *et al.* 1990; Forman and Alexander 1998; Lugo and Gucinski 2000; Forman *et al.* 2003). Such changes in soils have the potential to compromise primary ecosystem function, hydrological cycles, nutrient movement and availability, and surface stability. They can affect plant growth and species diversity and composition often resulting in an environment conducive to colonisation by exotic species (Frenkel 1970; Reiners 1983; Kuss *et al.* 1990; Forman and Alexander 1998; Johnston 1998; Spellerberg 1998; Tyser *et al.* 1998; Forman 2000; Jones *et al.* 2000).

Roads in national parks and other protected areas have four primary functions: access for fire control, resource access and use, recreation access and use and land management (Donaldson and Bennett 2004). The type, size and volume of traffic vary widely, however all roads affect the surrounding environment from their construction, use and maintenance (Donaldson and Bennett 2004).

The majority of research on the environmental impacts of roads has occurred in Europe and North America, with little data available on the specific effects of roads in Australian environments (Donaldson and Bennett 2004). Most studies relate to urban and agricultural areas with less research into the effect of roads in natural habitats such as protected areas (Donaldson and Bennett 2004). Limited studies have been undertaken in Australia into the impacts of roads on soil characteristics such as soil substrate properties, litter layer, soil compaction and invertebrate fauna (Donaldson and Bennett 2004).

The construction and maintenance of sealed and unsealed roads, access tracks and walking tracks is a major form of disturbance in the Kosciuszko National Park (Mallen-Cooper 1990; Pickering *et al.* 2003a) with approximately 1212 km of public

access roads, 1238 km of management trials and 192 km of walking tracks (estimated from NSW National Parks and Wildlife Service GIS database 2004).

Mallen-Cooper's (1990) study of the roadside vegetation in Kosciuszko National Park showed that the diversity and cover of exotic species varied with the level of roadside disturbance and/or altitude. There was a significant inverse relationship between altitude and the diversity of exotic species and a positive relationship between distance from road and the number and abundance of exotic species (Mallen-Cooper 1990).

Therefore the aim of this research was to examine impacts of road disturbance on plant assemblages and soil characteristics. This extends Mallen-Cooper's study by examining soil characteristics as well as vegetation in three road microsites; the road verge, the road drainage area, and the adjacent natural vegetation associated with public access roads in the subalpine section of Kosciuszko National Park.

### **4.3. METHODS**

#### **4.3.1. Sites**

Six road sites in subalpine areas were selected as examples of the road system in Kosciuszko National Park (Figure 4.1). The roads were constructed during the late 1950s to early 1960s as part of the Snowy Mountains Hydroelectric Scheme and the expanding ski industry, except Kosciuszko Road, which was originally constructed in 1906. All the roads are maintained annually or biannually. Five sites were located on sealed roads: four along Kosciuszko Road, one of the two major access roads into the Park, and the fifth on Guthega Road a sealed minor public access road. The sixth site was located along an unsealed management trail, Schlinks Pass. The sites were located in grassland habitats with altitudes ranging from 1460 to 1800m.

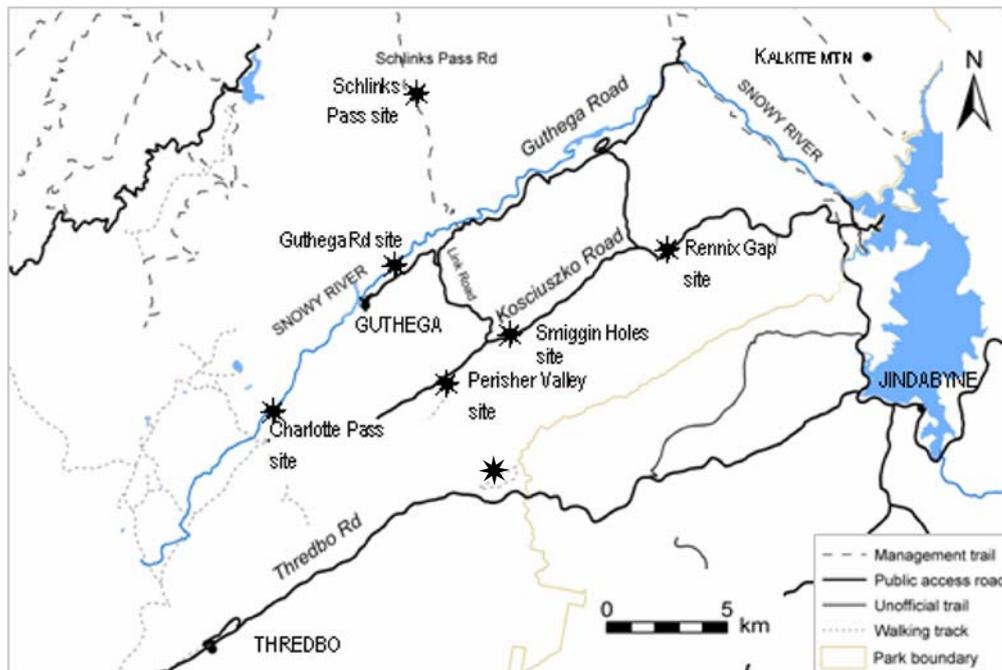


Figure 4.2. Location of six road disturbance sites (\*) in subalpine areas of Kosciuszko National Park where sampling was conducted in April 2001. Five sites were on sealed roads; Guthega (1627 m a.s.l), Smiggin Holes (1650 m a.s.l), Charlotte Pass (1800 m a.s.l), Rennix Gap (1450 m a.s.l), and Perisher Valley (1700 m a.s.l) and one on an unsealed management road Schlinks Pass (1634 m a.s.l).

#### 4.3.2. Experimental design

At each site 1 m<sup>2</sup> quadrats were randomly located in three areas; natural vegetation (undisturbed), the road verge, and the road drainage area (Figure 4.2). For the purposes of this study the three microsites are defined as: ‘natural vegetation’ – not disturbed by road construction or maintenance, typically 10-20 m from the road verge; ‘road drainage areas’ – natural or constructed water diversions from the road edge, approximately 2-5 m from the road verge; and ‘road verge areas’ – directly adjacent to the road, between 0-2 m from the solid, compacted or hardened road surface.

Percentage cover for each plant species and bare ground was visually estimated from each quadrat in each area. Within the quadrat five soil samples (approximately 1 kg) were collected from the top 10 cm of the soil profile and pooled. Soil samples were air dried, rolled and sieved (5 mm) to remove coarse material such as rock and roots. After sieving the soil for the gravel content (>2 mm), further particle size composition was determined using the Bouyoucos hydrometer method. The divisions between the sand, silt and clay fractions were 0.05 and 0.002 mm (Corbett 1969).



Figure 4.3. An example of the three microsites sampled (road verge, road drainage area and natural area) at the Schlinks Pass road site (Photo: S. Johnston 2001).

Electrical conductivity and pH were determined in a 1:5 distilled water dilution (Rayment and Higginson 1992). Organic carbon levels were determined using the Walkley and Black method (Rayment and Higginson 1992). Extractable phosphorus was determined using a bicarbonate extraction (modified from Olsen *et al.* 1954), extractable nitrogen using method 7C1c (from Rayment and Higginson 1992), and exchangeable cations (potassium, manganese, magnesium, calcium and sodium) using an ammonium acetate extraction (Lambert 1978).

#### *Data analysis*

Differences in vegetation between the three microsites were analysed using one-way ANOVAs in SPSS Version 10.0 for Windows (Coakes and Steed 2000) for the dependent variables exotic cover, native cover and bare ground with site as a block. No data transformations were necessary. Soil characteristics were compared using a series of one-way ANOVAs in SPSS Version 10.0 for Windows with site as a block and microsite as treatment. The significance level was adjusted for the multiple analyses on the same soil samples using a Bonferroni correction ( $\alpha = 0.003$ ).

## 4.4. RESULTS

### 4.4.1. Vegetation

There was a significant difference in the cover of exotics between the three microsites (ANOVA  $F = 4.122$ ,  $P = 0.022$ ) (Table 4.1). For the road verge vegetation, the exotic grass *Anthoxanthum odoratum* (28% cover) and the naturalised herb *Acetosella vulgaris* (20%) were the most abundant of the five exotic species recorded with the only two native species (*Poa* spp. and *Carex appressa*) accounting for just 6.8% of cover (Table 4.1; Figure 4.3). Nearly 29% of the ground was bare on the road verges.

Unlike the road verge, the road drainage areas had nearly complete vegetative cover (only 1.5% bare ground), the vast majority of which was *Achillea millefolium* (77%) (Table 4.1; Figure 4.3). Four other exotics, *Trifolium repens* (6.3%), *Hypochaeris radicata* (2%), *Echium plantagineum* (1.8%) and *Anthoxanthum odoratum* (4.3%) made up the rest of the exotic cover (total exotic cover of 91.3%). The only native species were *Luzula* spp. (3%), *Poa* spp. (6.3%) and *Oreomyrrhis eriopoda* (0.8%).

In contrast to the road verge and road drainage areas the undisturbed natural areas had a rich and diverse array of native vegetation types including trees, shrubs, herbs and grasses (Table 4.1; Figure 4.3). Over 30 native species were recorded in the natural areas. Native species such as *Grevillea australis*, *Poa fawcettiae*, *Poa helmsii*, *Oreomyrrhis eriopoda*, *Craspedia aurantia*, *Helichrysum scorpioides*, *Olearia phlogopappa*, *Hovea montana*, *Asperula gunnii* and *Acaena novae-zelandiae* dominated the vegetation cover ( $91.78\% \pm 1.49\%$ ) (Table 4.1; Figure 4.3). A small percentage of vegetative cover consisted of exotic species ( $6.15\% \pm 2.86\%$ ).

Table 4.1. Percentage cover (mean  $\pm$  SD) of the common species found in natural, road verge, and road drainage areas along road sites in subalpine areas of Kosciuszko National Park in April 2001. \* denotes exotic species

Species	Common Name	Road Verge	Road Drainage	Natural
<i>Achillea millefolium</i> *	Yarrow	6.33 $\pm$ 2.87	77.00 $\pm$ 13.89	2.16 $\pm$ 1.89
Exotic species		63.67 $\pm$ 5.31	91.30 $\pm$ 5.86	6.15 $\pm$ 2.85
Native species		7.5 $\pm$ 3.61	7.17 $\pm$ 4.51	91.78 $\pm$ 1.49
Bare ground		28.83 $\pm$ 5.49	1.50 $\pm$ 1.55	2.07 $\pm$ 1.92
<b>Total Number of Species</b>		<b>7</b>	<b>7</b>	<b>34</b>
Other species				
<i>Acaena novae-zelandiae</i>	Bidgee-widgee			3.08 $\pm$ 1.28
<i>Acetosella vulgaris</i> *	Sheep Sorrel	19.70 $\pm$ 3.14		2.63 $\pm$ 1.09
<i>Aciphylla simplicifolia</i>	Mountain Aciphyll			2.13 $\pm$ 0.56
<i>Anthoxanthum odoratum</i> *	Sweet Vernal Grass	28.30 $\pm$ 6.65	4.25 $\pm$ 3.25	1.35 $\pm$ 2.05
<i>Asperula gunnii</i>	Mountain Woodruff			3.03 $\pm$ 1.25
<i>Cardamine astoniae</i>	Aston's Bitter-cress			0.98 $\pm$ 0.93
<i>Carex appressa</i>	Sedge	2.28 $\pm$ 1.26		
<i>Carex breviculmis</i>	Shortflowered Dryland Sedge			0.65 $\pm$ 0.71
<i>Cassinia uncata</i>	Sticky Cassinia			1.25 $\pm$ 1.06
<i>Craspedia aurantia</i>	Orange Billy-button			3.63 $\pm$ 1.19
<i>Craspedia jamesii</i>	Billy-button			1.18 $\pm$ 0.69
<i>Deyeuxia quadriseta</i>	Bent-grass			1.83 $\pm$ 1.00
<i>Echium plantagineum</i> *	Paterson's Curse		1.83 $\pm$ 1.03	-
<i>Eucalyptus</i> sp.	Snow Gum			1.03 $\pm$ 0.76
<i>Euphrasia collina</i>	Eye Bright			1.98 $\pm$ 1.56
<i>Geranium potentilloides</i>	Alpine Swamp Crane's Bill			0.68 $\pm$ 0.57
<i>Grevillea australis</i>	Alpine Grevillea			12.6 $\pm$ 5.16
<i>Helichrysum scorpioides</i>	Button Everlasting			2.28 $\pm$ 1.48
<i>Hovea montana</i>	Alpine Hovea			6.23 $\pm$ 2.04
<i>Hymenanthera dentata</i>	Wood Rush			1.63 $\pm$ 1.51
<i>Hypochaeris radicata</i> *	Cat's Ear	4.67 $\pm$ 3.07	1.95 $\pm$ 1.78	
<i>Luzula novae cambriae</i>	Rock Woodrush			2.15 $\pm$ 1.16
<i>Luzula</i> spp.	Woodrush		3.00 $\pm$ 1.67	
<i>Mircroseris lanceolata</i>	Native Dandelion			1.80 $\pm$ 0.55
<i>Olearia algida</i>	Alpine Daisy Bush			2.55 $\pm$ 1.53
<i>Olearia phlogopappa</i>	Dusty Daisy Bush			3.37 $\pm$ 1.48
<i>Oreomyrrhis eriopoda</i>	Australian Caraway		0.83 $\pm$ 0.92	2.77 $\pm$ 1.24
<i>Pimelea alpina</i>	Alpine Rice-flower			1.95 $\pm$ 1.09
<i>Poa fawcettiae</i>	Smooth-blue Snow Grass			12.61 $\pm$ 4.22
<i>Poa helmsii</i>	Broad-leaved Snow Grass			2.36 $\pm$ 1.70
<i>Poa hiemata</i>	Soft Snow Grass			7.97 $\pm$ 2.40
<i>Poa</i> spp.	Snow Grass	4.50 $\pm$ 3.98	6.33 $\pm$ 3.83	
<i>Poranthera microphylla</i>	Mint Bush			0.90 $\pm$ 0.81
<i>Prasophyllum alpestre</i>	Highland Leek-orchid			0.57 $\pm$ 0.76
<i>Ranunculus graniticola</i>	Granite Buttercup			1.68 $\pm$ 1.29
<i>Scleranthus biflorus</i>	Twin-flower Knawel			1.43 $\pm$ 0.86
<i>Stellaria pungens</i>	Prickly Starwort			3.11 $\pm$ 0.78
<i>Trifolium repens</i> *	White Clover	4.67 $\pm$ 2.50	6.29 $\pm$ 5.96	

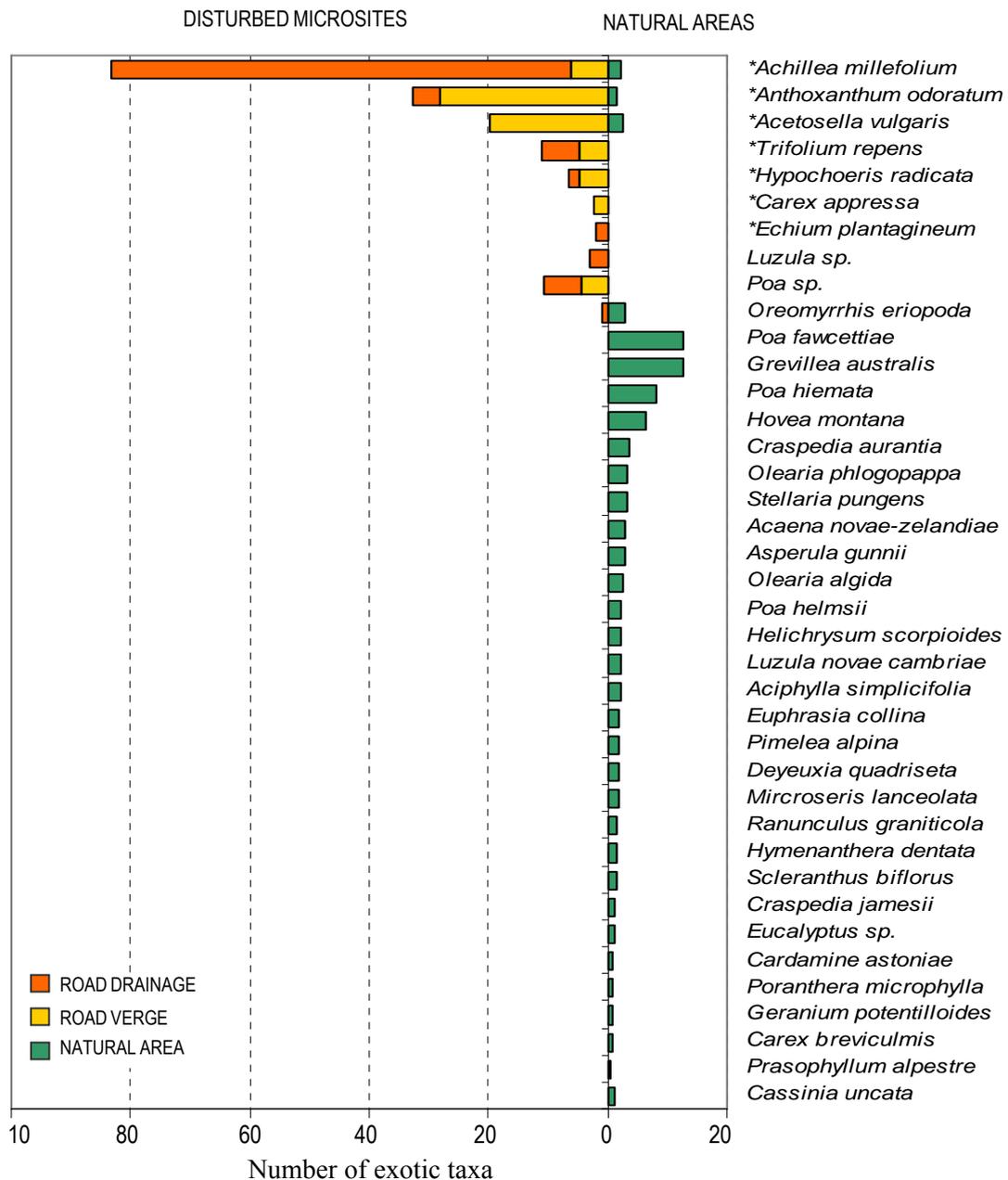


Figure 4.4. Frequency of native and exotics taxa in natural, road verge, and road drainage areas at six road sites in subalpine areas of Kosciuszko National Park in April 2001. \*denotes exotic species.

#### 4.4.2. Chemical and physical soil properties

The differences in the vegetation between the three areas were reflected in differences in the properties of the soils. For example, the soils on the road verge, in road drainage area and the adjacent natural soil differed in pH (ANOVA  $F = 153.8$ ,  $P < 0.001$ ) with natural soil the most acidic ( $4.7 \pm 0.2$ ), the road verge less acidic ( $5.3 \pm 0.2$ ), and the road drainage soil the most basic ( $6.3 \pm 0.24$ ) (Table 4.2). There were also significant differences in all of the measured total and exchangeable cations

(nitrogen, phosphorus, calcium, manganese, sodium, magnesium and potassium). For example, the soil in the road drainage area contained eight times the amount of total calcium and eighteen times the amount of exchangeable calcium compared to the undisturbed natural soil (ANOVA  $F = 6.85$ ,  $P < 0.001$ ,  $F = 218.9$ ,  $P < 0.001$  respectively) (Table 4.2). For the major nutrients, nitrogen and phosphorus, concentrations also differed between microsites (ANOVA  $F = 142$ ,  $P < 0.001$ ,  $F = 256.1$ ,  $P < 0.001$  respectively). The natural soil had the highest concentrations of the major nutrients, followed by the soil of the road drainage area and then the road verge soil. Road disturbance reduced the amount of organic matter in the soil. The natural soil had significantly higher amounts of organic matter ( $8.2\% \pm 1.3\%$ ) compared to the soil found on both the road verge ( $0.6\% \pm 0.4\%$ ) and drainage areas ( $2.3\% \pm 1.1\%$ ) (ANOVA  $F = 300.7$ ,  $P < 0.001$ ) (Table 4.2). The physical composition of the soil reflects the level of disturbance to the three soil types. There was a graduated transition from the finer natural undisturbed soil, to the runoff soil, to the coarser road verge soil. The natural undisturbed soil had an overall finer texture with a higher percentage of clay ( $18\% \pm 2.2\%$ ) and fine sand ( $44.6\% \pm 3.4\%$ ) and less coarse sand ( $26.4\% \pm 4.9\%$ ) compared to both other soils. The road verge soil had a high proportion of coarse material ( $54\% \pm 8.2\%$ ) and less fine material. The drainage area soil had intermediate amounts of both coarse ( $39.4\% \pm 6.4\%$ ) and fine material ( $16.6\% \pm 2.9\%$  silt and  $11.8\% \pm 1.9\%$  clay) (Table 4.2)

Table 4.2. Summary of chemical and physical properties for soil samples from road verges, road drainage areas and natural areas at six sites in Kosciuszko National Park. Five replicates (each replicate representing a pooled sample of five) were taken for each of the three areas at each of the six sites. Mean  $\pm$  SD tabulated. Units for total and exchangeable minerals are mg kg<sup>-1</sup>. Units for electrical conductivity (Ec) are mircosiemens.

	Natural Area	Road Verge	Road Drainage Area	F	P
pH	4.70 $\pm$ 0.22	5.36 $\pm$ 0.21	6.29 $\pm$ 0.24	153.86	<b>0.000</b>
Ec	87.76 $\pm$ 13.24	49.76 $\pm$ 18.96	263.07 $\pm$ 58.20	127.11	<b>0.000</b>
Total nitrogen	7229.69 $\pm$ 892.70	1350.53 $\pm$ 376.16	3219.53 $\pm$ 1506.45	142.05	<b>0.000</b>
Total phosphorus	1307.23 $\pm$ 97.71	537.23 $\pm$ 97.71	726.00 $\pm$ 136.16	256.13	<b>0.000</b>
Total calcium	1294.54 $\pm$ 241.48	3111.35 $\pm$ 1098.56	10081.29 $\pm$ 2932.89	6.85	<b>0.01</b>
Total manganese	1074.89 $\pm$ 204.61	511.90 $\pm$ 68.82	550.35 $\pm$ 32.78	35.56	<b>0.000</b>
Total sodium	172.14 $\pm$ 20.65	234.78 $\pm$ 44.07	219.81 $\pm$ 34.93	13.44	<b>0.000</b>
Total magnesium	7455.41 $\pm$ 686.87	10692.23 $\pm$ 1534.67	8648.16 $\pm$ 2158.44	21.77	<b>0.000</b>
Total potassium	7603.60 $\pm$ 303.50	9525.21 $\pm$ 1520.14	9978.93 $\pm$ 2380.88	6.85	<b>0.01</b>
Exchangeable calcium	401.92 $\pm$ 112.39	735.74 $\pm$ 154.83	7150.69 $\pm$ 1584.76	218.91	<b>0.000</b>
Exchangeable manganese	55.66 $\pm$ 16.85	17.89 $\pm$ 5.39	22.50 $\pm$ 10.11	45.90	<b>0.000</b>
Exchangeable sodium	6.54 $\pm$ 1.97	3.38 $\pm$ 1.11	7.92 $\pm$ 3.95	10.33	<b>0.000</b>
Exchangeable magnesium	185.14 $\pm$ 92.95	51.41 $\pm$ 15.49	106.86 $\pm$ 66.80	23.57	<b>0.000</b>
Exchangeable potassium	270.23 $\pm$ 47.15	118.25 $\pm$ 15.35	356.58 $\pm$ 94.05	62.41	<b>0.000</b>
Percentage organic matter	8.18 $\pm$ 1.25	0.61 $\pm$ 0.39	2.26 $\pm$ 1.16	300.73	<b>0.000</b>
Percentage silt	11.00 $\pm$ 2.70	11.20 $\pm$ 3.22	12.60 $\pm$ 2.95	0.73	0.49
Percentage clay	18.00 $\pm$ 2.26	7.10 $\pm$ 1.37	11.80 $\pm$ 1.98	152.45	<b>0.000</b>
Percentage coarse sand	26.40 $\pm$ 4.94	54.00 $\pm$ 8.23	39.40 $\pm$ 6.44	71.17	<b>0.000</b>
Percentage fine sand	44.60 $\pm$ 3.43	27.70 $\pm$ 7.08	36.20 $\pm$ 6.52	31.88	<b>0.000</b>

Significant P values are in bold. Location (d.f. = 2) and site (d.f. = 5).

## 4.5. DISCUSSION

In this study three subalpine microsites associated with road disturbance were studied; the road verge, the adjacent natural vegetation, and an intermediate microsite – the road drainage area. They differed in both soil characteristics and vegetation. The natural soil with its complete undisturbed profile supported a diversity of plant species along with a few exotics. The presence of exotic plants in the adjacent natural sites may be due to seed input from the exotics growing on the road verge into any gaps that form in the native vegetation. In contrast to these floristically diverse areas, the subalpine road verge soil supported a limited array of predominantly exotic species. These exotics growing along the road verge are likely to reflect the preference of some weed species for disturbed habitats (Amor and Stevens 1975; Humphries *et al.* 1991; Fox and Adamson 1999).

### 4.5.1. Vegetation and roads

The presence of such an extensive cover and diversity of exotics along roads in protected areas, including Kosciuszko National Park is of concern. These plants can act as sources for propagules that could colonise adjacent native vegetation if disturbed. For example, a study of exotic invasion in Santa Margarita Ecological Reserve in California found that exotic annual plants dominated the length of the road with little reestablishment of native plants 10 years post disturbance. From these disturbed sites exotics were found to invade into undisturbed woodland, coastal sage and grassland habitats (Zink *et al.* 1995).

Species found along the road verge in this study, such as *Acetosella vulgaris*, *Anthoxanthum odoratum*, *Echium plantagineum* and *Hypochaeris radicata* are commonly associated with human disturbance in the Australian Alps (Johnston and Pickering 2001a; Pickering *et al.* 2002; Chapter 3). For example in another study of the roadside vegetation in Kosciuszko National Park the dominant exotic species along the road verges were herbaceous (89%) with the most common species *Hypochaeris radicata*, *Rumex acetosella* and *Agrostis capillaris* (Mallen-Cooper 1990).

#### 4.5.2. Vegetation, roads and soils

Each of the three road microsites had a unique set of soil characteristics: the road verge was low in organic matter, coarse in texture and generally low in nutrient availability; the natural soil was rich in organic matter and available nutrients, acidic pH with a fine texture and the drainage area soil had a more basic pH, and intermediate amounts of organic matter, nutrients and soil texture composition.

In a similar experiment examining the plant species composition and soil properties along a pipeline corridor adjacent to undisturbed oak woodland, coastal sage, grassland and chaparral habitats in a Santa Margarita Ecological Reserve in California, significantly less organic matter and higher available nitrogen and extractable phosphorus were found in soils in the disturbed corridor area compared to undisturbed areas. The authors conclude this is due to rapid decomposition of leaf litter of annual exotics and higher nutrient mineralisation rates which favour the continued dominance of the exotic plant species in the disturbed soils (Zink *et al.* 1995).

In an examination of the effects of invasion by Japanese Barberry (*Berberis thunbergii*) and a Japanese grass (*Microstegium vimineum*) in three deciduous hardwood forests in northern New Jersey, the pH of soils in the exotic invaded plots was significantly higher than uninvaded plots. Soil organic layers and litter were thinner in the weed invaded plots (Kourtev *et al.* 1998). A study of understory plants growing alongside roads in northern U.S.A forests found that the roadsides (up to 5 m) supported a vegetation community different to that of the forest interior, with exotic species prominent near roads (Watkins *et al.* 2003). In another study of roadside vegetation in the southern part of the south island of New Zealand, road shoulders were characterised by a high degree of disturbance and unfavourable soil water conditions and that these characteristics appear to result in native plants being out competed by exotics (Ullmann *et al.* 1998). Other roadside studies have also shown a strong relationship between the degree of invasion by exotic species and soil nutrient levels, particularly of phosphorus resulting in soil conditions more conducive for the exotic species (Cale and Hobbs 1991; Riley and Banks 1996; Forman 2000; Jones *et al.* 2000; Lugo and Gucinski 2000; Trombulak and Frissell

2000). The greatest cause, however, of the establishment and growth of exotic plants appears to be the combination of soil disturbance and nutrient addition (Hobbs and Huenneke 1992; Ullmann *et al.* 1995, 1998; King and Buckney 2002; Kolb *et al.* 2002). For example, a study of soil nutrient status of soils along roads in the wheat belt of Western Australia found nutrient enrichment was associated with increase in weed invasion (Cale and Hobbs 1991).

It would appear that these former studies concur with the results of my study here, i.e. disturbance and an increase in nutrients are associated with an increase in exotic abundance. In particular the road drainage soil in this study appears to have been affected by disturbance and high amounts of nutrient, sediment, and water washoff. The high moisture soil of the drainage area was associated with a sharp increase in the amount of calcium in the soil. This in turn appears to have resulted in a change in pH from the natural soils of 4.7 to 6.3 in the road drainage areas.

This result is important as the increase in calcium, with the corresponding change in pH from acidic to a more basic pH soil, enables the other nutrients, particularly phosphorus and nitrogen to become more available for use by plants. In particular the increase in phosphorus, normally limiting in Australian soils, may limit native plant growth while conversely being conducive to exotic plant growth. It is documented (Rowell 1988; Wild 1988a,b) that it is the rise in pH, (to 6 to 7.5), which is necessary for the optimum availability of soil nutrients particularly phosphorus and nitrogen. Australian soils are characteristically phosphorus poor, to which the native plants have become adapted: the change in pH found in this study is therefore highly significant (Probert 1983; Williams and Raupach 1983; Johnston 1995; Johnston 1998). Higher phosphorus was measured in the road drainage areas compared to the road verge soils. With the change in the availability of phosphorus the soil conditions have changed from those suitable for native plants to those which may inhibit native plant growth while favouring exotic plant growth.

#### **4.5.3. *Achillea millefolium*, road verges and soils**

The exotic *A. millefolium*, originally from Europe and Asia, is adapted to soils with a higher pH and nutrient availability than the older nutrient leached soils of Australia (Hubble *et al.* 1983). Thus the characteristics of drainage/runoff soils; increased

water availability, increased amounts of nutrients especially calcium and increased organic matter could favour germination and establishment of *A. millefolium*. In this study *A. millefolium* was found in all three microsites. However, it was the dominant exotic in the drainage areas (77% cover), while only one of several weed species along the roadsides (6%) and a minor component of the natural vegetation (2%).

In a study of weeds as indicators of physical site characteristics of abandoned pastures in Canada and studies in Poland grasslands *A. millefolium* was found growing on a range of soils including those characterised by coarse and medium texture, low to medium organic matter, stoniness classes 3-5 (where 0 is stone free and 5 is bedrock) with good drainage (slope greater than 5%), in soils with pH ranging from 4.6-8.0 (Dale *et al.* 1965; Zarzycki 1976). These results, again, indicate that roadside drainage areas in the subalpine areas in Kosciuszko National Park have soil conditions suitable for *A. millefolium* growth: with acid pH, ample water but good drainage, ample organic matter and high nutrient availability.

*Achillea millefolium* is rated as serious threat to the natural alpine and subalpine vegetation by the NSW National Parks and Wildlife Service (NSW NPWS 2003). General observations made in subalpine and alpine areas of Kosciuszko National Park indicate that *A. millefolium* is well established in areas such as the drainage lines sometimes to the exclusion of both other exotic and native species (Johnston and Pickering 2001b; Johnston and Johnston 2003). There is a risk that it could spread from these sites into native vegetation down slope by seed and vegetative material transported by water and sediment particularly when native vegetation is disturbed.

#### **4.5.4. Conclusions**

This study has shown that vegetation differs between the three microsites found near roads in the subalpine areas of the Australian Alps. Differences in the chemical and physical properties of the soil could account for the differences in vegetation. The road verges were dominated by exotics, particularly *Anthoxanthum odoratum* and *Acetosella vulgaris*, supported on a soil characterised by low organic matter, coarse in texture and lower in nutrient availability compared to the other two microsites. This microsite was also characterised by the largest amount of bare areas compared

to the other two microsites. The adjacent natural areas, with their fine textured rich organic and nutrient rich soil, had a wide range of native plant species with only a few exotic species. The road drainage areas were unique as they were dominated by only one exotic, *A. millefolium*, growing on a soil with high water and sediment loads.

The next chapter examines the potential spread of exotics from these roadsides into adjacent sites by creating artificial small gaps in the native vegetation, and then determining what colonises them over a 21 month period. It also examines the seed bank of roadside and adjacent sites to determine if exotic propagules are already present in areas adjacent to sources of exotics such as roadsides.

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## **CHAPTER 5**

# **VEGETATION, SEED BANK, AND COLONISATION OF SMALL GAP DISTURBANCES ADJACENT TO A SUBALPINE ROAD**

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### **5.1. SUMMARY**

The abundance and diversity of exotic plants along roadsides in the Australian Alps is of concern as there is the potential for spread into adjacent native vegetation particularly if vegetation is disturbed. To examine the potential establishment and spread of exotics from roads, vegetation colonisation following small gap disturbance, (removal of above ground vegetation and some soil), was examined over 21 months (between April 2001 and December 2002) at ten sites along a gravel management road in the subalpine zone of Kosciuszko National Park using 50 cm x 100 cm quadrats located one, five and ten metres from the road verge. The diversity and abundance of species in the general area and vegetation composition in each quadrat was recorded prior to disturbance, and then again for quadrats at two, nine and 21 months after the initial disturbance.

Road verge quadrats were found to be largely recolonised by exotic species (73% relative cover and 51% absolute cover) with vegetation approaching pre-disturbance composition after 21 months. Quadrats five metres from the road were recolonised by both native and exotic species (51% and 49% relative cover respectively) while quadrats ten metres from the verge were dominated by natives (75% relative cover). Both the five and ten metre quadrats had increased relative cover of exotics compared with the relative cover prior to disturbance.

Soil samples were taken from the quadrats to determine which species were present in the seed bank. Although 74 species were recorded in the general area of the experiment only four native and four exotic species were observed to germinate during autumn and seven exotic species and 16 native species germinated in the following spring. Generally the diversity and abundance of seedlings matched the

post disturbance vegetation study i.e. exotics were more common in the one metre quadrats and the natives in the five and the ten metre quadrats. However the exotics *Acetosella vulgaris* and *Achillea millefolium* and the natives *Luzula* spp., *Poa* spp., *Olearia phlogopappa*, *Geranium potentilloides* var. *potentilloides*, *Asperula gunnii* and *Stellaria pungens* had seedlings germinate in soil from most quadrats irrespective of distance from the road.

## 5.2. INTRODUCTION

Disturbance is an important component of natural ecosystems influencing community structure and functioning (Sousa 1984; Hobbs and Huenneke 1992). Natural disturbance events include drought, bushfire, storms, landslides and native fauna herbivory, while anthropogenic disturbance includes clearing, livestock grazing and tourism. Natural and anthropogenic disturbance affect both short and long term vegetation patterns (Sousa 1984). Disturbance often results in the exposure of bare soil with vegetation recovery dependent on a range of factors including the extent of the bare area and the scale of ongoing disturbance (Wimbush and Costin 1979a). Small gaps in vegetation can often revegetate quickly, (provided little soil is lost), because of the presence of seed in the soil or clonal growth from plants on gap peripheries (Glenn-Lewin *et al.* 1992; van der Valk 1992). For larger disturbances, the community composition of the recolonised areas depends on the interaction of factors such as abiotic and biotic habitat characteristics, species availability (e.g. the presence or immigration of propagules) and species traits (e.g. morphology and physiology of the propagules) (Ebersole 1989; Glenn-Lewin *et al.* 1992; van der Valk 1992; Bakker *et al.* 1996; Drake 1998; Moles and Drake 1999; Booth *et al.* 2003) (Table 1).

Table 5.1. Hierarchical summary of some of the causes, processes and factors affecting vegetation dynamics (from Pickett *et al.* 1987).

<b>General cause</b>	<b>Contributing processes/condition</b>	<b>Modifying factor</b>
Site availability	Coarse scale disturbance	Size, severity, time, dispersion
Differential species availability	Dispersal Propagule pool Resource availability	Landscape configuration, dispersal agents. Time since last disturbance, land use treatment Soil condition, topography, microclimate, site history.
Differential species performance	Ecophysiology  Life history  Environmental stress Competition  Allelopathy  Herbivory, predation and disease	Germination requirements, assimilation rates, growth rates, population differentiation Allocation pattern, reproductive timing, reproductive mode Climate cycles, site history, prior occupants Hierarchy, presence of competitors, identity of competitors, within community disturbance, predators, herbivores, resource base Soil chemistry, soil structure, microbes, neighbouring species Climate cycles, predators cycles, plant vigour, plant defenses, community composition, patchiness

### **5.2.1. Human induced disturbance in Kosciuszko National Park**

Human induced disturbance to vegetation in Kosciuszko National Park has occurred on both a large and small scale from activities such as from cattle and sheep grazing, management fires, the construction the Snowy Mountains Hydro-electricity Scheme and tourism (ISC 2004; Worboys and Pickering 2004). The severity of impacts has depended on the intensity, duration, frequency and seasonality of the disturbance. For example, over 100 years of livestock grazing in the alpine and subalpine areas of Kosciuszko National Park resulted in dramatic changes in community structure, the loss of significant areas of vegetation cover with resulting severe sheet and gully erosion (Costin 1954). Removal of grazing pressure resulted in an increase in vegetation cover particularly in the cover of palatable species. However where the erosion was severe the reestablishment of vegetation has been slow and the species composition different to the original vegetation (Wimbush and Costin 1979 a,b,c; Scherrer 2003a,b,c,d). Tourism impacts have included trampling damage, (e.g.

physical damage to plants and changes in soil structure and local hydrology), nutrient addition to soil and water from human waste, collection of firewood, fire scars, root damage from digging, and the introduction and spread of exotic species (Johnston and Pickering 2001a; Pickering *et al.* 2003; Scherrer 2003a,b,c,d; Growcock *et al.* 2004).

### **5.2.2. Post disturbance vegetation recovery**

The patterns of recovery from disturbance in subalpine areas are affected by factors such as climate, senescence, primary and secondary succession and threshold events (Austin 1981). For example, when soils are disturbed the presence of a litter layer, and the size of the gaps in the natural vegetation will all affect the resulting post disturbance vegetation pattern and composition (Costin 1954; Wimbush and Costin 1979b; Good 1992a, b).

Succession following disturbance culminates in the re-establishment of a post-disturbance community. This succession may be through direct replacement of pre-disturbance species or through a series of succession stages (Clements 1916; Fox and Fox 1986; Ludwig *et al.* 1997). Post-disturbance succession in natural communities includes recruitment of native pioneer succession species. Later succession stages also include native plant species culminating in the climax natural vegetation community. However, succession in natural areas adjacent to populations of exotic species may result in successional pathway diversion from the native communities to an altered state to include both natives and exotics (Kostel-Hughes *et al.* 1998).

The manipulative field experiment reported in this chapter studied post disturbance vegetation succession following small gap disturbance in a subalpine heath/woodland area of Kosciuszko National Park associated with a major gravel management access road. The abundance and extent of exotics and natives as well as the role the seed bank may play in the recolonisation of disturbed sites was examined. The vegetation along the road verges studied was dominated by exotics, particularly *A. millefolium*. Therefore in addition to examining the overall impact of small gap disturbances generally on colonisation, this study focused on the response of one particular environmental weed, *A. millefolium* to gauge its potential colonising ability following disturbance in subalpine environments.

## 5.3. METHODS

### 5.3.1. Sites

To study the effect of small gap disturbance in the field, ten sites were randomly located along a section of Schlinks Pass road, a major (unsealed) management road in the subalpine section of Kosciuszko National Park. Schlinks Pass road extends from the Guthega Power Station to the Geehi Dam (Figure 5.1) passing through natural subalpine heath/woodland (Figure 5.2).

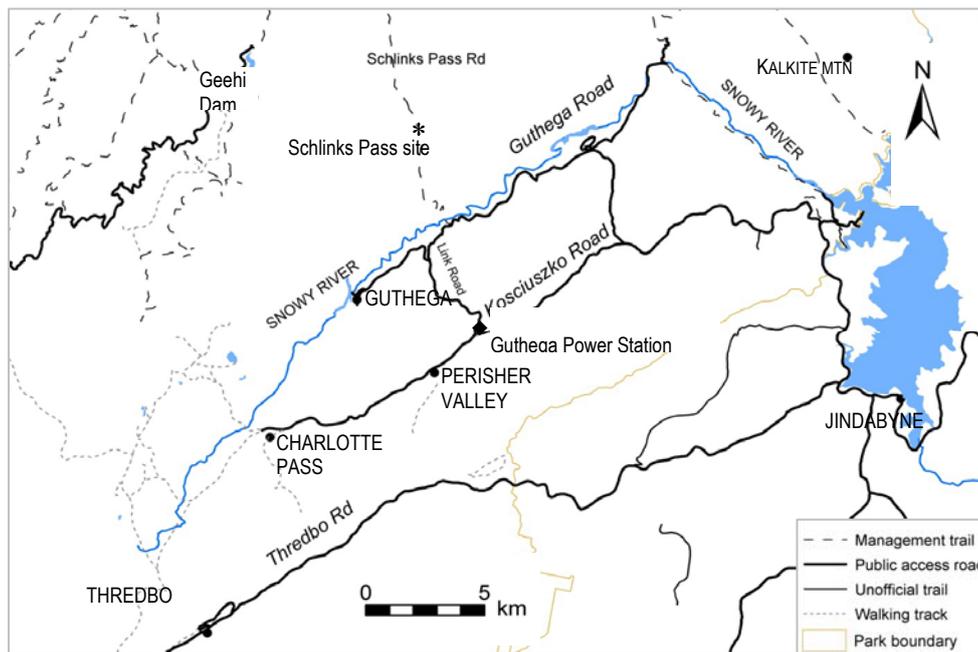


Figure 5.1. Location of small gap disturbance sites (\*) on an unsealed management road (Schlinks Pass road) in subalpine woodland in Kosciuszko National Park, Australia.

### 5.3.2. Small gap disturbance methodology

Ten sites were randomly located along a 400 m length of Schlinks Pass road in April 2001 (Figures 5.1 and 5.2) where the verge was heavily covered in exotic species, in particular *A. millefolium*. At each site a 10 m transect was randomly located from the edge of the verge into the adjacent vegetation and 50 cm by 100 cm quadrats were located at one, five and ten metres along the transect. Percentage vegetative cover and non vegetative cover (bare ground and litter) in each quadrat were estimated using a modified Braun-Blanquet scaling system (adapted from Sutherland 1996) as follows: 1 = present; 2 = <1%; 3 = 1-5%; 4 = 6-25%; 5 = 26-50%; 7 = 76-100%.



Figure 5.2. An example of a site along Schlinks Pass road Kosciuszko National Park used in the small gap disturbance experiment. The star pickets indicate the edge of the verge from where the 10 m transects were located in the adjacent vegetation (Photo S. Johnston 2001).



Figure 5.3. Example of fire damage to some of the Schlinks Pass road sites following the January 2003 bushfires. Flowering *A. millefolium* plants (white flowers) can be seen close to the gravel road edge (Photo S. Johnston 2003).

The vegetation in the general area was surveyed to record the presence of dominant and frequent species which were identified using Kosciuszko Alpine Flora (Costin *et al.* 2000) and the Flora of New South Wales 1990-1992 (Harden 1993).

Following the initial vegetation survey the vegetation was removed from each quadrat using a sharp spade to cut through and remove above and below ground material to a depth of 5 cm. The soil from the excavated side was retained for the seed bank analysis. Vegetation was re-surveyed in each quadrat at two, nine and 21 months post disturbance with the last survey taking place in December 2002. Large scale bushfires in January 2003 prevented further sampling of these sites (Figure 5.3).

### **5.3.3. Seed bank methodology**

The vegetative and soil material from each quadrat was bagged separately and taken from the field to plant culture facilities (Berridale, New South Wales). The samples were dried with the coarsest plant fragments and stones removed. The remaining soil was homogenised and spread in a 2 mm thin layer in individual trays to which a thin layer of commercial potting mix had been added to the bottom. The trays were placed into a shade house and watered daily. As the seedlings emerged they were identified, counted and removed. At no time during the germination period was the soil disturbed except to remove seedlings. The germination experiment was conducted over nine months from April 2000 to the end of spring of November 2001. As no germinants were observed in winter the results are tabulated for autumn and spring only.

### **5.3.4. Small gap disturbance statistical analysis**

The data were analysed as a time series change, comparing the vegetation composition prior to the removal of vegetation and soil to vegetation composition up to 21 months post disturbance. The data for each site (10 sites) included three distance measures (one, five and ten metres from road verge) and four sampling times (pre-disturbance, two, nine and 21 months post disturbance). The above ground cover for each species was transformed from the original Braun-Blanquet values to the midpoints of the cover intervals represented by each class. The percentage cover

for classes 1, 2, 3, 4, 5, 6, 7 became 0.1, 0.5, 3.0, 15, 37.5, 62.5, and 88% respectively. This conversion enabled parametric tests to be performed on the data, although it meant that the highest cover value per species that could be used was only be 88%, even if the actual percentage cover in the field was greater. The total cover per quadrat was estimated by subtracting the non vegetative cover values (bare ground and litter) from 100%.

The number of quadrats in which a species was recorded, and the average cover of species at each distance from the road verge at each sampling time were determined. Two-way repeated measures ANOVAs were conducted on the percentage cover of different species to determine if time and/or distance from the road affected cover of the species. Both time of sampling and distance from the road were used as repeated measures (Table 5.4). Differences between means were determined using Tukey's LSD Tests.

Ordinations were used to examine community composition among quadrats. The Bray-Curtis index of similarity and semi-strong hybrid (SSH) ordination were derived using PATN (Belbin 1991). The Bray-Curtis index was chosen as it does not attribute similarity to joint absences of species and is generally preferred over other metric measures for ecological studies (Minchin 1987; Hero *et al.* 1998). The optimal cut-off was determined from the histogram of association measures (Minchin 1987; Belbin, 1991). The percentage cover data were log transformed ( $\ln x + 1$ ) to give less emphasis to species with large values. Species which were recorded in less than 5% of quadrats were not used in the ordination. Species removed were *Agrostis capillaris*, *Galium proprinquum*, *Hypochaeris radicata*, *Luzula novae-cambriae*, and *Luzula novae-cambriae/modesta* (recorded in only one quadrat), *Carex inversa*, *Cerastium vulgare* (2 quadrats), *Grevillea australis* (3 quadrats), *Olearia algida*, *Poa costiniana*, *Ranunculus graniticola* (4 quadrats), and *Poa hiemata* and *Prasophyllum alpestre* (6 quadrats). As there were no major differences between two and three dimensional ordinations the two-dimensional ordination was used for ease of interpretation (2D cut-off 0.8; Stress = 0.24). PCA analysis was used to determine those species with the greatest explanatory power, species which had an  $r^2$  value of

>0.5 were retained and overlaid as vectors on a SPSS generated graph (SPSS Version 10.0 for Windows Coakes and Steed 2000).

### **5.3.5. Seed bank statistical analysis**

The seed bank data were analysed in two ways. To determine the effect of season and distance from the road verge on germination, Repeated Measures ANOVAs were performed on the spring and autumn germination data (SPSS Version 10.0 for Windows Coakes and Steed 2000). Season was used as the within subject factor with the number of germinants of each species as the dependant variable. Distance from the road verge (one, five and ten metres) was used as the between subject factor. Differences between means were determined using Tukey's LSD Tests.

A Semi-strong Hybrid Multi-Dimensional Scaling was performed using PATN software (Belbin 1991). Ordinations were performed on the untransformed presence/absence data of seed bank germination records from soil taken from the quadrats at the 10 sites at Schlunks Pass road. Germinations were in autumn 2000 and spring 2001. Two sites with no germinants in autumn were not included in the analysis (site 10: one metre from verge and site 8: ten metres from verge). The two dimensional representation of the data was used to interpret the ordination data (2D cut-off; 0.90; Stress = 0.27). PCA analysis was used to determine those species with the greatest explanatory power ( $r^2 > 0.5$  which were then overlaid as vectors on a SPSS generated graph (SPSS Version 10.0 for Windows Coakes and Steed 2000).

## **5.4. RESULTS**

### **5.4.1. Secondary vegetation succession**

A total of 74 plant species were surveyed in the vegetation surrounding the Schlunks Pass road sites (Appendix 1). The lifeforms included trees, shrubs, herbs and graminoids. Fifty-eight species (80%) were natives representing 26 families with 24% species of Asteraceae and 22% Poaceae. Exotics accounted for 20% of species, dominated (60%) by the families Asteraceae, Fabaceae and Poaceae. Of the 74 species in the general area, 42 species (57%) were initially recorded in the 30 small gap disturbance quadrats (Appendix 1; Table 5.2).

Prior to disturbance, quadrats one metre from the road verge were nearly completely covered by vegetation (95.4%), nearly all of which were exotics (85.5%) principally *Achillea millefolium* (50%) and *Anthoxanthum odoratum* (33.7%, Table 5.3). At five metres away from the road verge just over half of the vegetation cover was native (52%), but there was still quite high cover of exotics (26.6%) dominated by *Achillea millefolium* (25%). At ten metres, native vegetation was dominant (61%), with less exotics (9%) again chiefly *A. millefolium* (8.3%).

After disturbance seven native and four exotic species dominated colonisation of the quadrats with the species composition dependent on the distance from the road verge (Tables 5.2 and 5.3). In quadrats one metre from the road early colonisation was predominantly by the exotics *Acetosella vulgaris*, *Achillea millefolium* and *Anthoxanthum odoratum*. With time, other species were found including the exotics *Trifolium repens* and the native *Asperula gunnii*. By 21 months quadrats one metre from the road verge had 55% vegetation cover, 92% of vegetative cover (relative cover) was exotics, predominantly *Anthoxanthum odoratum* (59%) and *Achillea millefolium* (27%). The *A. millefolium* colonisation was due to both the encroachment of rhizome material from surrounding established plants and new seedlings from seed germination. In contrast *Anthoxanthum odoratum* was observed to re-establish from seed germination only.

In contrast, quadrats five and ten metres from the verge were colonised by a range of natives as well as the two exotics *Acetosella vulgaris* and *Achillea millefolium* (Tables 5.2 and 5.3). In the five metre quadrats species with high cover and frequency included the natives *Asperula gunnii*, *Melicytus* sp. and *Stellaria pungens*. In the ten metre quadrats a similar pattern was observed with the natives *A. gunnii* and *Poa fawcettiae* with both high cover and occurring in most quadrats while, *Olearia phlogopappa*, *Carex appressa*, *Melicytus* sp., *Cassinia uncata* and *Cardamine astoniae* had low cover, but were frequently recorded (Tables 5.3 and 5.4).

Table 5.2. Number of quadrats (out of 10) in which species were recorded at four times. (0 = prior to disturbance in March 2000, 2 = 2 months, 9 = 9 months and 21 = 21 months after disturbance) at 10 sites on Schlunks Pass road in subalpine woodland in Kosciuszko National Park. Quadrats located 1 m, 5 m and 10 m from verge. \* denotes exotic species.

Time since disturbance (months)	Distance from the road verge														
	1 metre					5 metres					10 metres				
	0	2	9	21	Total	0	2	9	21	Total	0	2	9	21	Total
<b>Exotic species</b>															
<i>Acetosella vulgaris</i> *		8	9	6	23	1	3	6	8	18	4	2	5	7	18
<i>Achillea millefolium</i> *	10	9	10	10	39	9	4	9	10	32	8	2	8	10	28
<i>Agrostis capillaris</i> *		1			1										
<i>Anthoxanthum odoratum</i> *	9	3	9	10	31	1	1	2	2	6	1			2	3
<i>Trifolium pratense</i> *		1			1										
<i>Trifolium repens</i> *	5	2	8	5	20		1			1					
<b>Native species</b>															
<i>Acaena novae-zelandiae</i>	1				1	1	1	1		3	1	1		1	3
<i>Aciphylla simplicifolia</i>						2			2	4	3		1	5	9
<i>Asperula gunnii</i>	3		5	5	13	9	4	9	9	31	8	10	9	10	37
<i>Cardamine astoniae</i>			1		1	2		4	4	10	3		5	3	11
<i>Carex appressa</i>				1	1	5		2	3	10	3		2	7	12
<i>Carex breviculmis</i>	1			2	3				5	5	1			5	6
<i>Carex inversa</i>						1				1			1		1
<i>Cassinia uncata</i>				3	3	6		2	3	11	5	3	1	3	12
<i>Cerastium vulgare</i>			2		2										
<i>Craspedia aurantia</i>											3	1	2	2	8
<i>Galium proprinquum</i>						1				1					
<i>Geranium potentilloides</i> var. <i>potentilloides</i>									2	2	1		2	4	7
<i>Grevillea australis</i>											1			2	3
<i>Helichrysum scorpioides</i>						1		1	1	3	2		2	3	7
<i>Hovea montana</i>						3			2	5	2				2
<i>Melicytus</i> sp. ( <i>Hymenantha dentata</i> )	5		2	2	9	8	4	7	8	27	7	2	5	8	22
<i>Luzula novae-cambriae</i>														1	1
<i>Luzula novae-cambriae/modesta</i>						1				1					
<i>Microseris lanceolata</i>				1	1	3			1	4	2	1	3	3	9
<i>Olearia algida</i>									1	1	2			1	3
<i>Olearia phlogopappa</i>	4		3	4	11	6	1	4	7	18	8	3	5	6	22
<i>Oreomyrrhis eriopoda</i>				1	1	2		2	3	7			1	1	2
<i>Pimelea alpina</i>									3	3	3		1	2	6
<i>Pimelea ligustrina</i>															
<i>Poa costiniana</i>				1	1				1	1				2	2
<i>Poa fawcettiae</i>	1	1	2		4	9	3	8	9	29	9	7	9	7	32
<i>Poa helmsii</i>						1			1	2	4		3	1	8
<i>Poa hiemata</i>						1		1		2	3		1		4
<i>Prasophyllum alpestre</i>						3				3	3				3
<i>Prostanthera microphylla</i>						1				1	1				1
<i>Ranunculus graniticola</i>						3			1	4					
<i>Ranunculus</i> spp.									1	1					
<i>Scleranthus biflorus</i>						4				4	3				3
<i>Senecio gunnii</i>						1				1					
<i>Stellaria pungens</i>	2		2	2	6	2	1	3	5	11	3		4	6	13

Table 5.3. Average cover of species (%) at four times; (0 = prior to disturbance in March 2000, 2 = 2 months, 9 = 9 months and 21 = 21 months after disturbance) at 10 sites on Schlunks Pass road in subalpine woodland in Kosciuszko National Park. Quadrats located 1 m, 5 m and 10 m from verge. \* denotes exotic species.

Time (months)	Distance from road verge											
	1 metre				5 metres				10 metres			
	0	2	9	21	0	2	9	21	0	2	9	21
<b>Total cover</b>	<b>95.4</b>	<b>5.7</b>	<b>47.2</b>	<b>54.9</b>	<b>78.4</b>	<b>2.3</b>	<b>14.3</b>	<b>33.9</b>	<b>70.3</b>	<b>3.0</b>	<b>23.1</b>	<b>27.0</b>
<b>Total Exotic cover</b>	<b>84.6</b>	<b>5.6</b>	<b>44.9</b>	<b>51.0</b>	<b>26.6</b>	<b>1.0</b>	<b>7.3</b>	<b>17.0</b>	<b>9.0</b>	<b>0.4</b>	<b>6.0</b>	<b>6.7</b>
<i>Acetosella vulgaris</i> *		2.5	1.3	2.5	0.1	0.3	3.9	5.7	0.6	0.2	4.8	1.7
<i>Achillea millefolium</i> *	49.7	0.9	11.1	15.0	25.0	0.4	3.0	10.9	8.3	0.2	1.2	4.6
<i>Agrostis capillaris</i> *		0.1										
<i>Anthoxanthum odoratum</i> *	33.7	1.9	31.2	32.6	1.5	0.2	0.4	0.4	0.2			0.4
<i>Trifolium pratense</i> *	0.2											
<i>Trifolium repens</i> *	1.0	0.2	1.3	0.9		0.2						
<b>Total native cover</b>	<b>10.9</b>	<b>0.1</b>	<b>2.4</b>	<b>4.0</b>	<b>51.8</b>	<b>1.3</b>	<b>7.0</b>	<b>16.9</b>	<b>61.3</b>	<b>2.6</b>	<b>17.1</b>	<b>20.3</b>
<i>Acaena novae-zelandiae</i>	0.3				0.2		0.1	1.5	0.3	0.1		0.2
<i>Aciphylla simplicifolia</i>					0.3			0.3	0.4		0.1	0.7
<i>Asperula gunnii</i>	0.7		0.9	0.9	2.2	0.4	1.9	2.0	2.9	1.0	1.9	3.2
<i>Cardamine astoniae</i>			0.1		0.2		0.8	0.9	0.4		0.7	0.5
<i>Carex appressa</i>				0.2	0.8		0.8	0.9	0.6		0.3	2.4
<i>Carex breviculmis</i>	0.2			0.3				0.8	0.1			0.8
<i>Carex inversa</i>					0.1				0.0		0.1	0.0
<i>Cassinia uncata</i>				0.6	4.0		0.3	0.7	0.9	0.3	0.1	0.7
<i>Craspedia aurantia</i>									4.4	0.1	0.3	0.3
<i>Galium proprinquum</i>					0.1							
<i>Geranium potentilloides</i> var. <i>potentilloides</i>								0.3	0.1		0.4	0.6
<i>Grevillea australis</i>									6.3			0.4
<i>Helichrysum scorpioides</i>					0.3		0.1	0.2	1.8		0.3	0.7
<i>Hovea montana</i>					0.4			0.4	0.3			
<i>Melicytus</i> sp. ( <i>Hymenantha dentata</i> )	2.4		0.5	0.3	3.1	0.4	1.0	1.4	3.8	0.2	0.7	1.3
<i>Luzula novae-cambriae</i>												0.2
<i>Luzula novae-cambriae/modesta</i>								0.2				
<i>Microseris lanceolata</i>				0.3	0.7			0.1	0.3	0.1	0.4	0.6
<i>Olearia algida</i>								0.3	0.4			0.3
<i>Olearia phlogopappa</i>	0.8		0.4	0.9	0.5		0.2	0.5			0.1	0.2
<i>Oreomyrrhis eriopoda</i>				0.2				0.3	0.6		0.1	0.3
<i>Pimelea alpina</i>								0.3	0.6		0.1	0.3
<i>Poa costiniana</i>				0.3				0.3				0.5
<i>Poa fawcettiae</i>	6.3	0.1	0.3		35.1	0.4	1.2	3.3	30.8	0.8	10.5	5.4
<i>Poa helmsii</i>					0.2			0.3	3.3		0.5	0.1
<i>Poa hiemata</i>					1.5		0.1		2.0		0.1	
<i>Prasophyllum alpestre</i>					0.1				0.1			
<i>Prostanthera microphylla</i>					0.4				0.3			
<i>Ranunculus graniticola</i>					0.5			0.2				
<i>Ranunculus</i> spp.								0.1				
<i>Scleranthus biflorus</i>					1.0				0.6			
<i>Senecio gunnii</i>					0.2							
<i>Stellaria pungens</i>	0.4		0.3	0.4	0.3	0.1	0.6	2.3	0.6		0.5	1.2

The responses of vegetation in relation to distance from the road and time since disturbance were investigated using ordination (Figures 5.4 and 5.5). These show that; (1) the vegetation in quadrats at one, five and ten metres from the road differed at all times (2) the greatest difference was between vegetation prior to sampling and two months later, and (3) by 21 months the vegetation was similar to, but still not the same as that prior to disturbance.

Based on the ordinations, the species that were important in differentiating between quadrats close to the road and those further away were the three exotics *Achillea millefolium*, *Anthoxanthum odoratum* and *Trifolium repens* which all had higher cover closer to the road, while the natives *A. gunnii*, *P. fawcettiae*, and *Melicytus* sp. were important in quadrats away from the road (Figure 5.4). Changes in the cover and frequency of the same six species were also important in recovery from disturbance (Figure 5.5).

Examining the response of specific species it can be seen that the naturalised weed *Acetosella vulgaris* was a frequent but minor component of the vegetation in nearly all quadrats at all times (Tables 5.2, 5.3). The exotic *Achillea millefolium* occurred in nearly all quadrats prior to disturbance. It recovered from disturbance fairly rapidly although it still had lower cover 21 months after disturbance than it did prior to disturbance. *Anthoxanthum odoratum* was an important exotic occurring at high cover and frequency, but only close to the road verge (Distance  $P < 0.001$ ). It did not tend to spread into quadrats away from the road even after they were disturbed. It recovered rapidly from disturbance (Time,  $P < 0.001$ , Tables 5.4). *Trifolium repens* was the third exotic species identified as important in the ordinations. Its occurrence was nearly entirely limited to the quadrats a metre from the road (Distance,  $P < 0.001$ ) where it is a frequent but minor component of the flora (Tables 5.4).

Table 5.4. Results of the Two-way Repeated Measures ANOVA of cover of those species identified as key explanatory species in the ordination of cover of species at 10 sites along Schlinks Pass road Kosciusko National Park. Time of sampling (prior, two, ten and 21 months following disturbance in April 2000) and distance from road verge (one, five and ten metres) were the repeated measures. Values are P significance values. Significant differences are in bold. Bonferroni correction for multiple tests on the same data set gives an  $\alpha = 0.008$ . \* denotes exotic species.

<b>Species</b>	<b>Time</b>	<b>Distance</b>	<b>Interaction</b>
<i>Acetosella vulgaris</i> *	<b>0.000</b>	0.450	0.120
<i>Achillea millefolium</i> *	0.010	0.020	0.040
<i>Anthoxanthum odoratum</i> *	<b>0.000</b>	<b>0.000</b>	0.250
<i>Trifolium repens</i> *	0.140	<b>0.000</b>	0.090
<i>Asperula gunnii</i>	<b>0.000</b>	<b>0.000</b>	0.050
<i>Melicytus</i> sp. ( <i>Hymenanthera dentata</i> )	<b>0.000</b>	0.140	0.150
<i>Poa fawcettiae</i>	<b>0.000</b>	<b>0.000</b>	0.020

The dominant native species observed during this subalpine post disturbance colonisation were *Asperula gunnii*, *Cardamine astoniae*, *Carex* spp., *Cassinia uncata*, *Melicytus* sp., *Olearia phlogopappa*, *Poa fawcettiae*, and *Stellaria pungens*. Both time ( $p < 0.001$ ) and distance from the road ( $p < 0.001$ ) were significant in explaining the abundance of *A. gunnii* (Table 5.4). *Asperula gunnii* increased in cover from the verge quadrats towards the 10 metre quadrats making it a significant vector in the ordination (Table 5.3 Figure 5.4). In addition the natives *P. fawcettiae* and *Melicytus* sp. were important components of the vegetation in the five, and particularly ten metre quadrats (Tables 5.2 and 5.3, Figure 5.4). In the five and ten metre quadrats *P. fawcettiae* was dominant, as would be expected, with a range of native, and some exotic herbs (notably *Acetosella vulgaris* and *Achillea millefolium*) growing in the inter-tussock spaces. Some of the native herbs such as *Asperula gunnii* and *Schleranthus biflorus* were found growing under the larger *Poa* spp. tussocks. *Poa* spp. was a significant vector for the ordination increasing in cover toward the five and ten metre quadrats (Figure 5.4). *Carex* spp. seedlings (time  $P = 0.02$ , time\*distance  $P = 0.01$ ) and *Melicytus* sp. regenerating from rootstock were observed with increasing cover with distance from road (Tables 5.4 and 5.5). Two further native species that were frequently found, post disturbance (although at low cover) were *Stellaria pungens* and *Olearia phlogopappa*. Both these species returned to pre-disturbed levels after 21 months, with greatest cover found in the five and ten metre quadrats (Tables 5.2).

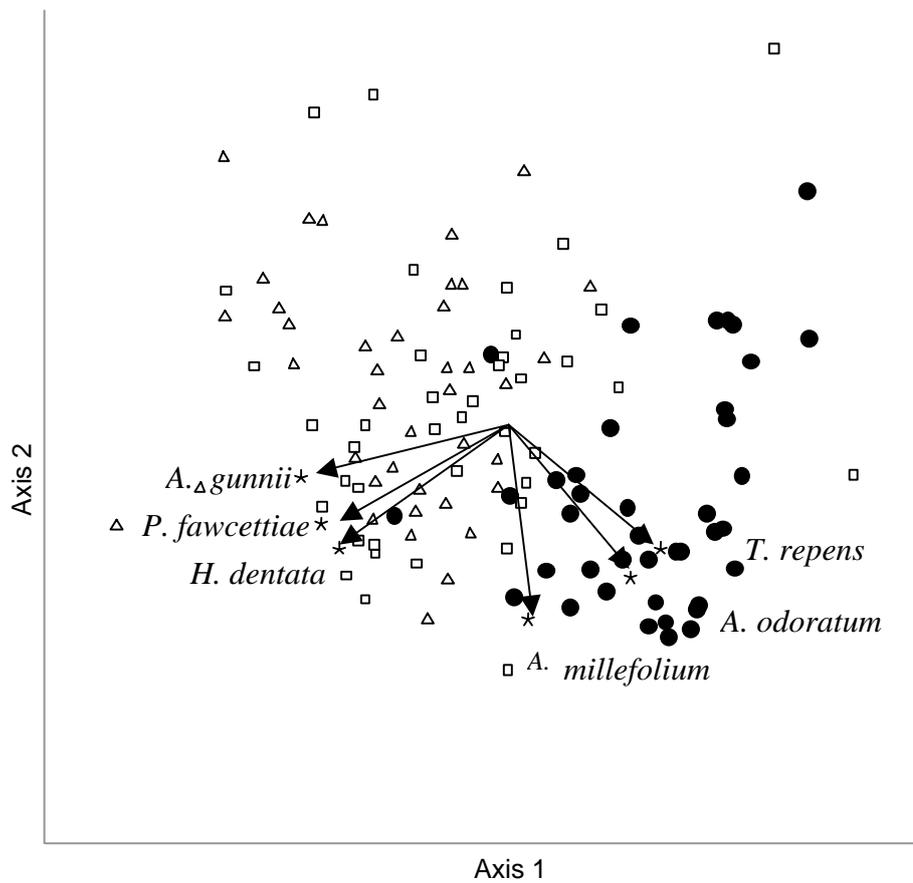


Figure 5.4. Effect of distance from the road verge on community composition estimated by cover values in quadrats as shown by Two-dimensional MDS ordination (two dimensional cutoff 0.8; stress 0.24) of log transformed ( $\ln x + 1$ ) percentage cover data of species over time recorded in quadrats at 10 sites along Schlinks Pass road, Kosciuszko National Park. Sampling times were prior to vegetation removal, 2 months, 9 months and 21 months after vegetation removal. Distances are labeled as ● = 1 m, □ = 5 m and Δ = 10 m from the road verge. Key explanatory species *Asperula gunnii*\*, *Poa fawcettiae*\*, *H. dentata*, *Achillea millefolium*\*, *Anthoxanthum odoratum*\* and *Trifolium repens*\* ( $r^2 > 0.5$ ) are overlaid as vectors.

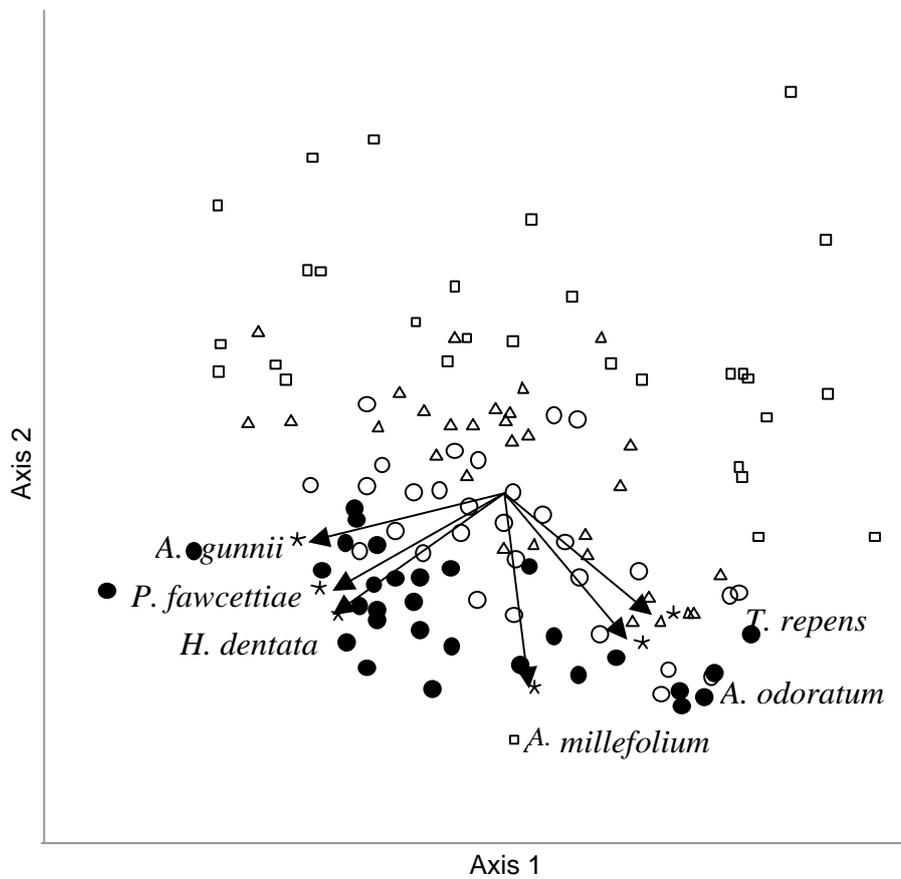


Figure 5.5. Effect of time since disturbance on community composition as shown by Two-dimensional MDS ordination (two dimensional cutoff 0.8; stress 0.24) of log transformed ( $\ln x + 1$ ) percentage cover data of species over time recorded quadrats at 10 sites along Schlinks Pass road, Kosciuszko National Park, Australia. Sampling times were (●) prior to vegetation removal, (□) 2 months, (Δ) 9 months and (○) 21 months after vegetation removal. Quadrats were one metre, five metres and 10 metres from the verge. The key explanatory species are *Asperula gunnii*\*, *Poa fawcettiae*\*, *H. dentata*, *Achillea millefolium*\* and *Anthoxanthum odoratum*\* and *Trifolium repens*\* which are overlaid as vectors ( $r^2 > 0.5$ ) are overlaid as vectors.

#### 5.4.2. Seed bank

The most common exotic species in the seed bank were *Acetosella vulgaris*, *Achillea millefolium* and *Anthoxanthum odoratum* with *Asperula gunnii* the commonest native species along with *Luzula* spp., *Poa* spp., *S. pungens*, *C. uncata*, *Geranium potentilloides* and *O. phlogopappa* (Table 5.6 and Figure 5.6).

Despite a total of 74 species recorded in the general area and 42 species in the quadrats, only four natives and four exotic seedlings were observed in the autumn germination trials. In the spring the number of exotic species germinating rose to seven with 16 native species emerging from the seed bank. This represented 31% of the total area flora and 54% of the pre-disturbance quadrat vegetation. Exotic

germinants were most common in the soil from the one metre quadrats and native germinants in the soil collected from the 5 and 10 metre quadrats (Figure 5.6). This reflects the post disturbance colonisation experiment observations. However, some species such as the exotics *Acetosella vulgaris* and *Achillea millefolium* and the natives *Luzula* spp., *Poa* spp. and *S. pungens* had seedlings in soil from most quadrats irrespective of the distance from the road.

In ordinations of the spring and autumn seed bank data combined, four species were found to differentiate between soil from quadrats close to the road and those further away – *Anthoxanthum odoratum*, *Acetosella vulgaris*, *C. uncata* and *Luzula* spp. (Figure 5.6). There were more *Anthoxanthum odoratum* germinants from soil from the quadrats adjacent to the road while there were more *Acetosella vulgaris* and *C. uncata* and *Luzula* spp. germinants in the soil from the five and ten metre quadrats. *Anthoxanthum odoratum* was found predominantly in soil from the one metre quadrats with a trend ( $p = 0.08$ ) for significantly more germinants than the five and ten metre quadrats (Table 5.5 and 5.6). It accounted for 8% and 17% of the total germinants for spring and autumn respectively. *Acetosella vulgaris* was common throughout the one, five and ten metre quadrats in both autumn and spring, accounting for 22% of all germinations in autumn and 44% of all spring germinations. Sixteen and 12% of germinants in spring and autumn were *Poa* spp. respectively. These *Poa* spp. seedlings were predominantly from the five and ten metre quadrats (Tables 5.5 and 5.6). The two other natives found to be significant vectors for the seed bank germinations were *Luzula* spp. and *C. uncata* (Figure 5.6).

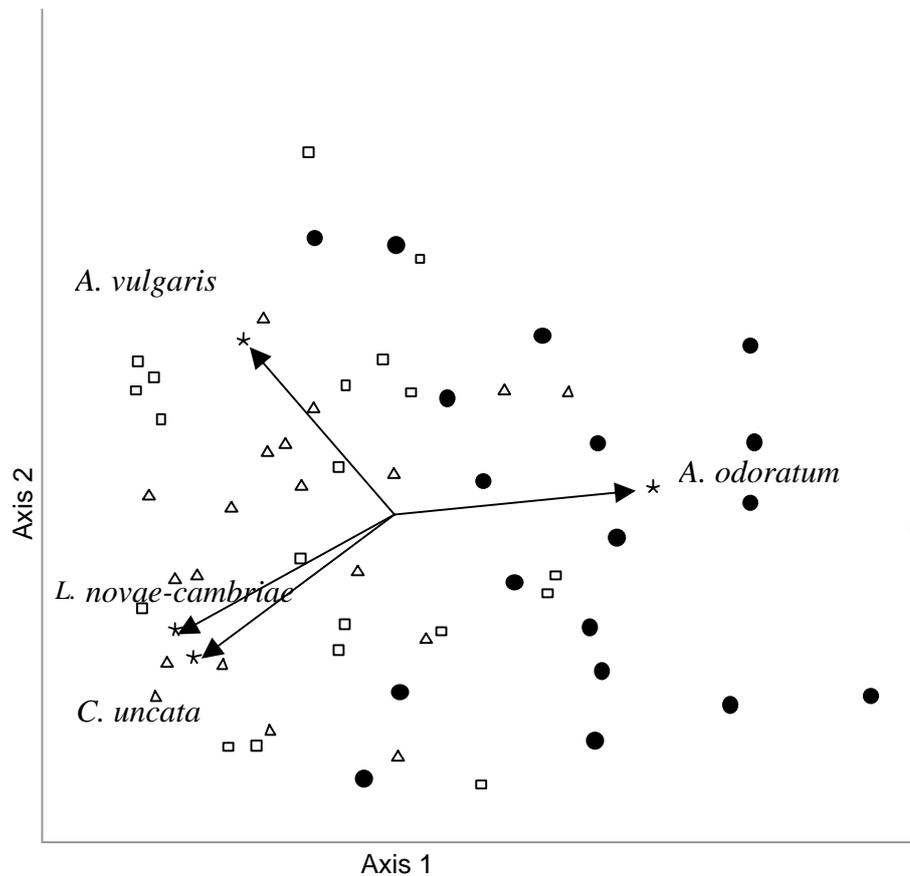


Figure 5.6. Effect of distance from the road on community composition of seedlings (autumn and spring germinations combined) from soil seed bank samples as shown by MDS ordination (two dimensional cutoff; 0.9 0; Stress = 0.27) from 10 sites along Schlinks Pass road, Kosciuszko National Park, Australia. Distances are labeled as ● = 1, □ = 5 and Δ = 10 metres from the verge. Species with the strongest explanatory power are overlaid as vectors

Table 5.5. Results for Two-way Repeated Measures ANOVA of number of germinants from soil for species identified as important in the ordinations from quadrats along Schlinks Pass road in the subalpine area of Kosciuszko National Park. Season of germination (autumn or spring) was the dependant variable. Distance from road verge (one, five and ten metres) was the repeated measure. Season\*Distance test for the interaction of the season and distance variables. Values displayed are P significance values.

Species	Season	Distance	Interaction
<i>Acetosella vulgaris</i> *	0.58	0.15	0.75
<i>Achillea millefolium</i> *	0.08	0.79	0.90
<i>Anthoxanthum odoratum</i> *	0.74	0.08	0.39
<i>Luzula</i> spp.	0.00	0.02	0.02
<i>Microseris lanceolata</i>	0.19	0.56	0.56
<i>Olearia phlogopappa</i>	0.00	0.36	0.36
<i>Poa</i> spp.	0.00	0.01	0.16

The species *Geranium potentilloides* var. *potentilloides* was not found to be a significant coloniser of the disturbed quadrats although it was relatively common native in the seed bank study comprising 5% of the seedlings in spring and 2% in

autumn. Seedlings were found mainly in the five and ten metre seed bank quadrats (Table 5.6).

Table 5.6. Number of germinants in autumn and spring of each species recorded at quadrats one metre, five metres and ten metres away from road verge in subalpine woodlands in Kosciuszko National Park. \* indicates exotic species

Species	Autumn				Spring			
	1 m	5 m	10 m	Total	1 m	5 m	10 m	Total
<b>Exotic plants</b>								
<i>Acetosella vulgaris</i> *	29	203	65	297	34	182	64	280
<i>Achillea millefolium</i> *	18	16	14	48	25	29	23	77
<i>Agrostis capillaris</i> *					2	0	0	2
<i>Anthoxanthum odoratum</i> *	107	10	0	117	77	20	7	104
<i>Trifolium pratense</i> *					9	2	0	11
<i>Trifolium repens</i> *	6	0	0	6	12	0	0	12
<b>Native species</b>								
<i>Asperula gunnii</i>	0	7	50	57	5	19	60	74
<i>Cardamine astoniae</i>	0	17	27	44	0	26	36	62
<i>Cassinia uncata</i>	0	11	8	19	0	11	20	31
<i>Geranium potentilloides</i> var. <i>potentilloides</i>	3	9	9	21	10	29	26	65
<i>Helichrysum scorpioides</i>	0	0	2	2	0	0	2	2
<i>Melicytus</i> sp. ( <i>Hymenantha dentata</i> )					1	2	0	3
<i>Luzula</i> spp.	8	42	43	93	26	59	93	178
<i>Microseris lanceolata</i>					0	2	1	3
<i>Olearia phlogopappa</i>					7	16	16	39
<i>Poa</i> spp.	7	36	43	86	24	86	91	201
<i>Prasophyllum alpestre</i>					0	2	1	3
<i>Prostanthera microphylla</i>					0	1	0	1
<i>Scleranthus biflorus</i>					0	2	1	3
<i>Stellaria pungens</i>					14	24	26	64

## 5.5. DISCUSSION

The post disturbance recolonisation study presented here found that vegetation composition of small gaps can be approaching that of natural vegetation within two years. By 21 months vegetation cover in the small gaps was around half of the pre-disturbance vegetation cover. Similar relatively rapid initial recovery was found in studies of subalpine grasslands after the 2003 fires (Bear 2004; Scherrer *et al.* 2004). Both studies found that the cover and composition of vegetation was starting to approach that of unburnt vegetation within a year of the fire, although Bear (2004) found that biomass of individual plants and the vegetation generally were substantially lower than unburnt grasslands.

Disturbance to the road verge (one metre quadrats) and five and ten metre quadrats along Schlinks Pass road revealed a gradient of colonisation from an exotic

dominated recovery adjacent to the road verge through to a native dominated colonisation at ten metres. Therefore the composition of the recovering vegetation was strongly related to pre-disturbance vegetation and site conditions. For example the gaps in the road verge quadrats were predominantly colonised by exotic species that appear to be well adapted to both repeated disturbance and the different physical and chemical properties of the soils on roadsides (Chapter 4).

The findings that pre-disturbance occupation of a site by exotics reduces post disturbance recolonisation by natives (McIntyre 1993) are supported by the results in this study. Some exotics, principally *Achillea millefolium* and *Acetosella vulgaris*, were already present in the natural vegetation adjacent to the road, with these exotics contributing 9% of the cover pre-disturbance to the quadrats 10 metres from the road. Post disturbance, they were also important taxa in the recovery at these sites, increasing in cover over time. They were also important components of the seed bank in these sites. The native species which appeared to colonise the disturbance quadrats in significant abundance in this study included *Asperula gunnii*, *P. fawcettiae*, *Melicytus* sp., *O. phlogopappa* and *S. pungens*. Whether these natives were able to out-compete the exotics post this study, particularly in the five and ten metre quadrats could not be determined due to the 2003 fires.

The seed bank represents a source from which new vegetation may quickly arise if the existing stand is disturbed (e.g. Freedman *et al.* 1982; Marks and Nwachuku 1986; Ebersole 1989; Bakker *et al.* 1996; Stocklin and Baumler 1996; Drake 1998; Urbanska *et al.* 1998; Moles and Drake 1999). The assumption of exotic and native seed input from the roadside into natural gaps is confirmed here where small gap disturbances (removing most of the soil) in native vegetation areas were recolonised by both roadside exotics and natives. The exotic dominated road verge is presumably the source of the propagules for this mixed 'successional' pathway. It was also observed that both encroachment from existing vegetation into the gaps and germination of seedlings from the seed bank occurred in this experiment for some exotics and natives.

Many seed bank studies have found a difference in composition between the established vegetation and the seed bank, with few authors finding a close correlation

between the compositions of the seed bank to the present vegetation (McGraw and Day 1997; Morin and Payette 1988; Lopez-Marion *et al.* 2000). However a study of the seed bank floras of three ski resort car park or car park verges in central Kosciuszko National Park found that two thirds of the exotics and most of the native species were present in the above ground vegetation within a 30 m radius of the sampling site (Mallen-Cooper 1990). In this study there was some relationship between the seed bank and above ground vegetation. The road verge seed banks were dominated by exotic propagules, particularly *Acetosella vulgaris*, *Achillea millefolium*, *Anthoxanthum odoratum* although the natives *Poa* spp. and *Luzula* spp. were also common. Soil from quadrats away from the road (the five and ten metre quadrats) produced more native germinants but also exotic species. Some species were observed more frequently in the seed bank than in the field colonisation observations such as *G. potentilloides* var. *potentilloides*. It is important to note that a different suite of species may have germinated in the field compared to those that germinated in the greenhouse.

#### **5.5.1. Response of *A. millefolium* to disturbance**

The results of this post disturbance colonisation study and the previous survey of roadsides and adjacent areas (Chapter 4) demonstrated that *Achillea millefolium* can be found in high density along road verges, and can occur in adjacent native vegetation in Kosciuszko National Park. In the subalpine sites selected here, the average pre-disturbance cover of *A. millefolium* along the roadsides was 50% and even 10 metres away from the road verge it was still 8.3%. *Achillea millefolium* recovered rapidly and was one of the few species recorded in the gaps two months after disturbance. By 21 months post disturbance the percentage cover of *A. millefolium* on the road verge approached pre-disturbance levels with 30% relative cover (prior to disturbance there had been 52% relative cover). However, in the quadrats 10 metres away cover had increased from 12% to 17% relative cover. *Achillea millefolium* was also the most frequently encountered species in each time period. It germinated rapidly, and regularly, with moderate numbers of seed present in both the autumn and spring germination trials for quadrats both on the road and in the adjacent native vegetation.

The dominance of *A. millefolium* along areas of road verge and its post disturbance presence recorded in this study is consistent with other research on this species. *Achillea millefolium* is described as both a pioneer species and an invasive species in disturbed sites. In studies in the U.S.A. *A. millefolium* is found both in the earliest stages of succession vegetation and persists throughout succession stages (Humphrey 1984; Agee 1996).

*Achillea millefolium* is an example of a sleeper weed in the Australian Alps, that is an exotic species whose invasion is characterised by a lag between the time when it is first found in an area to the time when the population increases rapidly (Kowarik 1995; Booth *et al.* 2003). Although the species has been in the Park for at least 50 years, it is only in the last 15 years that it has become common along roadsides and other areas of disturbance. Until 1995 *A. millefolium* was classified as a low priority weed, it was then listed as a high priority for monitoring, including any sudden population increases (NSW NPWS 1995). Within eight years (NSW NPWS 2003) *A. millefolium* has become a major weed in the Snowy Mountain region. The control of *A. millefolium* is now a top priority as it is considered to be a threat to the conservation, cultural heritage and recreational values of the Park in alpine and subalpine areas (NSW NPWS 2003).

The results of this disturbance recolonisation study support this recommendation for the control of this species as *A. millefolium* has the capacity to remain in the environment via both rhizome and seed material. These bud bank and seed bank stores indicate that *A. millefolium* may be a persistent exotic in the subalpine and alpine areas of Kosciuszko National Park. From the results here and those in Chapter 4 it appears that the limitations to the distribution of *A. millefolium* are that it requires disturbance to establish, has short seed dispersal distance and a preference for moist high nutrient soils. However whether *A. millefolium* can change the natural species composition of these areas needs to be addressed further by investigating its biology and ecology in the environments of Kosciuszko National Park including other potentially limiting factors to its distribution such as altitude. Therefore Section Two of this thesis examines the biology and ecology of this case study environmental weed.

Section Two begins with an examination of the literature and a risk assessment and distribution model to determine the ‘risk’ this particular species poses to the natural floral communities found in the Australian Alps. Section Two also includes chapters focusing on the distribution of *A. millefolium*, vegetative and flowering phenology of *A. millefolium*, resource allocation of *A. millefolium* between flowering, vegetative and underground structures, an examination of aspects of the seed ecology of this weed and the competitive interactions between *A. millefolium* and the native grass *Poa fawcettiae*.



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## CHAPTER 6

# BIOLOGY AND ECOLOGY OF *ACHILLEA* *MILLEFOLIUM*<sup>5</sup>

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### 6.1. SUMMARY

This chapter reviews the biology and ecology of *A. millefolium* including its taxonomy, worldwide distribution, morphology, seed production and lifecycle. These published data were used to conduct a weed risk assessment of *A. millefolium* using three methodologies employed for assessing new plant entries into Australia based on the environmental tolerances, vegetative and sexual reproductive traits, ease of dispersal and spread and weedy status of the species elsewhere. The assessments all indicate that *A. millefolium* presents as a high weed risk to Australia.

Published data were used to model the worldwide and Australian distributions of *A. millefolium* using the software package CLIMEX<sup>®</sup> under current climate parameters and the future climate scenario of + 2°C. It indicates that cool, temperate and Mediterranean climates are highly suitable for *A. millefolium* while areas with high temperatures and low rainfall (such as deserts), or high temperatures combined with wet periods (such as the tropics) are unsuitable. Under a conservative climate change scenario, there would be an overall reduction in areas suitable for *A. millefolium* worldwide but a possible increased distribution in high altitude regions of the world.

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<sup>5</sup>Johnston, F.M. and Pickering, C.M. (2001) Yarrow, *Achillea millefolium* L.: A weed threat to the flora of the Australian Alps. *Victorian Naturalist* **188**, 230-233.

Johnston, F., Pickering, C.M. and Enders, G. (2001) Yarrow a weed that thrives on tourism. Fact Sheet. Cooperative Research Centre for Sustainable Tourism. Griffith University Gold Coast, Queensland.

Johnston, F. (2002) Ecology of the Weed *Achillea millefolium* in alpine and subalpine habitats of Kosciuszko National Park. In: (eds C.M., Pickering, K., Green, and K.. Bridle) *Research on Australia's High Country 1999-2001*. Cooperative Research Centre for Sustainable Tourism, Griffith University Gold Coast, Queensland.

## **6.2. BIOLOGY OF *A. MILLEFOLIUM***

### **6.2.1. Taxonomy**

*Achillea millefolium* L. s.l. (Asteraceae) is part of the *Achillea millefolium* complex - a group of scarcely separable taxa found primarily throughout the temperate and boreal zones of the northern hemisphere and to a lesser extent, the southern hemisphere (Lawrence 1947; Clausen and Hiesey 1958; Clausen *et al.* 1958; Ehrendorfer 1959; Bourdôt *et al.* 1979; Holm *et al.* 1979; Chandler *et al.* 1982; Kubelka *et al.* 1999). The *Achillea millefolium* complex comprises many closely related diploid, tetraploid, hexaploid and octoploid cytotypes (Clausen *et al.* 1955; Clausen *et al.* 1958; Hiesey and Nobs 1970; Ehrendorfer 1959; Vetter and Franz 1996; Vetter *et al.* 1996; Vetter *et al.* 1997). The taxonomy of the group is difficult both among polymorphic taxa and for naturally occurring hybrids (Preitschopf *et al.* 1989; Purdy and Bayer 1996; Kubelka *et al.* 1999). Identification and classification is also difficult due to the indiscriminate use of the common names yarrow and milfoil to refer to several different species of *Achillea* (Chandler *et al.* 1982). *Achillea millefolium* L. *sensu stricto* the hexaploid ( $n = 27$ ) is the most widespread of the species belonging to the *A. millefolium* complex (Mulligan and Bassett 1959; Hiesey and Nobs 1970; Holm *et al.* 1979). The *A. millefolium* s.l. complex itself includes several subspecies such as subsp. *sudetica*, subsp. *ceretanum* (white flowers), subsp. *millefolium* (white flowers) and subsp. *alpestris* (pink flowers) (Ehrendorfer 1959; Guedon *et al.* 1993). The species examined in this dissertation is *A. millefolium* s.l. (*sensu lato*, with latitude) as identified in the Flora of New South Wales (Harden 1993).

### **6.2.2. Distribution**

*Achillea millefolium* is native to Europe and Asia, with its distribution extending from the Mediterranean region to northern Iran to the Arctic Circle (Harden 1993, Zhang *et al.* 1996). The species has been recorded in every province of Canada (Clausen *et al.* 1958; Holm *et al.* 1979; Warwick and Black 1982; Mitich 1990). The species has also been found in southern hemisphere countries including New Zealand and Australia, where it was introduced as a fodder food, an ornamental and for its herbal qualities. In temperate New Zealand *A. millefolium* is a major weed in mixed

cropping farms, particularly in white clover, peas, beans, beets and other root crops (Bourdôt *et al.* 1979; Bourdôt and Butler 1985; Bourdôt *et al.* 1985; Bourdôt and Field 1988; Bourdôt *et al.* 1988). Although often sold in nurseries in Australia *A. millefolium* is regarded as an environmental weed in the Australian Capital Territory (Anon 1998), New South Wales (Blood 2001) and Victoria (McDougall and Appleby 2000). *Achillea millefolium* has been documented as an environmental weed in the Australian Alps (Sainty *et al.* 1998).

### 6.2.3. Morphology

*Achillea millefolium* is a perennial herb that can have an extensive rhizomatous root system with well-developed adventitious roots and root hairs (Chandler *et al.* 1982; Mitich 1990). Plants consist of basal rosettes of leaves which can produce unbranched erect flower stems often 10-100 cm tall. Leaves produced on the basal rosette and on the flowering stem are grey-green, lanceolate and pinnately dissected. Both stems and leaves are covered with short white hairs. Leaves are highly variable in size ranging from 3-20 cm in length and 1-6 cm in width (Figure 6.1a) (Chandler *et al.* 1982; Harden 1993).

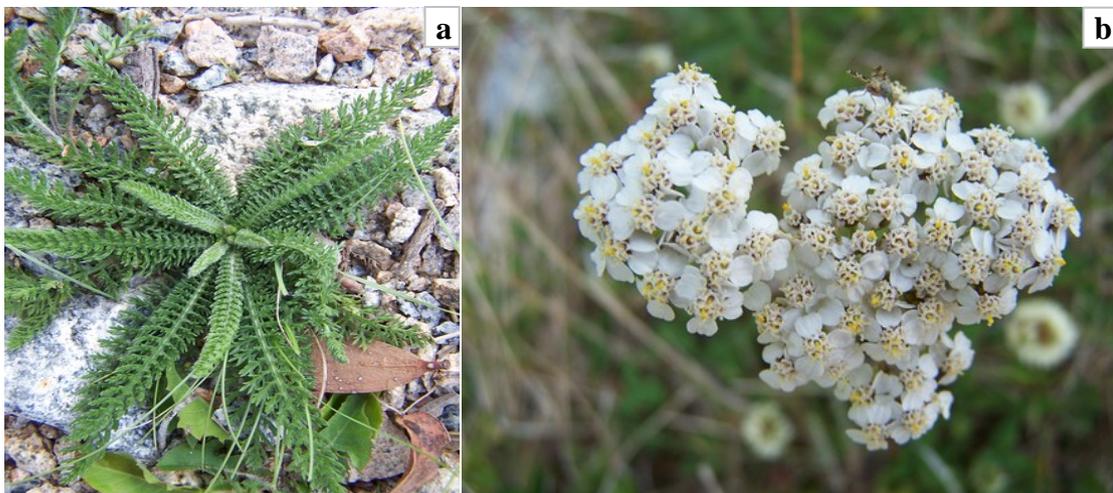


Figure 6.1. (a) Basal rosette of a single *A. millefolium* plant growing in a gravel site in Kosciuszko National Park, showing the lanceolate, pinnately dissected leaves (Photo Z. Bear 2004). (b) Single inflorescence of *A. millefolium* showing the plant's ray and disk florets being visited by a native wasp. This plant was growing in subalpine zone of Kosciuszko National Park (Photo Z. Bear 2004).

Flower stems are simple or forking above, and can be very sparsely to rather densely villous or woolly-villous. Leaves are clustered at the base of the angular flowering

stems with smaller leaves alternating up the stems (Warwick and Black 1982). The flower heads are numerous, occurring in flat-topped paniculate-corymbiform inflorescences (Figures 6.1b and 6.2).

Flowering heads (capitula) are described as consisting of around five ray florets that are three toothed, 2-4 mm long, pistillate and fertile, usually white in colour though both pink and magenta flowers occur (Warwick and Black 1982). Disk-florets (10-30) are bisexual and fertile. Florets are self-incompatible (Chandler *et al.* 1982; Warwick and Black 1982).

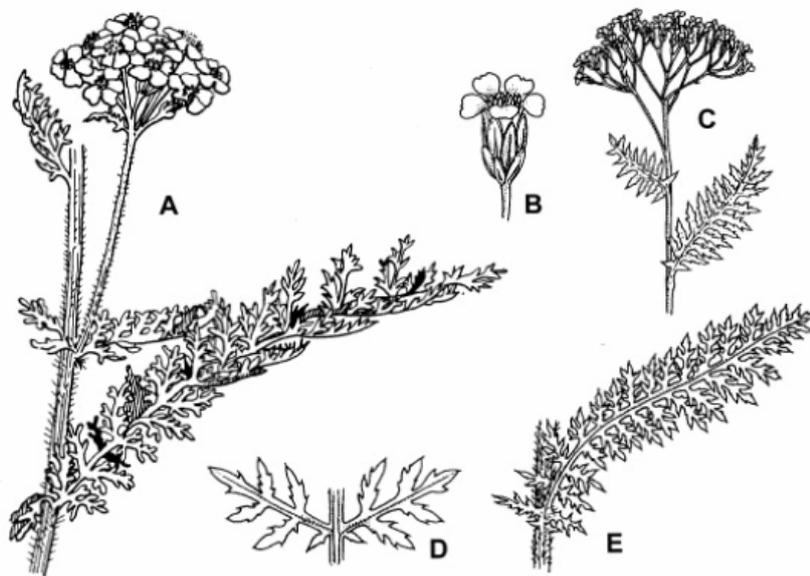


Figure 6.2. Inflorescences and leaves of *A. millefolium* (L.). A. Lateral corymbiform inflorescence and cauline leaves; B. Individual head; C. Terminal branched corymbs; D. Leaflet; E. cauline leaves (adapted from Stanley and Ross 1983 (A) and Harden 1993 (B-E)).

#### 6.2.4. Flowering, pollination and seed production

Flowering, pollination and seed production have been examined for *A. millefolium* as a weed in agricultural areas in New Zealand (Bourdôt *et al.* 1979; Bourdôt and Field 1988; Henskens *et al.* 1992), as a weed in Canada (Deschenes 1974; Warwick and Black 1982) and as a garden plant (Zhang *et al.* 1996). *Achillea millefolium* is a long day flowering plant with an effective photoperiod between 12-18 hours, with flowers appearing from spring through to autumn (Chandler *et al.* 1982; Zhang *et al.* 1996). A range of insects have been found to act as pollinators for *A. millefolium* in Canada

including species from Diptera, Coleoptera, Hymenoptera, Lepidoptera and Hemiptera (Warwick and Black 1982).

Seeds (achenes) are described as oblong 1.5-2.0 mm long with thick wing-margins, without a pappus and are grey-white (Rydberg 1916; Chandler *et al.* 1982; Warwick and Black 1982; Stanley and Ross 1983; Zhang *et al.* 1996). Dispersal of the seed is primarily by wind with the small seed (~0.158 mg) having limited aerodynamic efficiency with the average dispersal distance of 2 to 3 m from the parent (Bourdôt *et al.* 1979).

The potential number of seed produced by established *A. millefolium* plants is high (Henskens *et al.* 1992). It was estimated there was a potential seed output of 900 000 per m<sup>2</sup> in a population with 320 flower stems per m<sup>2</sup> and 25 florets per flowering head in arable land in New Zealand (Bourdôt *et al.* 1979). The average number of flower heads per stem reported in a study in temperate agricultural land is 109 and the mean number of seeds/flower heads is 25.5 equating to 2800 seeds per stem (Bourdôt *et al.* 1979). Another estimation of seed production (Kannangara and Field 1985) found that for pure stands of *A. millefolium* growing in arable land the population stabilised at approximately 58 plants per m<sup>2</sup>, with a resulting estimated seed production of 243 000 seed per m<sup>2</sup>. Single plants growing without interference can form up to 20 flowering stems forming approximately 60 000 seeds. Studies by Bostock and Benton (1979) estimate the mean number of seed per stem at 1660 after seed predation. The small seed of *A. millefolium* has been found to be easily incorporated into the soil where it can remain viable for several years (Bostock 1978).

#### **6.2.5. Seed germination and life cycle in temperate climates**

Seeds can germinate readily except under existing *A. millefolium* plants (Bourdôt *et al.* 1979). In temperate climates, seed germination can occur throughout the year except for the coldest months. When sown on bare ground *A. millefolium* seed has been found to germinate both after fruiting (summer to autumn) and in the following spring. Freshly shed seed can respond to a number of environmental stimuli, including light, scarification and nutrient addition (Field and Kannangara 1983).

Germination viability can be high, between 85% to 99% for fresh seed and 41% for nine year old seed (Robocker 1977; Bostock and Benton 1979; Bourdôt *et al.* 1979).

In temperate conditions vegetative rosettes of *A. millefolium* plants can form in the first season of growth with some rosettes flowering in the first year (Warwick and Black 1982). However, in general flowering does not occur until the second year with plants flowering and setting seed from summer to early autumn. During late autumn, senescence of the flowering structures occurs in temperate environments with the rapid decline in above ground dry weight and a marked proportional increase in the dry weight of rhizomes (Bourdôt *et al.* 1979). In winter the plants can die back to non-flowering rosettes. Winter rhizome growth can involve rapid extension with the formation of many dormant lateral buds. The majority of these rhizome buds do not sprout to form above ground rosettes unless the rhizome is damaged releasing the buds from apical dominance (Bourdôt *et al.* 1979).

Rhizomes are initiated on seedlings at the 8-14 leaf stage or from regenerating rhizome pieces at the 5-6 leaf stage (Bourdôt and Field 1988). They do not generally penetrate deeply in the soil with 80% of the rhizome mass found at a maximum depth of 105 mm (Bourdôt *et al.* 1982; Bourdôt 1984). Plants of *A. millefolium* can spread laterally underground using the rhizome system, with the rhizome extension rate estimated at 7 to 20 cm per year (Bostock and Benton 1979). There is no pronounced dormancy in the generation of rhizome buds, which therefore have the potential to occur at any time of the year as soon as environmental conditions are suitable (Bourdôt *et al.* 1982; Kannangara and Field 1983; Field and Jayaweera 1985b).

### **6.3. ASSESSMENT OF *A. MILLEFOLIUM* AS A WEED SPECIES**

A number of methods have been used prior to importation to assess the risk of a plant species becoming a weed in Australia (Salisbury 1961; Forcella 1985; Hazard 1988; Carr *et al.* 1992; Panetta 1993; Virtue *et al.* 2001; Pheloung 2001). Three methods that use biological and biogeographical attributes were selected from these screening procedures to examine the risk *A. millefolium* presents (Lonsdale and Smith 2001).

The Hazard (1988) method uses generalised indicators of potential weediness including the history as a weed elsewhere, related plants with weed histories,

capacity for vegetative reproduction, capacity for wind/water dispersal and capacity for bird dispersal. Each attribute is allocated a score, the total score is added together – if the total exceeds a certain threshold the plant is classified a weed (Table 6.1). Using this system *A. millefolium* scored a total of 59 points where scores totalling 20 or more indicate grounds for rejection.

Table 6.1. Scoring system used to assess *A. millefolium* as a weed risk using the Hazard (1988) method.

	<b>Criterion</b>	<b>Points<sup>1</sup></b>
1	Is the species a free floating (surface or submerged) aquatic or can it survive, grow and reproduce as free floating aquatic?	0/20
2	Does the species have a history of being a major weed elsewhere in similar habitats?	20/20
3	Does the species have a close relative of similar biology with a history of weediness in similar habitats?	10/10
4	Are the plants spiny?	0/10
5	Does the plant have spiny diaspores?	0/10
6	Are the plants harmful to humans and or animals?	0/8
7	Do the plants produce stolons?	0/5
8	Do the plants have other forms of vegetative reproduction?	8/8
9	Are the diaspores wind dispersed?	8/8 <sup>6</sup>
10	Are the diaspores dispersed by animals and or machinery?	8/8
11	Are the diaspores dispersed by water?	0/5
12	Are the diaspores dispersed by birds?	5/5

<sup>1</sup> Scores totaling  $\geq 20$ , between 12 and 19, or  $< 12$  indicate grounds for rejection, further examination or acceptance, respectively.

Panetta (1993) suggests that the information concerning the status of a species as a weed elsewhere is a reliable basis for predicting weediness in Australia. This system uses a decision tree with Yes, Don't know or No answers to questions with each decision point flowing onto the next question and ultimately to a reject, accept or evaluate conclusion (Figure 6.3). Using this decision tree screening system for proposed plant introductions, again *A. millefolium* would be rejected as a potential environmental weed.

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<sup>6</sup> The seed is primarily, but not exclusively dispersed by wind (with limited aerodynamic efficiency) (Bourdôt *et al.* 1979).

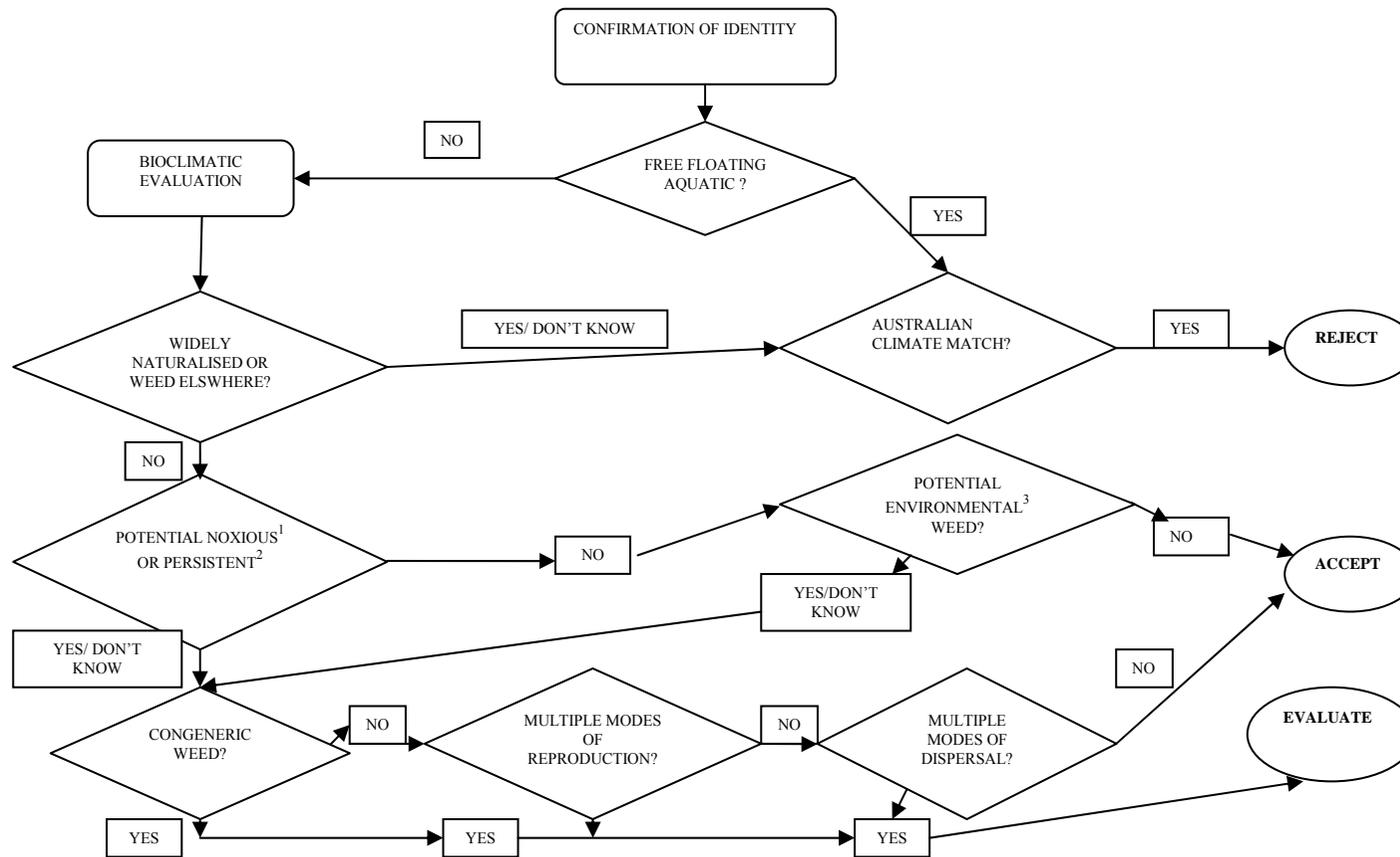


Figure 6.3. A screening system for proposed plant introductions (modified from Panetta 1993).

<sup>1</sup>Noxiousness: poisonous or unpalatable; produces spines, thorns or burrs; harmful to humans; parasitic; competitive <sup>2</sup>Persistence: resistance to herbicides; regrowth from mutilation; long lived propagules

<sup>3</sup>Environmental weed: fruit attractive to wild animals; scrambling or climbing growth form grass, woody legume or geophyte.

The Weed Risk Assessment system (Pheloung 2001) is based on a number of criteria including the history as a weed overseas, climatic match and various biological attributes. In most cases one point is added for a weedy attribute and one point deducted for a non-weedy attribute. The climate and weed elsewhere questions differ from the typical scoring system in that they generate a score using a weighting system. The system compares the total score for species to the critical threshold values to determine the recommended score for the species. The system tallies the numbers of questions in each section, allowing for knowledge gaps while still requiring responses to a minimum number of questions in each its three different categories. The categories include history/biogeography; climate and distribution weed elsewhere, biology/ecology, reproduction, dispersal mechanisms and persistence attributes. The Weed Risk Assessment system also has some capacity to suggest the type of ecosystem likely to be affected by the plant assessed (Table 6.2).

Based on the Weed Risk Assessment results *A. millefolium* would be rejected today by the Australian Quarantine and Inspection Service system as a significant threat to both agriculture and the natural environment. It scored a total score of 31, an agricultural score of 26 and an environmental score of 23. In this method scores > 6 indicate grounds for rejection (Pheloung 2001). For each of these weed risk assessment methods the criterion and source of data used as grounds for rejection of *A. millefolium* are given in Table 6.3. In a 2003 assessment of weed species in natural and agricultural ecosystems in Australia *A. millefolium* was classed as a naturalised and minor weed on land for agricultural use while in natural areas it is a naturalised species known to be a major problem in natural environments in four or more locations within a State or Territory (Groves *et al.* 2003).

Table 6.2. Scores for *A. millefolium* using the Pheloung (2001) Weed Risk Assessment System. Yes (Y) or no (N) or leave blank was given for each question unless otherwise indicated. Agricultural score = 26. Environmental score = 23. Total score = 31. Therefore the outcome was to reject this species.

Criterion	Response	Score	Category
<b>Biogeography/Historical</b>			
<b>1. Domestication/cultivation score</b>			
1.01 Is the species highly domesticated?	Y	1	C
1.02 Has the species become naturalised where grown?	Y	1	C
1.03 Does the species weed races?			C
<b>2. Climate and distribution</b>			
2.01 Species suited to Australian climates (0-low; 1-intermediate; 2-high)	Y	2	C
2.02 Quality of climate match data (0-low; 1-intermediate; 2-high)	Y	1	C
2.03 Broad climate suitability (environmental versatility)	Y	1	C
2.04 Native or naturalised in regions with extended dry periods	N		C
2.05 Does the species have a history of repeated introductions outside its natural range?			
<b>3. Weed elsewhere</b>			
3.01 Naturalised beyond native range	Y	2	C
3.02 Garden/amenity/disturbance weed	Y	2	C
3.03 Weed of agriculture	Y	4	A
3.04 Environmental weed	Y	4	E
3.05 Congeneric weed			C
<b>Biology/ecology</b>			
<b>4. Undesirable traits</b>			
4.01 Produces spines, thorns or burs	N		C
4.02 Allelopathic	N		C
4.03 Parasitic	N		C
4.04 Unpalatable to grazing animals	Y/N		A
4.05 Toxic to animals	Y/N		C
4.06 Host for recognised pests and pathogens	N		C
4.07 Causes allergies or is otherwise toxic to humans	N		N
4.08 Creates a fire hazard in natural ecosystems	N		E
4.09 Is a shade tolerant plant at some stage of its lifecycle	Y	1	E
4.10 Grows on infertile soils	Y	1	E
4.11 Climbing or smothering habit	N		E
4.12 Forms dense thickets	Y	1	C
<b>5. Plant type</b>			
5.01 Aquatic	N		E
5.02 Grass	N		C
5.03 Nitrogen fixing woody plant	N		E
5.04 Geophyte	N		C
<b>6. Reproduction</b>			
6.01 Evidence of substantial reproductive failure in native habitat	N		C
6.02 Produces viable seed	Y	1	C
6.03 Hybridises naturally			A
6.04 Self-compatible or apomictic	N	-1	C
6.05 Requires specialist pollinators	N		C
6.06 Reproduction by vegetative fragments	Y	1	A
6.07 Minimum generative time (years)	1	1	C
<b>7. Dispersal mechanisms</b>			
7.01 Propagules likely to be dispersed unintentionally (plants grow in heavily trafficked areas)	Y	1	A
7.02 Propagules dispersed intentionally by people	Y	1	C

<b>Criterion</b>	<b>Response</b>	<b>Score</b>	<b>Category</b>
7.03 Propagules likely to disperse as a produce contaminant	Y	1	A
7.04 Propagules adapted to wind dispersal	Y	1	C
7.05 Propagules buoyant	Y		E
7.06 Propagules bird dispersed	Y	1	E
7.07 Propagules dispersed by other animals (externally)	N	-1	C
7.08 Propagules survive passage through gut	Y	1	C
<b>8. Persistence attributes</b>			
8.01 Prolific seed production (>2000/m <sup>2</sup> )	Y	1	C
8.02 Evidence that a persistent propagule bank is formed (>1 yr)	Y	1	C
8.03 Well controlled by herbicides	Y/N		A
8.04 Tolerates, or benefits from, mutilation or cultivation	Y	1	A
8.05 Effective natural enemies present in Australia	N	-1	C

A= agricultural, E= environmental, N= nuisance, C= combined

Table 6.3. Plant traits and sources of information used in the determination of risk of *A. millefolium* using weed risk assessment and methodology.

<b>Plant trait</b>	<b>Source</b>
History of being a major weed elsewhere in similar habitats and climates	Bourdôt <i>et al.</i> 1979; Holm <i>et al.</i> 1979; Warwick and Black 1982.
Exhibits a broad climate suitability	Holm <i>et al.</i> 1979; Mitich 1990; Carr <i>et al.</i> 1992; Aleksoff 1999; Suleimenov <i>et al.</i> 2001.
Shade tolerant	Fenner 1978; Kannangara and Field 1983; Bourdôt <i>et al.</i> 1984; Kannangara and Field 1985.
Plants can be harmful to humans and/or animals	Warwick and Black 1982; Stubbendieck <i>et al.</i> 1989.
Reproduction by vegetative fragmentation	Bourdôt <i>et al.</i> 1979; Henskens <i>et al.</i> 1992.
Prolific production of viable seed	Bourdôt <i>et al.</i> 1979; Kannangara and Field 1983, 1985; Warwick and Black 1982; Henskens <i>et al.</i> 1992.
Seed is wind dispersed	Bourdôt <i>et al.</i> 1979; Warwick and Black 1982
Propagules can survive passage through animal and or bird gut	Salisbury 1961.
Propagules dispersed intentionally by people	Zhang <i>et al.</i> 1996; Thornton-Wood 1999.
Persistent propagules bank	Robocker 1977; Bostock 1978; Bourdôt <i>et al.</i> 1979; Bourdôt <i>et al.</i> 1982; Bourdôt 1984; Bourdôt and Field 1987 Field and Kannangara 1987.
Tolerates disturbance including cultivation	Bourdôt <i>et al.</i> 1982; Bourdôt <i>et al.</i> 1984; Bourdôt and Butler 1985; Field and Jayaweera 1985a,b; Volland and Dell 1981; Howe 1994.
Has no effective natural predators present in Australia	Warwick and Black 1982; Corey per. comm. CSIRO Division of Entomology 2002
Not effectively controlled by herbicides	Bourdôt <i>et al.</i> 1979; Field and Jayaweera 1985b; Rutherford 1986; Bourdôt and Field 1988; Sanecki <i>et al.</i> 2003

#### **6.4. MODELLING CURRENT AND POTENTIAL DISTRIBUTION OF *A. MILLEFOLIUM***

Published data were used to model the current and potential distribution of *A. millefolium* worldwide using the computer package CLIMEX<sup>®</sup> Windows Version 1.1 (Sutherst *et al.* 1999). This model can be used to assess potential habitats in terms of vulnerability to invasion (Kriticos 1996; Sutherst *et al.* 2000; Kriticos and Randall 2001; Kriticos *et al.* 2003b). CLIMEX<sup>®</sup> was used to create a model of the climatic requirements to predict the potential geographical distribution of *A. millefolium* using the Compare Locations module. The climatic response functions are inferred from its known geographical distribution, relative abundance and seasonal phenology and projected onto independent locations (Sutherst *et al.* 1999; Kriticos and Randall 2001). The functions are hand-fitted to the geographic information using an iterative adjust-and-compare method.

An annual growth index was used in CLIMEX<sup>®</sup> based on response functions for temperature and moisture to describe the potential for population growth during favourable climate conditions and stress indices to describe the probability that the population can survive adverse conditions (Sutherst *et al.* 1999). The growth and stress indices are calculated weekly from interpolated monthly climate data and are combined into an ecoclimatic index of climate suitability. The climatic response parameters for the CLIMEX<sup>®</sup> temperature and moisture indexes and the cold, hot, dry and wet stresses for *A. millefolium* (Table 6.4) were inferred from the global distribution of *A. millefolium*, with the exception of Australia (Figure 6.3).

The CLIMEX<sup>®</sup> model of *A. millefolium* is consistent with the description of the native range of the species as circumboreal i.e. in the continuous zone in northern hemisphere found between 50° and 70° latitude (Figure 6.5a). This model also predicts that many other temperate and Mediterranean zones would be suitable for the survival of *A. millefolium* including those in the southern hemisphere such as in Australia and New Zealand. It shows the entire area of western Europe, temperate and high elevation areas of Africa, high elevation parts of Japan and high altitude areas of China, Tibet and Nepal as suitable for *A. millefolium*. The CLIMEX<sup>®</sup> generated map accords with herbarium records with *A. millefolium* found in many

temperate and Mediterranean climates of the northern and southern hemispheres (Figure 6.4). *Achillea millefolium* distribution maps from older published records (e.g. Holm *et al.* 1979) broadly agree with the CLIMEX<sup>®</sup> projections, although at a coarser scale than the CLIMEX<sup>®</sup> results.

Table 6.4. CLIMEX<sup>®</sup> model parameter values for *A. millefolium* derived from climatic data associated with known distribution. Parameter mnemonics from Sutherst *et al.* 1999.

<b>Index</b>	<b>Parameter</b>	<b>Value</b>
<b>Temperature</b>	DV0 = lower threshold	2.5
	DV1 = lower optimum temperature	8
	DV2 = upper optimum temperature	22
	DV3 = upper threshold	28
<b>Moisture</b>	SM0 = lower soil moisture threshold	0.15
	SM1 = lower optimum soil moisture	0.5
	SM2 = upper optimum soil moisture	1
	SM3 = upper soil moisture threshold	1.5
<b>Cold Stress</b>	TTCS = temperature threshold	0
	THCS = stress accumulation rate	0
	Degree-day threshold	14
	Degree-day rate	-0.0008
<b>Heat Stress</b>	TTHS = temperature threshold	30
	THHS = stress accumulation rate	0.004
	Degree-day threshold	0
	Degree-day rate	0
<b>Dry Stress</b>	SMDS = threshold soil moisture	0.15
	HDS = stress accumulation rate	-0.005
<b>Wet Stress</b>	SMWS = threshold soil moisture	2.5
	HWS = stress accumulation rate	0.002
<b>Hot-Wet Stress</b>	TTHW = hot-wet temperature threshold	22
	MTHW = hot-wet moisture threshold	1.2
	PHW = hot-wet stress accumulation rate	0.008

Considering the CLIMEX<sup>®</sup> model, herbaria records and other published data, the distribution of areas suitable for *A. millefolium* range from temperate, Mediterranean, to tundra and subarctic zones. In general, the most suitable areas for *A. millefolium* have constant rainfall throughout the year. The climates which were found to be unsuitable for *A. millefolium* were those of extreme cold (Arctic and Antarctic regions), warm regions, or those that are both warm and wet. Regions unsuitable for *A. millefolium* include tropical south-east Asia, tropical Africa, and those too dry such as the desert areas of Africa, Australia and parts of central North America (Figure 6.4a).

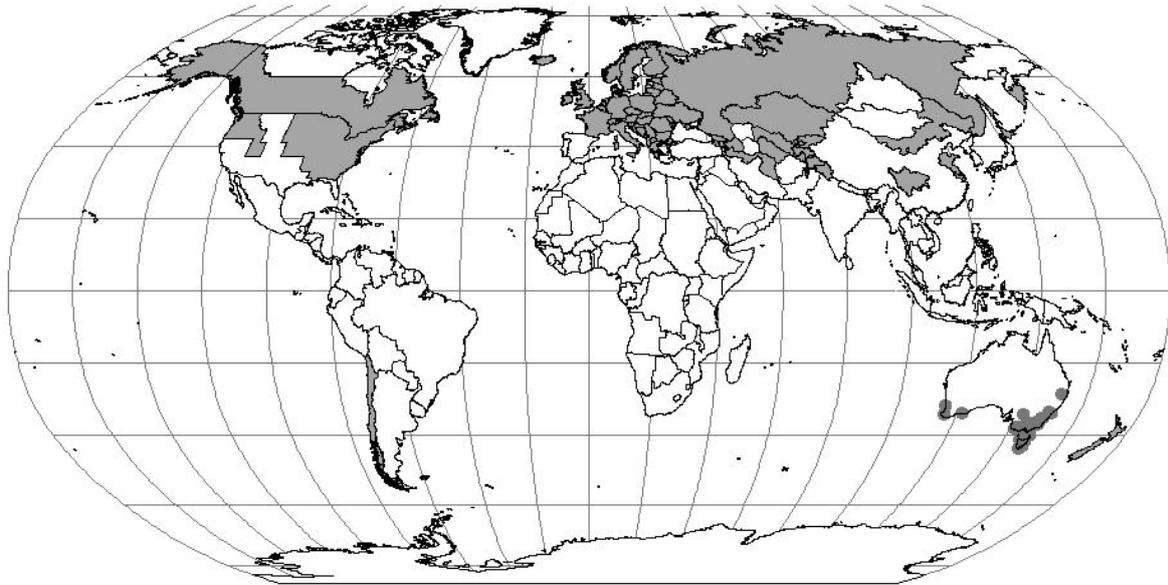


Figure 6.4. Worldwide distribution of *A. millefolium*. Shaded areas indicate regions with *A. millefolium*, not the actual territory occupied by this species. Australian distribution from Australia's Virtual Herbarium (<http://www.cpbr.gov.au/cgi-bin/avh.cgi>) and (Author unpublished data). Other distribution adapted from Holm *et al.* (1979) and the Swedish Museum of Natural History Virtual Herbarium (<http://linnaeus.nrm.se/flora/di/astera/achil/achimil.html>).

The overall effect of climate change upon the worldwide distribution of *A. millefolium* is likely to be one of range contraction. On a global scale climate change (+2°C) will likely enable an expansion of *A. millefolium* into areas that are presently too cold, at either high latitudes or altitudes, with a decrease in the suitability of regions presently experiencing Mediterranean climates (Figure 6.5b).

For Australia, climate change (+2°C) will make the areas of southern Queensland, Mediterranean South Australia and Western Australia less suitable for *A. millefolium*, while the cooler wetter climates of the high country of New South Wales, Victoria and Tasmania will become more suitable for *A. millefolium* (Figure 6.6a,b). CLIMEX<sup>®</sup> accurately predicted that *A. millefolium* is not limited by the climatic range in the Australian Alps with predicted and actual presence conforming closely (Chapter 7).

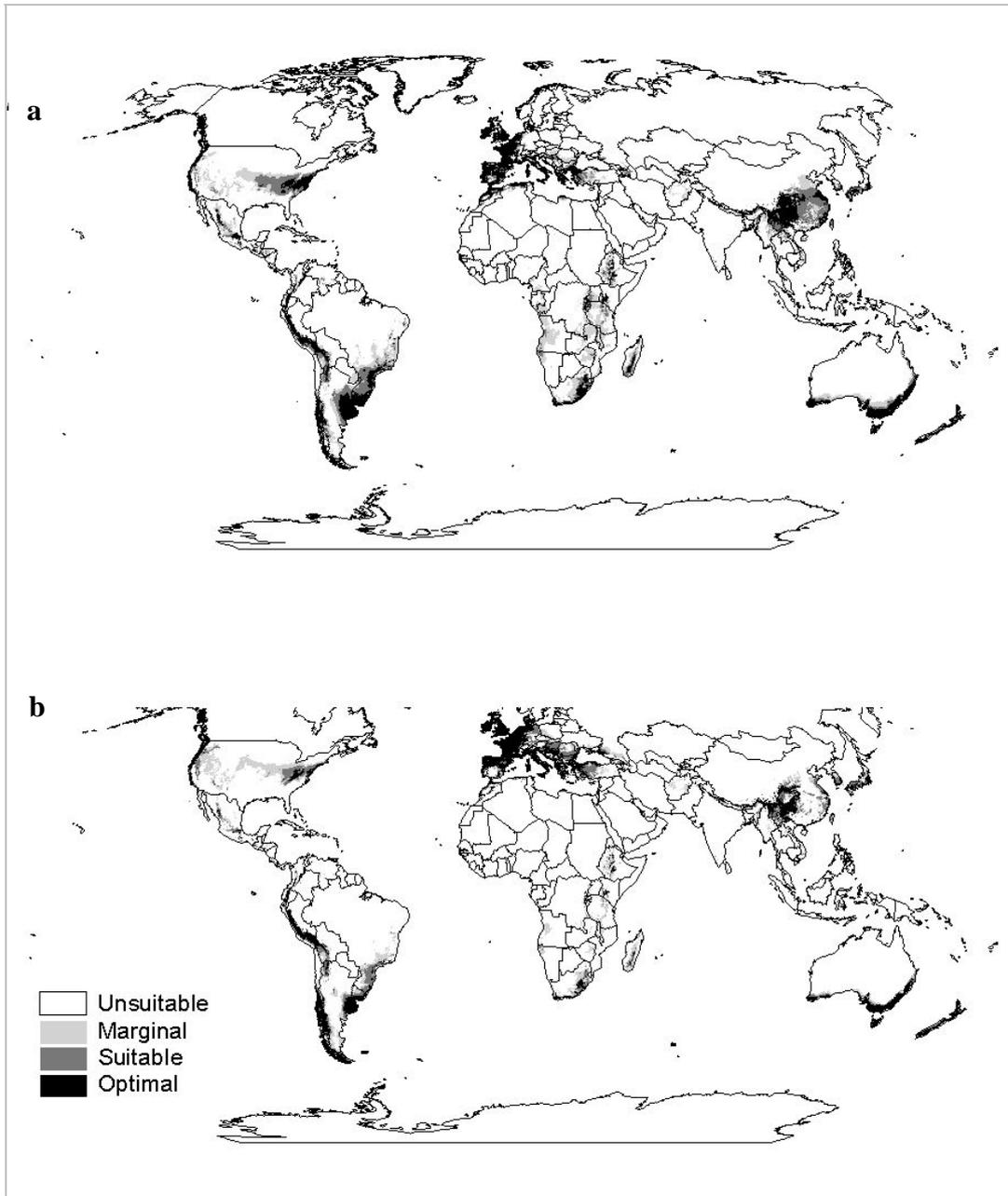


Figure 6.5. World map showing predicted climatic suitability (Ecoclimatic Index) for *A. millefolium* under; (a) current climate, and (b) future climate scenario (+2°C). These maps generated using the CLIMEX<sup>®</sup> program using distribution parameters and equations detailed in Table 6.2 and Sutherst *et al.* (1999).

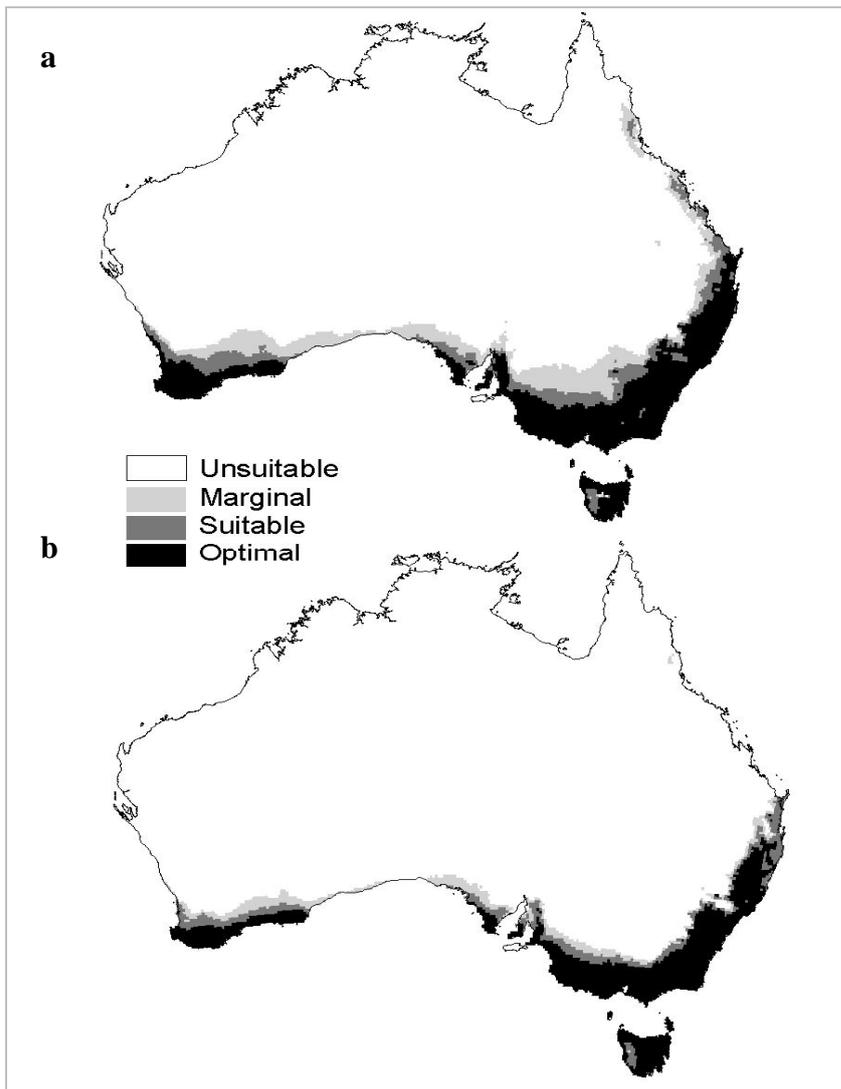


Figure 6.6. Australia showing predicted climatic suitability (Ecoclimatic Index) for *A. millefolium* under (a) current climate and (b) future climate scenario (+2°C). Maps generated using the CLIMEX<sup>®</sup> program using distribution parameters and equations detailed in Table 6.2 and Sutherst *et al.* 1999.

## 6.5. DISCUSSION

*Achillea millefolium* is a perennial herb native to Europe and Asia and a weed in many cold, temperate and Mediterranean climates (Bourdôt *et al.* 1979; Holm *et al.* 1979; Warwick and Black 1982). The plant is tolerant to a wide range of natural and agricultural environments (Holm *et al.* 1979; Mitich 1990; Carr *et al.* 1992; Aleksoff 1999; Suleimenov *et al.* 2001). The plant has a long flowering period with large numbers of viable seed produced each season (Robocker 1977; Bostock 1978; Bourdôt *et al.* 1979; Volland *et al.* 1981; Bourdôt *et al.* 1982; Warwick and Black

1982; Kannangara and Field 1983; Bourdôt 1984; Bourdôt and Butler 1985; Field and Jayaweera 1985a, b; Kannangara and Field 1985; Field and Kannangara 1987; Bourdôt and Field 1988; Henskens *et al.* 1992; Howe 1994). The underground rhizome system is primarily used to utilise resources but its large number of dormant buds are rapidly activated to produce daughter plant upon rhizome fragmentation (Bourdôt *et al.* 1979; Henskens *et al.* 1992).

Based on existing information on the biology, ecology and climatic preferences of this species, *A. millefolium* appears to be a serious threat as an environmental weed in the cooler regions of Australia including the Australian Alps. Previous published surveys of vegetation (Chapter 3), along with the research conducted in Chapters Four and Five demonstrate that *A. millefolium* can occur in alpine and subalpine areas of the Australian Alps in a range of habitats, principally along roadsides and in roadside drainage areas. It can also be found in adjacent native vegetation.

The next chapter examines the distribution of *A. millefolium* in more detail in the southern section of Kosciuszko National Park. Then the vegetative and flowering phenology, resource allocation, seed ecology and competitive abilities of the species are examined.



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## CHAPTER 7

# DISTRIBUTION OF *ACHILLEA MILLEFOLIUM* IN KOSCIUSZKO NATIONAL PARK

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### 7.1. SUMMARY

This chapter examines the distribution of the environmental weed *A. millefolium* in Kosciuszko National Park based on data from species specific surveys of *A. millefolium* and field experiments during this study and general vegetation surveys conducted between 1986 and 2004. *Achillea millefolium* was recorded at a total of 376 sites with most associated with human disturbance (91% of sites) particularly the verge of roads and trails (72%) and around buildings and other ski tourism infrastructure. It was estimated that *A. millefolium* occurs along more than 100 km of public access roads, management trails and walking tracks within Kosciuszko National Park. Most sites with *A. millefolium* were in the subalpine (57%) and montane (27%) zones and it was relatively uncommon in alpine areas where it was almost exclusively located on the verge of walking tracks. The general vegetation surveys indicate that although *A. millefolium* can be found in many sites in the Park it is still not common, particularly in undisturbed vegetation. It was found in only 6.4% of disturbed sites and 2% of natural sites surveyed.

The observed distribution of *A. millefolium* in Kosciuszko National Park was examined in relation to altitude, temperature and rainfall. *A. millefolium* was recorded in sites with altitudes between 800 m and 2100 m, with most sites between 1200 m and 1830 m elevation. The average temperatures of the subalpine and montane area where *A. millefolium* was common lie between 0-9°C with an average rainfall of 1201-2500 mm. This distribution concurs with that predicted by CLIMEX<sup>®</sup> modelling in Chapter 6.

### 7.2. INTRODUCTION

Distribution boundaries of native and exotic plants are limited by biotic and abiotic factors (Booth *et al.* 2003). Abiotic climatic characteristics such as temperature,

precipitation and wind together with light, soil, nutrients, habitat disturbance and species specific characteristics are the major ecological determinants of distribution and abundance (Swincer 1986; Crawley 1987; Cronk and Fuller 1995; Booth *et al.* 2003).

In mountain ecosystems increasing altitude is generally correlated with increasing severity of conditions (Körner 1999; Costin *et al.* 2000). This includes decreasing temperatures, increasing risk of severe climatic events such as frosts and increasing duration of snow cover in winter (Billings and Mooney 1968; Green and Osborne 1994; Körner 1999; Costin *et al.* 2000).

In the Australian Alps plants growing in the subalpine zone can experience snow cover for one to four months per year and minimum temperatures below freezing for around six months per year (Brown and Millner 1989; Green and Osborne 1994). In the alpine zone plants can experience snow cover for at least four months per year with increased risk of frosts even in summer (Green and Osborne 1994; Costin *et al.* 2000). As a result of the increasingly severe conditions many species are unable to establish at higher altitude sites. Such changes in environmental conditions can also affect the ability of exotic taxa to establish and grow (Mallen-Cooper 1990; Chapter 3).

Alteration to the habitat associated with human disturbance can also affect the ability of exotics to establish (Hobbs 1987,1989; Ebersole 1989; Glenn-Lewin *et al.* 1992; van der Valk 1992; Kotanen 1997; Mack and D'Antonio 1998; Booth *et al.* 2003). The study reported in Chapter 3 has already demonstrated the strong association between exotics and roadsides in Kosciuszko National Park, including the presence of *A. millefolium* along roadsides and around buildings (Costin 1954; McDougall 1982; Mallen-Cooper 1990; Sanecki 1999; Chapters 3, 4 and 5).

Although recorded as early as 1949 in grasslands in the subalpine zone of Kosciuszko National Park (New South Wales Soil Conservation Herbarium database; Costin 1954), populations of *A. millefolium* appear to have increased rapidly during the 1990s (R. Knutson pers. comm. NSW National Parks and Wildlife Service 1999; Sanecki 1999). The increase in *A. millefolium* is possibly associated with the use of gravel from weed-contaminated dumps in the construction and

maintenance of roads and other infrastructure (R. Knutson pers. comm. NSW National Parks and Wildlife Service, 1999). Recent surveys (Sanecki 1999; Chapters 4 and 5) found *A. millefolium* growing along roadsides and in drainage areas in subalpine areas of the Park with plants present up to 10 m in the adjacent natural vegetation.

This chapter describes the distribution of *A. millefolium* in Kosciuszko National Park using data collected during this thesis and data from vegetation surveys in the Park between 1986 and 2004. The association of *A. millefolium* with roads and the climatic variables altitude, temperature and rainfall was assessed using geographic information system (GIS) software. The distribution of *A. millefolium* in this chapter is not a complete record of this species in the Park, but rather it is a broad indication of the pattern of its distribution.

### **7.3. METHODS**

#### **7.3.1. Sources of location records of *A. millefolium***

Three data sources were used to estimate the distribution of *A. millefolium* within the southern and central sections of Kosciuszko National Park. Firstly, specific surveys were conducted along selected roads and around other infrastructure. Between January and March in 1999 and 2000 sites were surveyed for the presence of *A. millefolium* approximately every two km along the major public access roads (Kosciuszko Road, Alpine Way and the Snowy Mountains Hwy), selected secondary roads (Guthega Road, Link Road, Island Bend Road and the Summit Road) and selected management trails (Cascade trail, Schlinks Pass Road and Valentine fire trail). In addition, disturbed areas around buildings at ski resorts (Smiggin Holes, Perisher Valley and Thredbo Village) and other infrastructure such as huts, toilets, picnic grounds were surveyed for *A. millefolium*.

Secondly, location data were obtained during the field experiments for this thesis including the phenology of *A. millefolium* (Chapter 8), resource allocation (Chapter 9) and seed ecology of *A. millefolium* (Chapter 10). These sources are referred to as *A. millefolium* specific records/surveys.

Thirdly, location records were obtained from 18 vegetation surveys of 499 sites conducted between 1986 and 2004 in Kosciuszko National Park (Bear *et al.* Under review; Appendix 2).

Where *A. millefolium* was present its geographic coordinates were recorded and an estimate made of its density. At infrastructure sites such as solitary huts a single assessment was made of density. Density was estimated on a six level scale (Low = isolated plants < 5 cm<sup>2</sup> in size. Medium-Low = isolated plants > 5 cm<sup>2</sup> in size. Medium = discontinuous cover with distinct gaps between patches between 5 cm<sup>2</sup> and 30 cm<sup>2</sup> in area. Medium-High = discontinuous cover with distinct gaps between plants between 30 cm<sup>2</sup> and 50 cm<sup>2</sup> in area. High = continuous cover of *A. millefolium* in areas between 50 cm<sup>2</sup> and 70 cm<sup>2</sup>. Very-High = continuous cover areas greater than 70 cm<sup>2</sup> in size. In these surveys *A. millefolium* was found at 300 sites in the Park.

Location records of *A. millefolium* were also selected from a database of 18 general vegetation surveys in Kosciuszko National Park from 1986-2004 which included 1228 records of 173 exotic taxa from 363 sites as well as the location of 136 sites that only had native species (Bear *et al.* Under Review). The 18 surveys included published research papers, PhD and Honours theses, NSW National Parks and Wildlife Service reports and unpublished research by members of the School of Environmental and Applied Sciences, Griffith University (Appendix 2). Each exotic taxon record had information on its spatial coordinates, vegetation zone, altitude, vegetation community or anthropogenic disturbance type (Appendix 2).

### **7.3.2. Mapping the distribution of *A. millefolium***

Using the location records of *A. millefolium* from (1) the specific surveys, (2) the experiments during this thesis and (3) the 18 general surveys, the distribution of *A. millefolium* in Kosciuszko National Park was mapped in relation to altitude/floristic zone (alpine = ~1850 m to 2228 m; subalpine = ~1500 m to ~1850 m and montane = ~1500 to 500 m), climatic parameters (average rainfall and average temperature) and location of roads and tracks using spatial data from the NSW National Parks and Wildlife Service geographic information system (GIS) database and ESRI: ArcVIEW GIS software. The locations of 319 sites from the 18 general vegetation surveys

where there were exotics other than *A. millefolium* were also mapped to indicate the geographic range of exotics in Kosciuszko National Park. The location of the 136 sites in the 18 general vegetation surveys where there were no exotics were also mapped to indicate total distribution of surveyed sites.

## 7.4. RESULTS

From the *A. millefolium* specific surveys, field experiments and general vegetation surveys in Kosciuszko National Park there were a total of 376 sites with *A. millefolium* in the southern and central sections of Kosciuszko National Park (Table 7.1). There were an additional 323 sites that contained exotics other than *A. millefolium* and 136 sites where only native taxa were found.

### 7.4.1. Altitude and climate

*Achillea millefolium* was recorded in all floristic zones of the Park. Over half of all sites were in the subalpine zone (215 sites) with 103 in the montane, 38 in the alpine and 20 in the tableland zones. Most *A. millefolium* sites were in disturbed areas particularly along the verges of roads and management trails in the subalpine and montane zones and at landfill sites at lower altitudes in the tableland zone (Table 7.1; Figure 7.1).

Table 7.1. Number of sites where *A. millefolium* was recorded by location type. (Sources: *A. millefolium* specific surveys and experiments this thesis and 18 general vegetation surveys Bear *et al.* (Under Review).

Location type	Sites with <i>A. millefolium</i>	Sites with <i>A. millefolium</i> (%)
Infrastructure	44	11.7
Main road	104	27.6
Secondary road	115	30.5
Management trail	55	14.6
Walking track	26	6.9
Native vegetation	32	8.5
<b>Total</b>	<b>376</b>	<b>100</b>

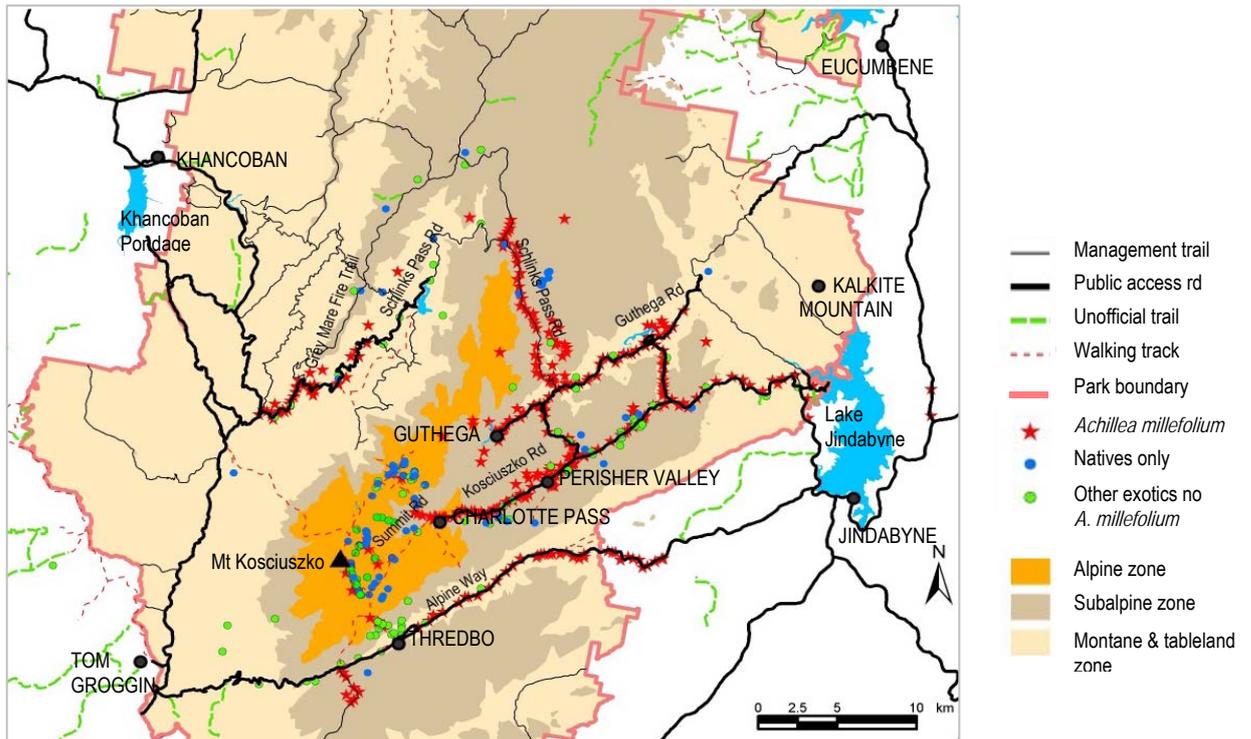


Figure 7.1. Distribution of *A. millefolium* in relation to altitude/floristic zone in Kosciuszko National Park based on 376 sites with *A. millefolium*. Alpine: 38 sites; subalpine: 215 sites; montane: 103 sites; tableland: 20 sites. Sites that did not contain *A. millefolium* but either contained other exotics or only natives are included to indicate the total distribution of sites surveyed. (Sources: *A. millefolium* specific surveys and experiments this thesis, and 18 general vegetation surveys Bear *et al.* (Under Review)).

*Achillea millefolium* was recorded at sites between 800 m and 2100 m altitude with the majority of sites between 1200 m and 1900 m (Figure 7.1). The highest altitude site at which *A. millefolium* was recorded was 2100 m on Mount Twynam where it was growing in the eroded wheel tracks of an old management trail (Figure 7.2).



Figure 7.2. *Achillea millefolium* flourishing at high altitude in the eroded wheel tracks of an old management trail on Mt Twynam (2010 m). Rhizomes are encroaching into adjacent natural vegetation burnt in the 2003 bushfires (Photos: S. Johnston January 2005).

Although *A. millefolium* was recorded from the tableland to the alpine in Kosciuszko National Park eighty five percent of sites with *A. millefolium* were located in subalpine and montane areas. The climate of these zones fall within the rainfall and temperature parameters predicted to be highly suitable habitat for *A. millefolium* in Chapter 6. Based on the GIS maps of climatic variables the mean annual temperatures of most *A. millefolium* sites were relatively cool ranging from 3°C to 9°C. Rainfall in these sites were high ranging from 1201 to 2500 mm of precipitation per year (Figures 7.3 and 7.4).

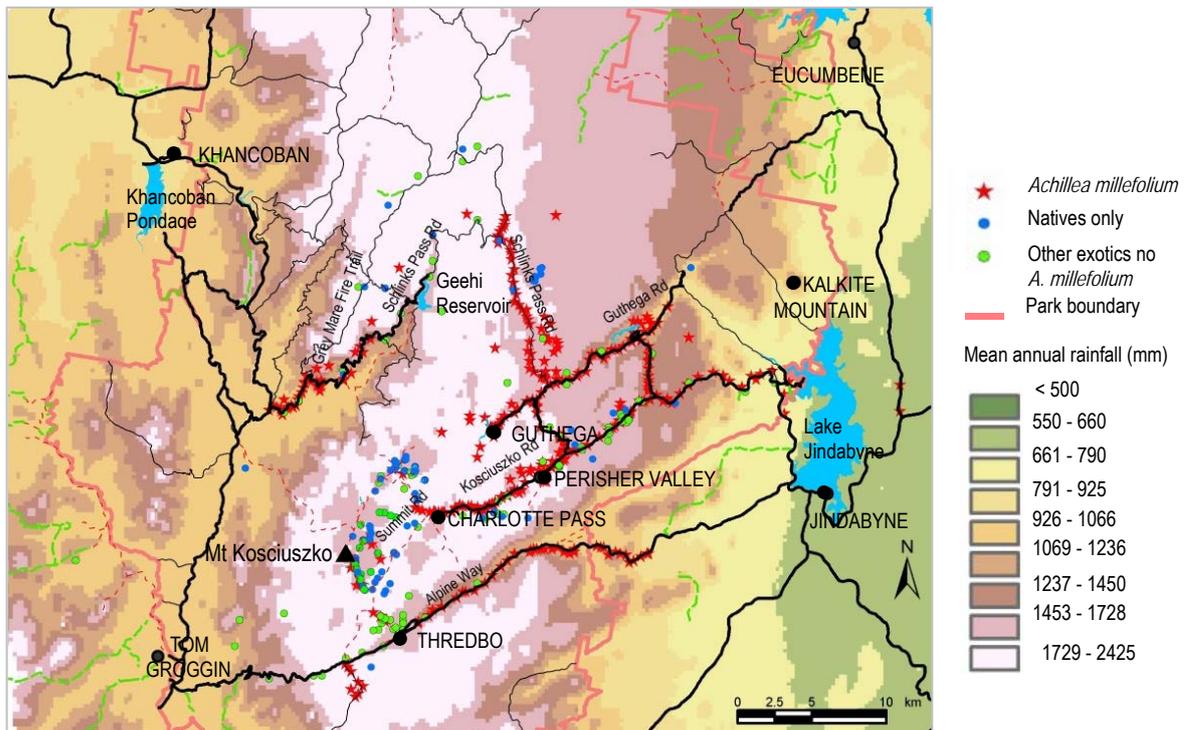


Figure 7.3. Distribution of *A. millefolium* in relation to mean annual rainfall (mm) in Kosciuszko National Park and surrounds. Sites that did not contain *A. millefolium* but either contained other exotics or only natives are included to indicate the total distribution of sites surveyed. (Sources: *A. millefolium* specific surveys and experiments this thesis, and 18 general vegetation surveys Bear *et al.* (Under Review)).

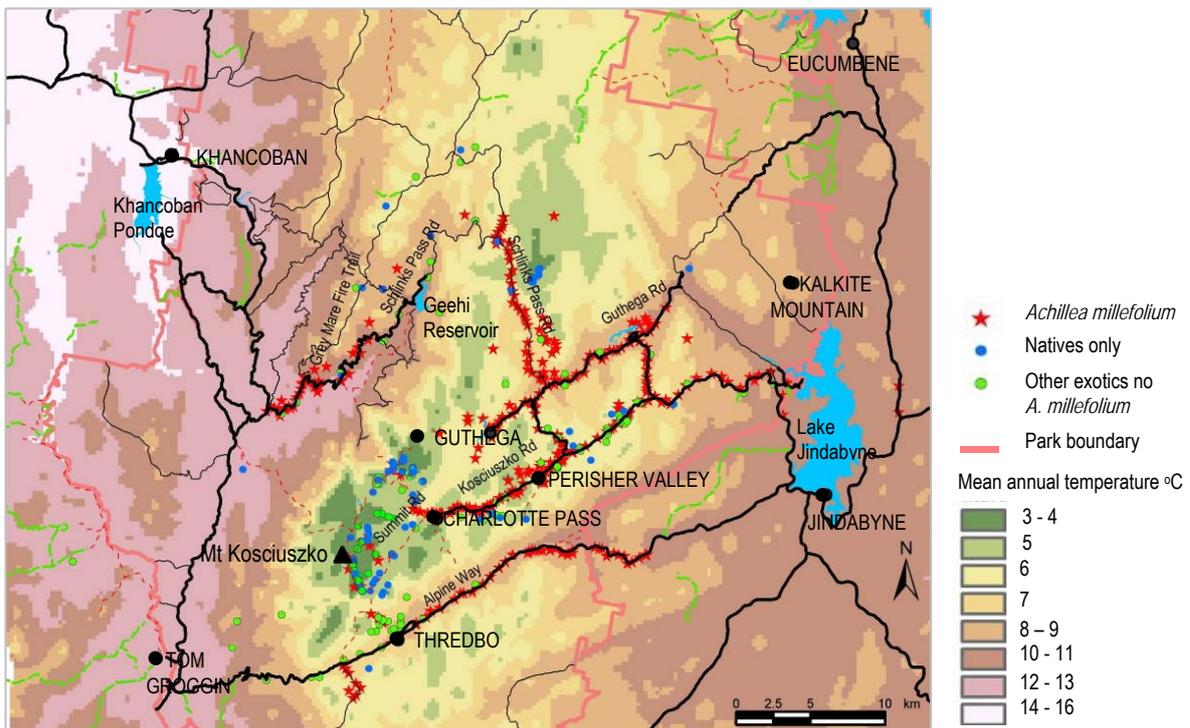


Figure 7.4. Distribution of *A. millefolium* in relation to mean annual temperature (°C) in Kosciuszko National Park and surrounds. Sites that did not contain *A. millefolium* but either contained other exotics or only natives are included to indicate the total distribution of sites surveyed. (Sources: *A. millefolium* specific surveys and experiments this thesis, and 18 general vegetation surveys Bear *et al.* (Under Review)).

#### 7.4.2. Roads, infrastructure and walking tracks

Kosciuszko National Park is dissected by roads, track and clearings producing an extensive network of edges. It was estimated that there are 1212 km of public access roads, 1238 km of management trails and 192 km of walking tracks (source: NSW National Parks and Wildlife Service GIS database). Within the central southern region of the Park alone there are approximately 71 km of sealed major roads, 134 km of unsealed minor roads and more than 50 km of fire trails (Mallen-Cooper 1990).

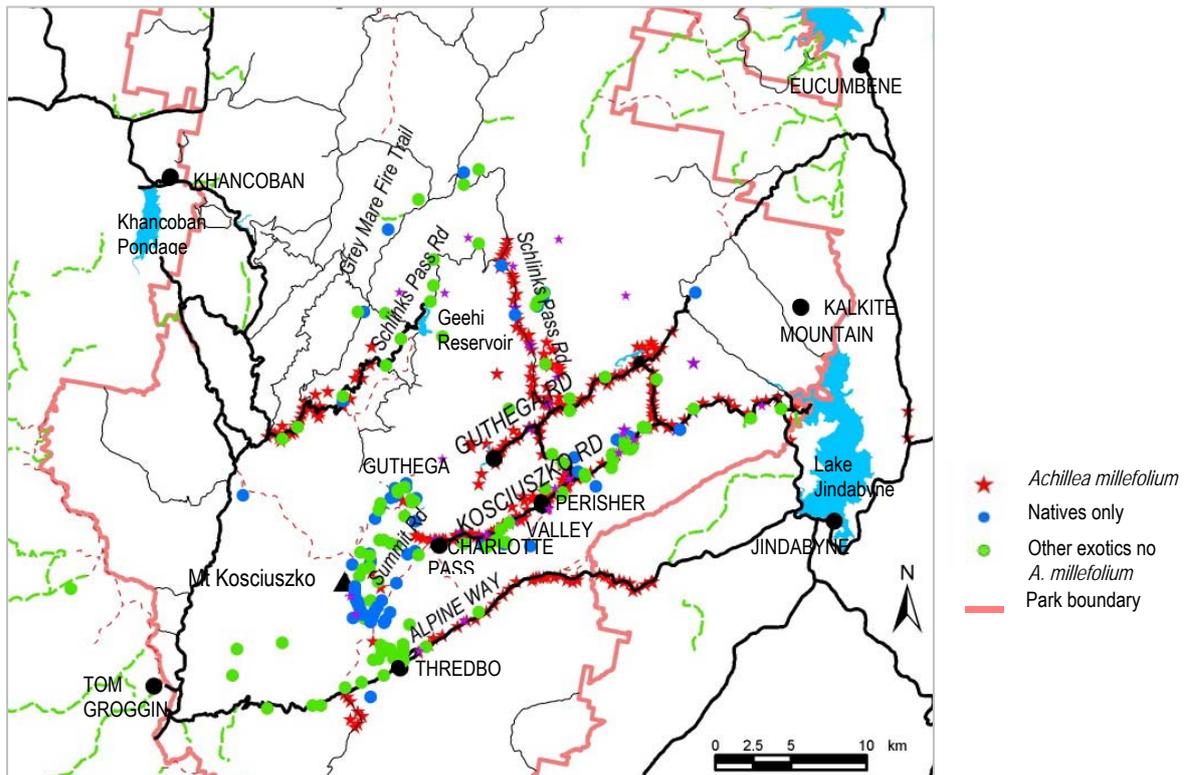
The distribution of *A. millefolium* was strongly associated with anthropogenic disturbance, particularly roads and infrastructure (Tables 7.1). Of the 376 sites at which *A. millefolium* was recorded, 91% were in areas affected by human disturbance. This exotic was recorded along more than 100 km of walking tracks, public access roads and management trails in the Park – 104 sites along main roads, 115 sites on secondary roads, 55 sites on management trails, and 26 sites on walking tracks (Figure 7.4). *Achillea millefolium* was recorded at 44 sites around infrastructure but was in only 32 sites where vegetation was classified as natural.

There are two major sealed access routes to the southern section of Kosciuszko National Park, the Kosciuszko Road between Jindabyne and Charlotte Pass and the Alpine Way from near Jindabyne to Khancoban (Figures 7.5 and 7.6). Along the Kosciuszko Road *A. millefolium* plants were found from the boundary of the montane/subalpine zone (Sawpit Creek) to Charlotte Pass in the high subalpine. In some areas along this road plants were also found in adjacent native vegetation (Chapter 4). Along the Alpine Way populations were found from the entrance to the Park (tableland zone) through to Thredbo Village onto Pilot Lookout (Figure 7.4).

*Achillea millefolium* populations were also common along verges of minor sealed and unsealed roads including the Guthega Road between the Guthega Power Station and Schlinks Pass road. Populations of *A. millefolium* were found growing along the length of Schlinks Pass road though to Disappointment Spur with large monoculture populations found at the Disappointment Spur aqueduct. Populations were found along the following minor roads and management trails; the Cascade Trail, Pilot Lookout Trail, Farm Creek, Snow Ridge Road, Goat Ridge Road, Link Road, King

Cross Road, Ridge Four Wheel Drive Trail, Valentine Fire Trail, minor roads within the Island Bend Road complex, Swampy Plain Bridge Road, and Rock Creek trail (Figure 7.4). *Achillea millefolium* was also along management trails through the Jugungal Wilderness area.

Figure 7.5. Distribution of *A. millefolium* along roads in central Kosciuszko National Park. Sites that did not contain *A. millefolium* but either contained other exotics or only natives are included to



indicate the total distribution of sites surveyed. (Sources: *A. millefolium* specific surveys and experiments this thesis, and 18 general vegetation surveys Bear *et al.* (Under Review)).

### 7.4.3. General observations

Although most common in disturbed areas *A. millefolium* grows in a number of natural vegetation communities including short alpine herbfield, tall alpine herbfield, sod tussock grassland, subalpine woodland and tall heath associations (Figure 7.6) (Author obs.). For example *A. millefolium* plants were observed in subalpine grassland (*Poa* spp.) near Dicky Cooper Creek where there was no obvious signs of recent disturbance (Author obs). Along sections of the Geehi River *A. millefolium* was observed growing from the edge of the road down to the water edge (Author obs.).



Figure 7.6. Population of *Achillea millefolium* growing between eroded wheel tracks and in adjacent grassland vegetation in a subalpine area of Kosciuszko National Park. The highest density appears at the lowest point of the road where greatest water and nutrient wash off occurs. *Achillea millefolium* also appears to be spreading out from the road into surrounding vegetation (Photo: Z. Bear 2004).

Although it is clear that there are many places in the southern and central sections of the Park where *A. millefolium* can be found there are also many disturbed and natural areas where it does not occur. Based on data from the 18 general vegetation surveys *A. millefolium* occurred in only 12% of all sites where exotics were recorded. In natural areas *A. millefolium* was even less common and was found in just 4% of sites with exotics (Table 7.2) (Bear *et al.* Under Review) (Table 7.2).

Table 7.2. Number of sites in 18 general vegetation surveys in Kosciuszko National Park with *A. millefolium*, with exotics other than *A. millefolium* and where only native species were recorded. (Source: Bear *et al.* Under Review).

Zone	Vegetation	<i>A. millefolium</i>	Exotics other than <i>A. millefolium</i>	Natives only	Total
Alpine	Disturbed	1	48	17	66
	Natural	0	72	98	170
Subalpine	Disturbed	26	58	0	84
	Natural	10	53	15	78
Montane	Disturbed	5	55	1	61
	Natural	2	33	5	40
<b>Total</b>		<b>44</b>	<b>319</b>	<b>136</b>	<b>499</b>

Although currently uncommon in the alpine zone there are isolated plants and small populations along the Summit Road, the Blue Lake walking track, the Main Range

walking track and around Seaman's Hut near Mount Kosciuszko (Sanecki *et al.* 2003). Of concern is a population on a disused track on Twynam Ridge (2100 m) which has increased substantially in size since the 2003 bushfires. In 1999 *A. millefolium* covered an area of ~20-40 m<sup>2</sup> on the track: January 2005 the area covered by *A. millefolium* was around 160 m<sup>2</sup> although this was discontinuous cover (Figure 7.2). The exotic also appears to be spreading into adjacent subalpine grassland vegetation burnt in the 2003 fires (Author obs.).

Other disturbed areas with *A. millefolium* include those areas surrounding infrastructure such as the ski resorts, ranger's stations, sewage works and power stations (Figure 7.8). Locations with large populations of *A. millefolium* included Perisher Valley, Smiggin Holes, Guthega Village, Cabramurra, Selwyn, Thredbo, Kiandra, Old Kiandra Goldfields, Island Bend, Guthega, Perisher, Wilson's Valley, Sawpit Creek, Falls Creek, and Charlotte Pass. In some of these areas dense monocultures of *A. millefolium* were recorded. For example in outwash areas from a culvert opposite a ski lodge and ski lift in Perisher Valley *A. millefolium* was seen growing up to 39 m from the road verge (Author obs.).



Figure 7.7. *Achillea millefolium* growing in between concrete pavers along the Blue Lake walking track in the alpine/high subalpine section of Kosciuszko National Park between Charlotte Pass and the Snowy River (Photo: S. Johnston 2005).



Figure 7.8. *Achillea millefolium* growing in front of the Marritz Hotel in Perisher Valley, Kosciuszko National Park (Photo: S. Johnston 2000).

The density of *A. millefolium* was measured at 300 sites along primary roads, secondary roads, management trails, and other infrastructure. Density appeared to be associated with the degree of disturbance and water and nutrient availability (Table 7.3). For example sites with the densest populations were in road drainage areas (Figure 7.6) and around buildings such as sewage treatment areas (Figure 7.7). At some road drainage sites *A. millefolium* was observed spreading into surrounding natural vegetation (Figure 7.6). At sites adjacent to buildings etc. *A. millefolium* was always either medium-high or very-high density. Along main roads density was more variable with some sites having low density but other medium-high density. Along secondary roads and fire/management trails densities were quite high and less variable. Along secondary roads density was recorded as between medium- to medium-high (e.g. Figure 7.6). Along fire trails density was often high. In contrast at most sites where *A. millefolium* was recorded along walking tracks the densities were low (Table 7.3).

Table 7.3. Densities of *A. millefolium* recorded at sites along selected roads and around buildings in Kosciuszko National Park in specific surveys between January and March 1999 and 2000.

Density	Buildings	Main road	Secondary road	Fire trail	Walking track	Total
Low	2	20	1		15	38
Med-low	3	4	2	5	1	15
Medium	3	20	30	14	7	74
Med-high	14	24	68	36	1	143
High	3	4	6		2	15
Very-high	11	2	3			16
Total	36	74	110	55	26	301

Low = isolated plants < 5 cm<sup>2</sup> in size. Medium Low = isolated plants > 5 cm<sup>2</sup> in size. Medium = discontinuous cover with distinct gaps between plants area covered greater than 5 cm<sup>2</sup> but less than 30 cm<sup>2</sup>. Medium High = discontinuous cover with distinct gaps between plants greater than 30 cm<sup>2</sup> but less than 50 cm<sup>2</sup>. High = continuous cover areas greater than 50 cm<sup>2</sup> but less than 70 cm<sup>2</sup>. Very High = continuous cover areas greater than 70 cm<sup>2</sup> in size.

## 7.5. DISCUSSION

*Achillea millefolium* is found in all floristic zones of the Park with the majority of sites in the subalpine (57%) and montane (27%) zones. Nearly all sites with *A. millefolium* were in places where vegetation and soils have been affected by human disturbance (91%). Although the majority of *A. millefolium* sites were along main and secondary roads, the greatest density of *A. millefolium* was recorded at sites around buildings. This may be due to these areas having higher amounts of water and nutrients compared to road and track verges thus providing better growing conditions

(Johnston and Johnston 2004). When *A. millefolium* was found on walking track verges it was at low density probably reflecting the lower level of disturbance in these areas.

*Achillea millefolium* was not common in undisturbed vegetation and occurred in less than 4% of sites where exotics were recorded in the general vegetation surveys (Bear *et al.* Under Review). Therefore *A. millefolium* appears to principally be a weed of disturbed sites, particularly in areas with high water and sediment wash and nutrient rich soils (Chapter 4). However it may be starting to establish and spread in natural vegetation where it can be difficult to remove once established (Chapter 5, Sanecki *et al.* 2003).

The spread of a plant begins with the removal of dispersal barriers and/or the creation of suitable new habitats (Cousens and Mortimer 1995). From the distribution of *A. millefolium* in Kosciuszko National Park it appears that human activities have provided suitable habitat for its establishment and may have contributed to its spread. *Achillea millefolium* may not have reached the limit of its distribution in the Park as there are suitable sites that have not yet been colonised.

This species will continue to spread in the Park, particularly in areas of disturbance, unless there is a successful control program. As human activities in the Park have created suitable habitat for *A. millefolium* there will need to be changes to these activities in order to stop *A. millefolium* spreading. This is particularly important under future climate change which is predicted to increase the area of habitat suitable for *A. millefolium* (Chapter 6).

To understand how this species could be controlled and how human disturbance and altitude are affecting the species more information is required about the ecological characteristics of the species in Kosciuszko National Park.

### **7.5.1. Conclusions**

*Achillea millefolium* is found in many sites in Kosciuszko National Park (at least 375 sites) covering the four climatic/vegetation zones (tableland, montane, subalpine and alpine zones). Altitude appears to be having some limiting effect, with fewer sites and smaller patches at higher altitudes. Its distribution was also associated with

disturbance, with most *A. millefolium* sites on roadsides or adjacent to other infrastructure.

In the following chapters (Section Three) the ecology of *A. millefolium* is investigated further including the effects of altitude and disturbance regimes, by examining the phenology (Chapter 8), resource allocation (Chapter 9) and seed ecology of this weed in Kosciuszko National Park (Chapter 11).

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## CHAPTER 8

### PHENOLOGY OF *ACHILLEA MILLEFOLIUM*<sup>7</sup>

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#### 8.1. SUMMARY

The phenology of *A. millefolium* was examined over a growing season in areas within and adjacent to Kosciuszko National Park. Vegetative and reproductive characteristics were compared for sites at four different altitudes (medium and high montane, low subalpine and high subalpine) and types of infrastructure (primary road, secondary road and building). Altitude, infrastructure and time of year did not affect percentage cover of vegetation at the 12 sites sampled. Altitude did affect flowering phenology, with the beginning of flowering (elongating inflorescences) occurring earlier and the end of reproduction (shedding of mature seed) occurring later at the lower altitude montane sites than at higher altitude sites. This resulted in a longer flowering period in the medium montane sites (900 m, over 100 days of flowering) compared to the high subalpine sites (~1760 m, around 80 days of flowering). The only differences in phenology associated with the different types of infrastructure was the number of reproductive structures at the peak of flowering, with *A. millefolium* growing next to buildings having two to three times more inflorescences per m<sup>2</sup> than *A. millefolium* sampled along primary and secondary road verges. The average maximum number of inflorescences present per m<sup>2</sup> quadrat at each site was 36.

#### 8.2. INTRODUCTION

Plant phenology is the study of the timing of seasonal life cycle events such as bud initiation, flowering and the commencement and senescence of vegetative growth. The observed phenological patterns are in part controlled by genetics (Best and McIntyre 1972; Lack 1982; Pollard and Briggs 1982; Turkington 1983; Shaver *et al.* 1986; Pors and Werner 1989) and in part by environmental factors such as

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<sup>7</sup> Johnston FM and Pickering CM (Under Review) Phenology of *Achillea millefolium* L. (yarrow, Asteraceae) on altitudinal and disturbance gradients in the Australian Alps. *Nordic Journal of Botany*.

temperature, moisture, wind and light (Harberd 1957; Lewis and Richmonds 1960; Paton 1968; Pemadasa and Lovell 1974; Swincer 1986; Larigauderie and Kummerow 1991). The timing of phenological events is important for the survival and reproductive success of a plant. Changes to timing of flowering, for example flowering earlier in the season, can result in limited pollinator availability, inefficiency of resource use and increased susceptibility to herbivory and seed predation (Rathcke and Lacey 1985; Brody 1997).

In high altitude environments climatic conditions limit the time that is available for growing, flowering and seed production. As altitude increases, climatic conditions become more severe, with longer periods of snow cover, intense solar radiation and low temperatures including greater risk of frosts during the snow free period (Billings and Mooney 1968; Bliss 1971; Pickering 1997; Körner 1999). Consequently, the diversity, abundance and activity of pollinators decline with increasing altitude (Inouye and Pyke 1988; Pickering 1997; Körner 1999). The timing of phenological events needs to match the appropriate climatic window if the plant is to survive and successfully reproduce in high altitude areas.

The few studies of the phenology of plants in the Australian Alps have focused on native species in the alpine zone (Inouye and Pyke 1988; Pickering 1994, 1995, 2000). They found that flowering tends to be rapid in the alpine zone (around three to six weeks for many species), with most species flowering in January to early February (Inouye and Pyke 1988; Pickering 1995, 2000). These studies did not compare flowering at different altitudes for the same species, or in different habitats within an altitude, factors that may both affect phenology.

At lower altitudes growth and flowering are likely to commence earlier in the season (e.g. flowering in spring rather than summer) and may occur over a longer time period. Also plants in different habitats at the same altitude may have slightly different phenological patterns, with larger plants, more flowers, longer periods of growth and flowering at more favourable sites at a given altitude.

*Achillea millefolium* has been found at a range of altitudes and habitats within Kosciuszko National Park (Chapters 3, 4, 5 and 7). It is therefore likely that the phenological characters of *A. millefolium* plants growing at different altitudes and

habitats may differ. This chapter examines the flowering and growth of the exotic *A. millefolium* over an altitudinal gradient (montane to subalpine) during one growing season (spring to autumn) at habitats in and around Kosciuszko National Park modified by different types of infrastructure. The purpose was to determine: (1) if vegetative and reproductive characters were affected by the altitude; and (2) if different types of infrastructure affect the phenology of *A. millefolium*.

### 8.3. METHODS

#### 8.3.1. Sites

Vegetative and flowering characteristics of *A. millefolium* were measured at 12 sites representing key infrastructure types within the range of altitudes where *A. millefolium* is found in Kosciuszko National Park. The infrastructure types were; primary road (sealed with bitumen), secondary road (unsealed), and building. The altitude categories were: medium montane (~900 m a.s.l.), high montane (~1460 m a.s.l.), low subalpine (~1600 m.a.s.l.), and high subalpine (~1760 m a.s.l.) (Table 8.1, Figure 8.1).

Table 8.1. Location of populations of *A. millefolium* sampled between 900 m and 1760 m altitude in Kosciuszko National Park and surrounds in the 1999-2000 growing season.

Location	Climatic zone	Altitude (m)	Northing	Easting
<b>Primary road</b>				
Berridale, Kosciuszko Rd	Mid montane	860	5973600	6636000
Wilson's Valley, Kosciuszko Rd	High montane	1460	5975900	6363000
Perisher Valley, Kosciuszko Rd	Low subalpine	1650	5969800	6263000
Spencer's Creek, Kosciuszko Rd	High subalpine	1760	5967700	6208000
<b>Secondary road</b>				
Eucumbene Rd	Mid montane	900	5974100	6504000
Schlinks Pass Rd	High montane	1440	5976400	6265000
Schlinks Pass Rd	Low subalpine	1580	5980300	6254000
Schlinks Pass Rd	High subalpine	1780	5982800	6244000
<b>Building</b>				
Private Property, 'Jadai', Eucumbene Rd	Medium montane	900	5974100	6504000
Wilson's Valley Ranger's Station	High montane	1460	5975900	6362000
Perisher Lodge, Perisher Valley Ski Resort	Low subalpine	1650	5969400	6264000
Charlotte Pass Ski Resort	High subalpine	1760	5966800	6193000

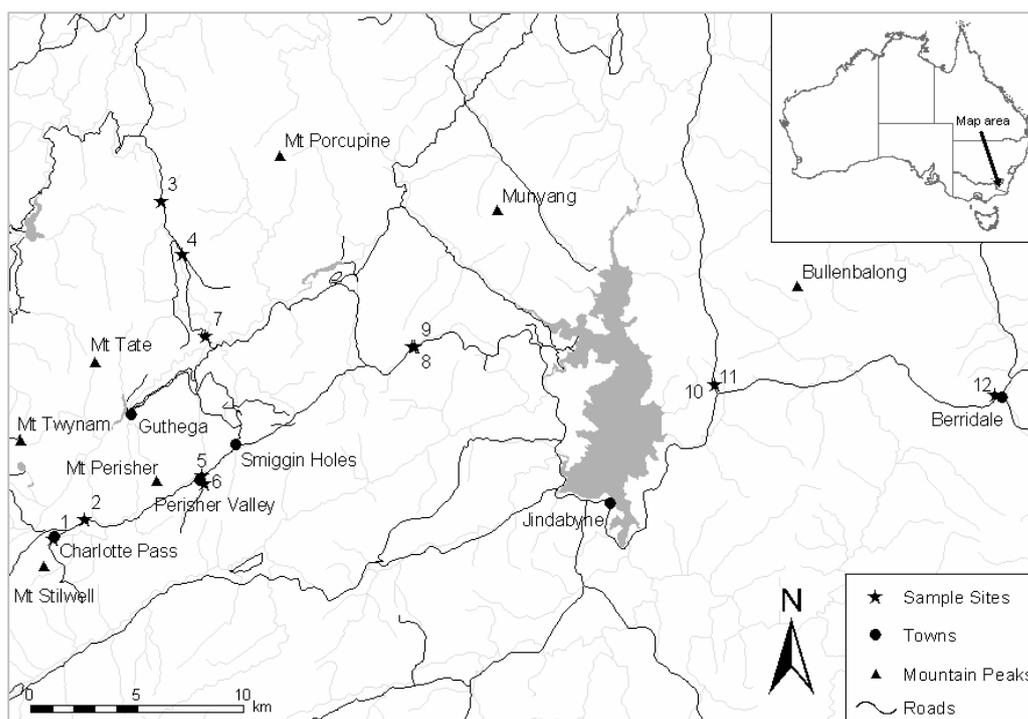


Figure 8.1. Location of the 12 sites where the growth and flowering of *A. millefolium* was measured. The sites are in or near Kosciuszko National Park, Australia. Site 1: Charlotte Pass Resort; Site 2: Spencer's Creek, Kosciuszko Rd; Site 3: Schlunks Pass high; Site 4: Schlunks Pass mid; Site 5: Perisher Valley, Kosciuszko Rd; Site 6: Perisher Lodge; Site 7: Schlunks Pass low; Site 8: Wilson's Valley Ranger Station; Site 9: Wilson's Valley, Kosciuszko Rd; Site 10: Eucumbene Rd; Site 11: Private Property; 'Jadai', Eucumbene Rd; Site 12: Berridale, Kosciuszko Rd.

### 8.3.2. Phenology measurements

At each site five permanent 1 m<sup>2</sup> quadrats were randomly located along a 20 m linear transect laid out parallel to the road in the road verge vegetation or laid within 2 m from the edge of the building through each population of *A. millefolium*. Due to the extensive vegetative growth of *A. millefolium* it was not possible to distinguish individual plants. Therefore all measurements were made per quadrat (e.g. number of flowering stems per 1 m<sup>2</sup> quadrat), with the quadrats at least two metres apart. The data for each quadrat were then averaged over the five quadrats to obtain a site level response. Growth and reproduction of *A. millefolium* were measured fortnightly between the 12<sup>th</sup> November 1999 (spring) and 27<sup>th</sup> of April 2000 (autumn) (12 sampling times over 168 days by the same observer). The cover of *A. millefolium* was estimated as the percentage of the ground covered by the vertical projection of foliage and stems of plants. The total number of elongating inflorescences, inflorescences with buds, inflorescences with flowers, inflorescences setting seed, and inflorescences shedding seed were recorded for each time, in each quadrat, and

quadrat data then averaged. The maximum number of inflorescences present in a quadrat at each site was calculated. The numbers of reproductive structures at the time of peak production were compared between altitudes and infrastructure types.

### **8.3.3. Statistical analysis**

To investigate the effect of altitude and infrastructure and time on vegetative and reproductive growth, data were analysed using a Repeated Measure Two-way ANOVA (SPSS Version 10.0 for Windows, Coakes and Steed 2000). The fixed factors were altitude and infrastructure type, with time as the repeated measure. Due to logistical difficulties in obtaining replicates for infrastructure sites (i.e. the 12 different combinations of altitude and infrastructure type), sites were unreplicated. Therefore a custom model was used, with the interaction between infrastructure type and altitude not included in the model.

To determine the effect of altitude and infrastructure type just at the peak stage of reproductive production, a Two-way ANOVA (SPSS Version 10.0 for Windows) was performed on the maximum values for each variable examined (number of buds, etc.). Again, interactions between factors could not be tested. Tests for population normality and homogeneity of variance for the models were satisfied. Differences between means were determined by Tukey's LSD tests.

## **8.4. RESULTS**

### **8.4.1. Effect of altitude and infrastructure type on vegetative growth**

There was considerable variation among sites in vegetative cover, with an overall maximum cover for each site of 66% for *A. millefolium* (Table 8.2). Despite this variation among sites, there was no detectable effect of either altitude or infrastructure on vegetative cover of *A. millefolium* (Table 8.3). Early in the growing season (12<sup>th</sup> November 1999, 316 Julian<sup>8</sup> days) there was vegetative cover at all sites, with cover values ranging from 25% to almost 90% (Figure 8.2). There was no consistent pattern of increasing cover detected during the warmer summer months,

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<sup>8</sup> Julian date is the cumulative number of days from a specific start date, usually the first of January.

other than a slight increase in cover between the first and second sampling periods (Figure 8.2). As a result of frosts, vegetative growth ceased at low montane sites by the end of April (27<sup>th</sup> April 2000, 482 Julian days). In the montane, low subalpine and high subalpine sites, frosts and the cessation of growth were slightly earlier in April, marking the end of the growing season.

Table 8.2. Maximum vegetative cover and number of inflorescences per 1 m<sup>2</sup> of *A. millefolium* at each site in Kosciuszko National Park, Australia.

Location	Climatic zone	Altitude (m)	Max vegetative cover (%)	Max number of inflorescences
Primary road	Mid montane	860	55	47.5
	High montane	1460	24	21.4
	Low subalpine	1650	63	48.8
	High subalpine	1760	40	30.5
Secondary road	Mid montane	900	62	23.0
	High montane	1440	72	4.6
	Low subalpine	1580	79	21.0
	High subalpine	1780	44	28.4
Building	Medium montane	900	91.3	97.3
	High montane	1460	90.24	5.2
	Low subalpine	1650	54.9	8.9
	High subalpine	1760	54	17.8
<b>Average</b>			<b>66</b>	<b>36.2</b>

Table 8.3. Results from Two-way ANOVA (time as repeated measure) for vegetative cover +Kosciuszko National Park, Australia.

Variable	Altitude		Infrastructure type		Time		Time* Altitude		Time* Infrastructure	
	F	P	F	P	F	P	F	P	F	P
	Percentage cover	3.633	0.084	2.493	0.163	5.474	0.000	1.586	0.056	1.417
Number of inflorescences										
- developing	1.984	0.218	4.760	0.058	5.360	0.000	2.339	0.002	1.256	0.236
- with buds	1.154	0.401	1.910	0.228	13.807	0.000	1.277	0.197	1.472	0.116
- with flowers	1.453	0.318	1.561	0.285	14.621	0.000	1.266	0.206	1.251	0.239
- setting seed	1.662	0.273	1.424	0.312	7.070	0.000	0.657	0.901	0.201	0.100
- shedding seed	2.947	0.120	1.586	0.280	9.497	0.000	2.884	0.000	1.586	0.077

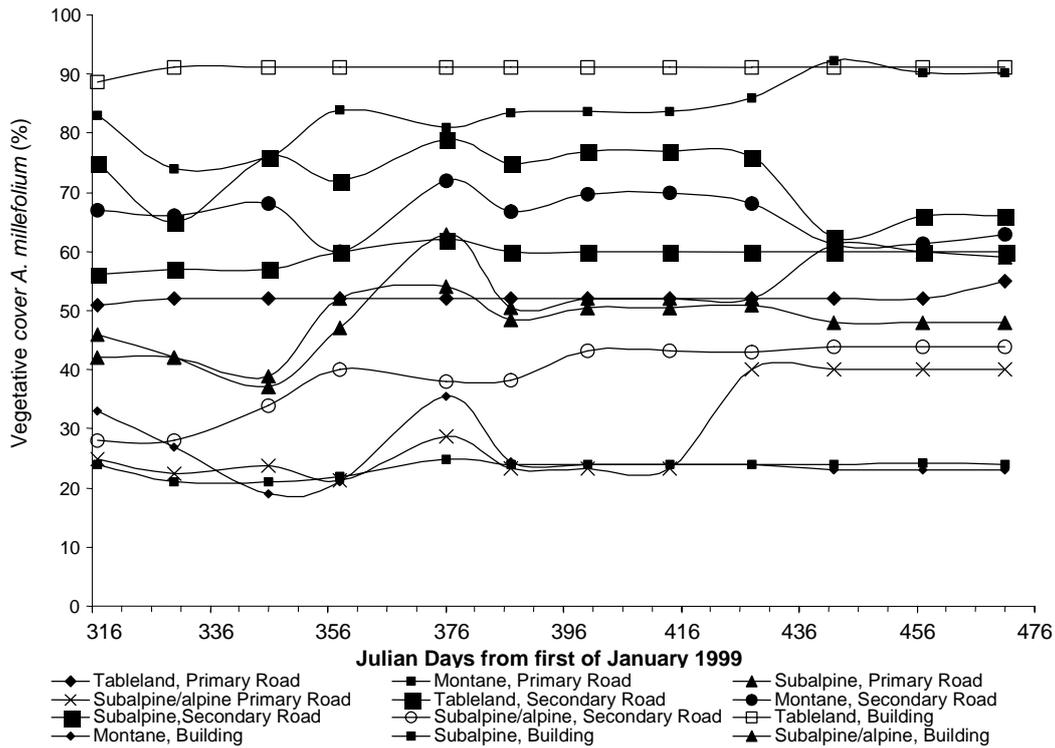


Figure 8.2. Vegetative cover of *A. millefolium* sampled in 1 m<sup>2</sup> quadrats at a range of sites in Kosciuszko National Park and adjacent areas in south-eastern Australia over the 1999-2000 growing season.

#### 8.4.2. Effect of altitude and infrastructure type on timing of reproduction

As for cover there was also considerable variation among sites in the number of inflorescences, and the phenology of flowering (Table 8.1, Figures 8.3 and 8.4). The average maximum number of inflorescences produced per 1 m<sup>2</sup> quadrat was 36.2. Again, despite variation among sites, there was no detectable effect of infrastructure on any measure of reproduction over the measurement period (Table 8.3, Figure 8.3). However there were differences among infrastructure types for the peak number of each flowering stage (Tables 8.4 and 8.5, Figure 8.3). There were more than twice as many inflorescences in bud and in flower at the sites adjacent to buildings as there were for *A. millefolium* plants growing on the sides of roads (Table 8.5, Figure 8.3). It also appears that seed maturation may take slightly longer at the sites adjacent to buildings, as on the last date sampled there were still large numbers of inflorescences setting seed but few shedding seed (Table 8.5, Figure 8.3).

Table 8.4. Results from a Two-way ANOVA on number of reproductive structures of *A. millefolium* for peak (maximum number) stages of flowering. Date is the number of Julian days from the 1st January 1999. Calendar data as recorded in the field from the 12th November 1999.

Variable	Date of peak production		Altitude		Infrastructure type	
	Julian	Calendar	F	P	F	P
Number of inflorescences						
- developing	358	23 <sup>rd</sup> Dec 99	2.677	0.057	2.497	0.092
- with buds	387	20 <sup>th</sup> Jan 00	6.069	0.001	5.735	0.006
- with flowers	428	2 <sup>nd</sup> March 00	7.226	0.000	8.605	0.001
- setting seed	471	13 <sup>th</sup> April 00	2.843	0.047	2.717	0.076
- shedding seed	471	13 <sup>th</sup> April 00	6.632	0.001	3.713	0.031

Table 8.5. Mean  $\pm$  SE for the number of reproductive structures per 1 m<sup>2</sup> of *A. millefolium* for peak (maximum number) stages of flowering at three types of structures in Kosciuszko National Park, Australia. Calendar data from the 12th November 1999.

Variable	Date of peak production		# Days	Primary road	Secondary road	Building
	Julian	Calendar				
Number of inflorescences						
- developing	358	23 <sup>rd</sup> Dec 99	42	1.90 $\pm$ 0.81	0.45 $\pm$ 0.10	2.06 $\pm$ 1.14
- with buds	387	20 <sup>th</sup> Jan 00	71	16.26 $\pm$ 5.49	10.50 $\pm$ 4.32	36.44 $\pm$ 18.59
- with flowers	428	2 <sup>nd</sup> March 00	112	17.43 $\pm$ 7.18	11.45 $\pm$ 4.37	42.83 $\pm$ 20.46
- setting seed	471	13 <sup>th</sup> April 00	155	2.25 $\pm$ 1.30	0.00	10.83 $\pm$ 9.25
- shedding seed	471	13 <sup>th</sup> April 00	155	3.95 $\pm$ 3.36	4.45 $\pm$ 2.58	0.30 $\pm$ 0.30

There were detectable effects of altitude on the timing of the beginning and end of reproduction (Table 8.3). Both the elongation of inflorescences and shedding of seed from inflorescences began earlier at lower altitude sites than at higher altitudes. For example, when measurements commenced on the 12<sup>th</sup> November 1999 (316 Julian days), there was an average of 3.9 inflorescences elongating and 4.1 inflorescences in bud per m<sup>2</sup> at the mid montane sites (~ 900m, Figure 8.4). At the high montane sites there was only one expanding inflorescence on the 12<sup>th</sup> of November, with the first inflorescences in bud recorded on the 25<sup>th</sup> of November (331 Julian days). For the higher altitude sites, inflorescences with buds were first recorded on the 11<sup>th</sup> of December (345 Julian days).

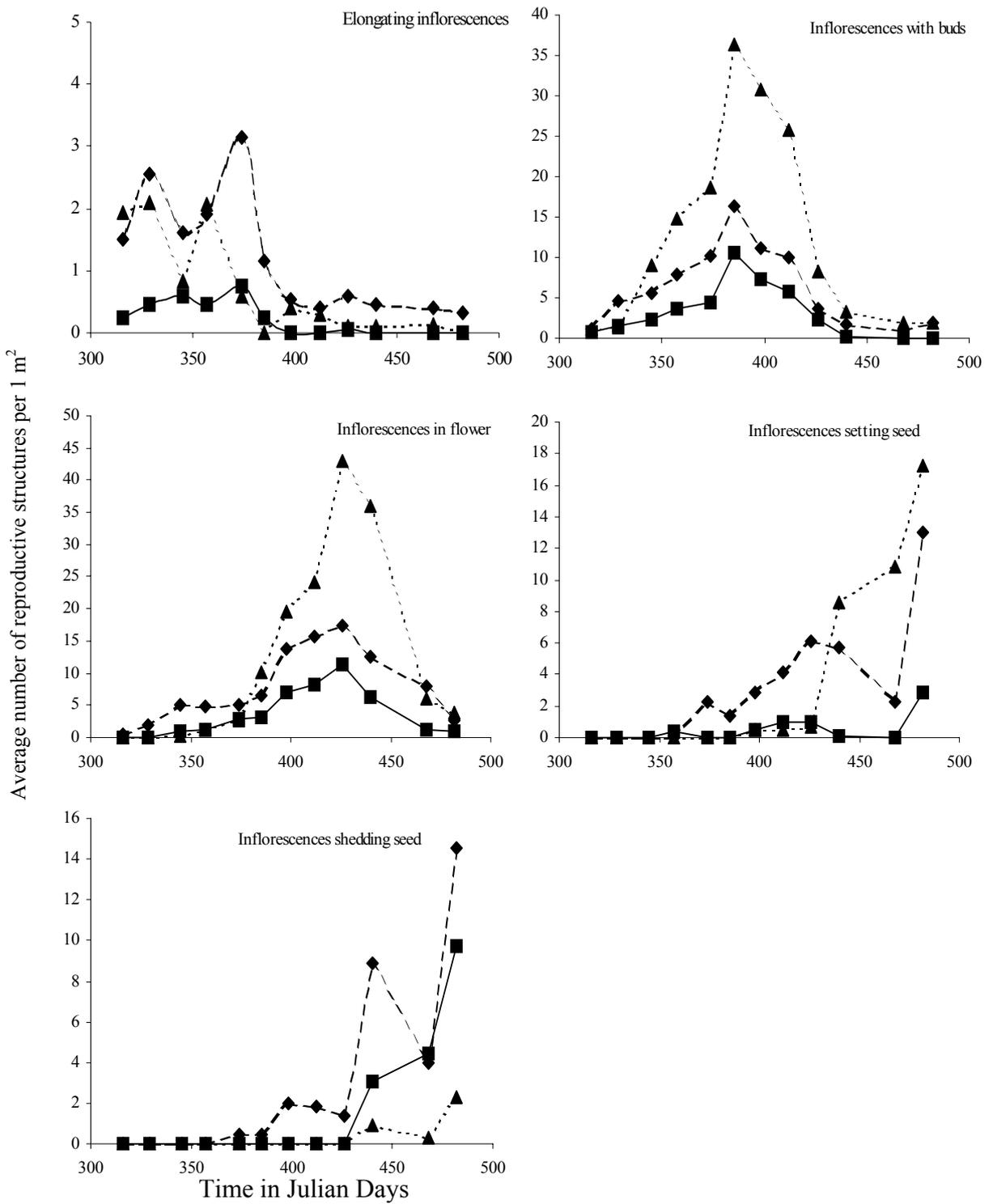


Figure 8.3. Average number of reproductive structures of *A. millefolium* per 1 m<sup>2</sup> from sites at a range of infrastructure types in Kosciuszko National Park. ♦Primary road; ■secondary road; ▲ building.

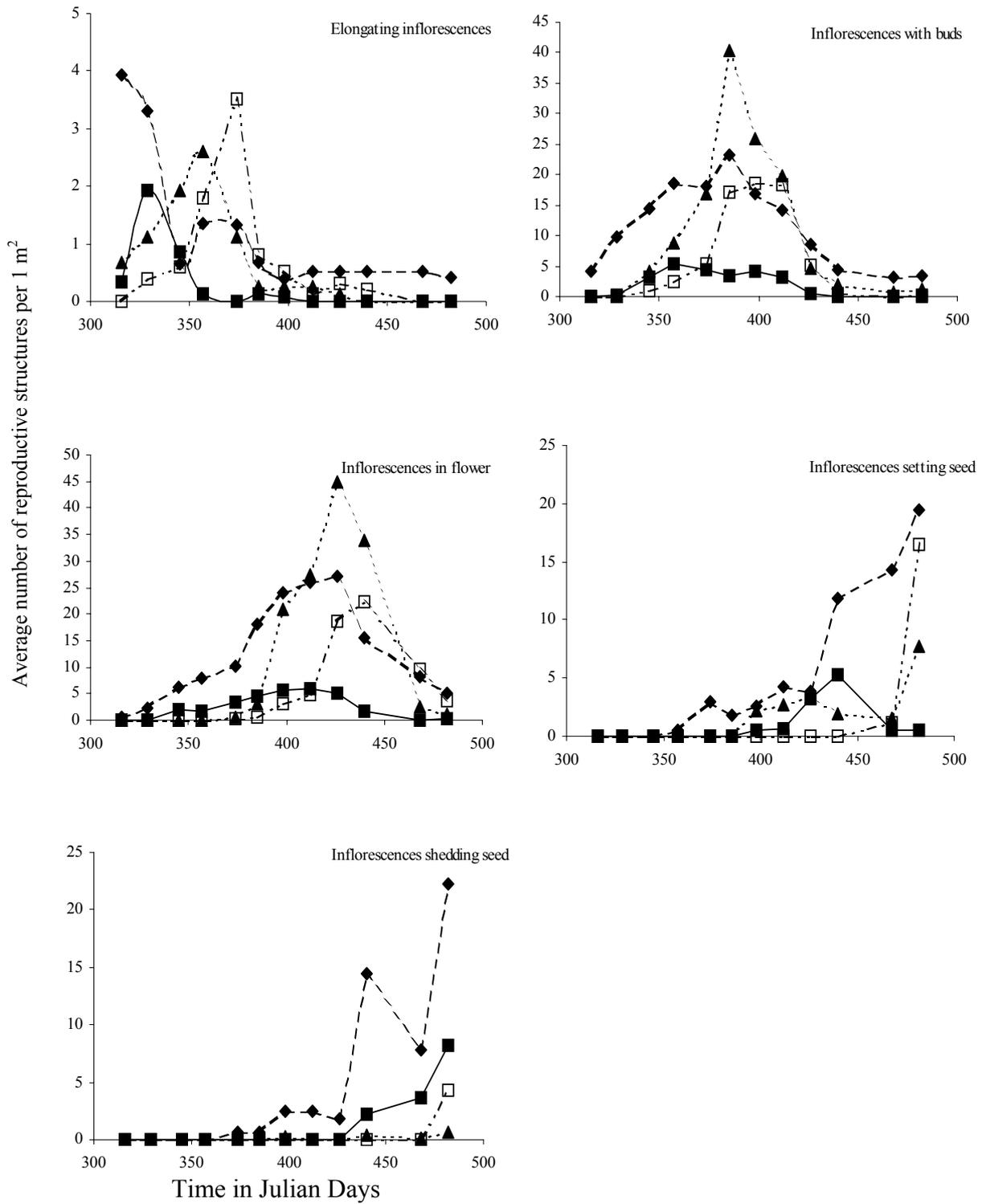


Figure 8.4. Average number of reproductive structures of *A. millefolium* per 1 m<sup>2</sup> from sites at a range of altitudes in the Australian Alps.

◆ ~900 m = low montane    ■ ~1460 m = montane;  
 ▲ ~1600 m = low subalpine;    □ ~1760 m = subalpine

New inflorescences continued to be produced over a long period at all altitudes, with inflorescences in bud only starting to become uncommon in mid March (~440 Julian days, Figure 8.4). Inflorescences with open flowers were apparent as early as the 12<sup>th</sup> of November (316 Julian days) at one mid montane site (primary road), but it was not until mid December (~345 Julian days) that all sites in the mid montane and one in the montane had open flowers.

Peak flowering occurred in late February (~412 Julian days) or early March (~425 Julian days) depending on the altitude, with flowering peaking later at higher altitude sites. Inflorescences with open flowers declined from mid April (~468 Julian days) at all sites (Figure 8.4). At this time flower production was overlapping with the formation and shedding of seed. Inflorescences setting seed were found from early January (~374 Julian days) until late April, with the peak production of seed at the end of April (482 Julian days, Figure 8.4).

The release of seed from heads commenced in early February (~398 Julian days) in mid montane sites and a month later at other sites, continuing until the end of April (Figure 8.4). The flowering season (inflorescence initiation to shedding seeds) for *A. millefolium* is relatively long, ranging from 165 days at the mid montane sites to 140 days for the high subalpine sites (Figure 8.4). Seed started to form soon after flowering, lasting on average 50 days for the mid montane sites but only 20 days for the high montane, low subalpine and high subalpine sites. All flowering ceased with the first frost in early April for plants above 1600 m and three weeks later (482 Julian days) in sites below 1600 m (Figure 8.4).

When the number of reproductive structures at the peak time of each flowering stage was compared, there was an altitude effect. Altitude affected the number of inflorescences with buds, with flowers and those shedding seed (Table 8.4). The number of inflorescences in each of the flowering stages was lowest in the montane sites (except for number of inflorescences shedding seed), relative to sites at other altitudes. The number of inflorescences setting and shedding seed was lowest for the subalpine and high subalpine sites, compared to the lower altitudes, at the end of the flowering season (Table 8.6).

Table 8.6. Mean  $\pm$  SE for the number of reproductive structures per 1 m<sup>2</sup> of *A. millefolium* for peak (maximum number) stages of flowering at four altitudes in Kosciuszko National Park.

Variable	Date of peak production		Low montane	Montane	Subalpine	High subalpine
	Julian	Calender				
Number of inflorescences						
- developing	358	23 <sup>rd</sup> Dec 99	1.35 $\pm$ 0.48	0.13 $\pm$ 0.07	2.60 $\pm$ 1.40	1.80 $\pm$ 1.10
- with buds	387	20 <sup>th</sup> Jan 00	23.25 $\pm$ 17.27	3.47 $\pm$ 2.07	40.33 $\pm$ 19.24	17.22 $\pm$ 3.62
- with flowers	428	2 <sup>nd</sup> March 00	27.17 $\pm$ 23.22	5.13 $\pm$ 3.43	44.80 $\pm$ 19.50	18.63 $\pm$ 2.34
- setting seed	471	13 <sup>th</sup> April 00	14.30 $\pm$ 12.17	0.47 $\pm$ 0.47	1.53 $\pm$ 1.53	1.13 $\pm$ 1.13
- shedding seed	471	13 <sup>th</sup> April 00	7.80 $\pm$ 4.12	3.67 $\pm$ 2.37	0.13 $\pm$ 0.13	0.00

## 8.5. DISCUSSION

In the Kosciuszko National Park *A. millefolium* is able to grow and flower in sites at a range of altitudes from montane to high subalpine and at sites modified by various types of infrastructure. Altitude did affect the timing of reproduction, as would be expected, with shorter flowering periods at higher altitudes. However, *A. millefolium* plants growing at around 1760 m were still able to flower and set seed before frosts and the first snow falls of autumn.

The timing of flowering of *A. millefolium* in this study was consistent with that observed for *A. millefolium* plants growing in temperate New Zealand, Canada and North America. Flowering and seeding of *A. millefolium* in these other regions occurred from spring to early winter for established rhizomatous plants (Clausen *et al.* 1958; Mulligan and Bassett 1959; Bourdôt *et al.* 1979; Warwick and Black 1982; Bourdôt and Field 1988; Henkens *et al.* 1992). In this study flowering was continuous, with inflorescence development starting in November (spring) and ceasing only with the onset of colder weather in April (autumn) in the mid montane sites. In general the lower the altitude of a site, the earlier the onset of each flowering stage and the longer the stage lasted. This is probably due to the generally milder climate of the mid montane sites compared to the higher altitude sites, as well as the longer time between the last frosts of spring and the first frosts of autumn.

In this study the vegetative and reproductive phenology of *A. millefolium* was examined on sites adjacent to infrastructure over the altitudinal range where it is common. The maximum number of reproductive structures was affected by the type of infrastructure at the site (primary road, secondary road and buildings), with more inflorescences present at sites next to buildings. Sites adjacent to buildings may be

more favourable to *A. millefolium* than road verges, the latter characterised by soil with low nutrients and organic carbon (Johnston and Johnston 2004). This result is consistent with those reported in Chapters 4, 5 and 7. Although all sites with *A. millefolium* need to be controlled, areas around buildings need to be targeted in control programs as they appear to be a major source of *A. millefolium* propagules. The high variability in the number of reproductive structures observed among sites indicates that, in addition to the factors measured (altitude and type of infrastructure), site-specific characters may affect flowering. These differences between the sites may partially mask some effect due to altitude or infrastructure type. For example, the amount of nutrients and water availability, disturbance regime, or types of weed control may be more important for the phenology and sexual reproduction of *A. millefolium* in Kosciuszko National Park.

This study only examined flowering phenology in one field season. Phenology of *A. millefolium* may vary from year to year. In addition, the restricted number of altitudinal and disturbance infrastructure matched sites that were available for this study meant that any interaction between altitude and human modification could not be examined here study. The small number of sites in this study also meant that a significant effect of either factor may not have been detected.

### **8.5.1. Conclusions**

*Achillea millefolium* is able to grow and flower from montane to high subalpine disturbed environments. The results indicate that altitude does have some effect on the timing of growth and reproduction of *A. millefolium* in Kosciuszko National Park. The flowering season is shorter at the high subalpine sites, compared to the milder mid montane climate; however, *A. millefolium* still flowers over a long period at all altitudes. Differences were observed between infrastructure sites versus the roadsides, where the maximum number of reproductive structures was greater next to buildings. The effect of altitude on growth is explored in more detail in the next chapter where patterns of resource allocation of this plant are examined over an altitudinal gradient.



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## CHAPTER 9

# BIOMASS AND RESOURCE ALLOCATION IN *ACHILLEA MILLEFOLIUM*<sup>9</sup>

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### 9.1. SUMMARY

Previous chapters have shown that *A. millefolium* occurs and is able to flower and set seed at a range of altitudes in Kosciuszko National Park. This chapter examines vegetative and reproductive biomass of *A. millefolium* including whether biomass allocation is affected by the increasing severity of the climate with increasing altitude. Specifically the relative and absolute biomass allocation (dry weight) to reproductive (flower heads, flowering stems and associated leaves), vegetative (leaves not on the flowering stem) and below ground structures (rhizome and roots) were measured for *A. millefolium* at the peak of the flowering season at nine sites along a 620 m altitudinal gradient from the montane to alpine zone of Kosciuszko National Park. Increasing altitude resulted in a decrease in relative and absolute allocation of biomass to reproductive structures. For example, the dry weight of inflorescences declined as altitude increased due to a decrease in the weight of the terminal and side branches of the inflorescences. The total number of flower heads (capitula) produced however was not affected by altitude. There was also a trend for increased relative allocation to below ground structures with increasing altitude, though altitude did not affect absolute allocation to below ground and vegetative structures, or the total dry weight of *A. millefolium*. Therefore it appears that the production of flowers, below ground and vegetative structures is not limited by the environmental conditions in the Australian Alps.

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<sup>9</sup> Johnston, F.M. and Pickering, C.M. (2004) Effect of altitude on resource allocation for the weed *Achillea millefolium* (yarrow, Asteraceae) in the Australian Alps. *Australian Journal of Botany* **52**, 1-6.

## 9.2. INTRODUCTION

Within mountain ecosystems, environmental conditions such as climate commonly become more severe with increasing altitude (Körner 1999; Costin *et al.* 2000). For example, the duration of snow cover and frequency of frosts increase while average temperatures decline with increasing altitude (Brown and Millner 1989; Körner 1999). In Kosciuszko National Park snow cover can range from a few days of snow on the ground below 1200 m to an average of 142 days at 2000 m, with some areas under late lying snow banks with even shorter snow free periods (Brown and Millner 1989; Costin *et al.* 2000). In the Park with each 100 m increase in altitude there is an average decline of 0.77°C (temperature lapse rate) and around a 17-day increase in the duration of snow cover (Brown and Millner 1989).

Such changes in the severity of the climate with increasing altitude can affect plant growth, resulting in reductions in overall plant size and in the size of individual plant structures (Chapin and Chapin 1981; Korner and Renhardt 1987; Korner and Larcher 1988; Körner *et al.* 1989; Mendez and Obesa 1992; Molau 1993; Pickering 1995; Schmid *et al.* 1995; Körner 1999). In addition to changes in the size of a plant there can be a decrease in the absolute and/or relative allocation to sexual reproduction and an increase in absolute and/or relative allocation to vegetative structures with increasing altitude (Mendez and Obeso 1992; Pickering 1995; Schmid *et al.* 1995). In contrast to lowland species, plants growing at high altitude in cold environments often allocate few resources to reproduction compared to those allocated to leaves, storage organs and roots (Körner and Larcher 1988; Körner 1999). Other differences between plants growing at high and low altitudes include high altitude plants having higher amounts of non-structural carbohydrate tissue mass, greater concentrations of lipids, thicker leaves with thicker cell walls, less leaf area and leaf mass, larger root length per root mass and higher root to shoot ratios (Körner *et al.* 1989; Körner 1999).

Knowledge of the response of exotic plant species to changes in the severity of the environment with altitude is important for management, potentially influencing the application methods and success of different weed control program. Most research into the changes in allocation pattern over increasing altitude has examined native

plants (Körner 1999 and references therein). There is a body of overseas research on the ecology of *A. millefolium*, some of which have examined the association between altitude and patterns of biomass allocation (Clausen *et al.* 1958; Henskens *et al.* 1992). Research on *A. millefolium* in California found that at higher altitudes *A. millefolium* plants produced more roots and rhizomes in relation to above ground structures compared to populations at lower altitudes (Hiesey 1953; Clausen *et al.* 1958). The patterns of biomass allocation were examined in the Australian Alps in order to determine: (1) the relative and absolute biomass allocation (dry weight) to reproductive structures, vegetative material and underground rhizome and roots; and (2) if biomass declined with increasing severity of climate. To achieve these aims *A. millefolium* was sampled along a 620 m altitudinal gradient from 1251 m (montane) to 1872 m (alpine) in Kosciuszko National Park. It was expected there would be a decline in total biomass, in allocation to reproductive structures and a potential increase in proportion of biomass allocated to below ground structures with increasing severity of environmental conditions associated with increasing altitude.

### **9.3. METHODS**

#### **9.3.1. Sites**

*Achillea millefolium* was sampled at nine sites where it was abundant along a 620 m altitudinal gradient (1252 – 1872 m) during February 2002 (Table 9.1). Sites were along the two major access roads through Kosciuszko National Park, Kosciuszko Road and the Alpine Way. The Sawpit Creek, Alpine Way, Thredbo Entrance, Wragges Creek, Rainbow Lake, Spencers Creek and Guthrie Creek sites were located on the road verge (sample was taken at the beginning of soil past the gravel substrate at the road edge). The Smiggin Holes and Perisher Valley Fire Station sites were adjacent to infrastructure and approximately 10 to 15 m from the road verge. The Charlotte Pass Lookout site was adjacent to the road verge and toilet infrastructure.

Table 9.1. Location of the nine sites at which *A. millefolium* was sampled to measure biomass along an altitudinal gradient in Kosciuszko National Park, Australia during February 2002.

Location	Altitude (m)	Latitude	Longitude
Sawpit Creek, Kosciuszko Rd	1252	36°20'53.8"S	148°34'5.8"E
Alpine Way, The Alpine Way	1307	36°28'49.4"S	148°21'3.2"E
Thredbo Entrance, The Alpine Way	1383	36°29'56.5"S	148°19'5.2"E
Wragges Creek, Kosciuszko Rd	1624	36°22'40.6"S	148°27'47.6"E
Rainbow Lake, Kosciuszko Rd	1627	36°22'11.9"S	148°28'28.2"E
Smiggin Holes, Kosciuszko Rd	1706	36°23'39.6"S	148°25'36.8"E
Spencers and Guthrie Creeks, Kosciuszko Rd	1770	36°25'42.8"S	148°21'59.6"E
Perisher Valley Fire Station, Kosciuszko Rd	1867	36°24'17.5"S	148°24'44.7"E
Charlotte Pass Lookout, Kosciuszko Rd	1872	36°25'54.3"S	148°19'43.6"E

### 9.3.2. Biomass allocation among plant structures

To investigate changes in biomass allocation between plant structures seven to 10 replicate quadrats were sampled at each of the nine sites. Biomass allocation was divided into reproductive, underground and vegetative structures. Due to the extensive above and below ground vegetative growth of *A. millefolium*, individual ramets and genets could not be distinguished, so measurements were made on 10 cm<sup>2</sup> quadrats rather than for individual plants. As the rhizomes of *A. millefolium* do not penetrate deeply in the soil, with usually more than 80% of the rhizome mass in the top 5 cm (Bourdôt *et al.* 1979), the 10cm sampling depth was chosen to include the rhizome and some of the fine root material. All plant material in the quadrat was harvested. Plant material was separated into: reproductive structures (all inflorescences cut off at ground level – included pedicels, peduncles and associated leaves, terminal and side corymbs); vegetative material (any leaf material not associated with an inflorescence); and below ground material (rhizomes and root material to a depth of 10 cm). Soil was removed from the below ground material prior to drying.

Samples were dried at 70°C for five days. Dry weights were obtained for the reproductive structures, vegetative material and below ground material. In addition to examining if altitude affected absolute allocation, relative allocation of resources to different structures was examined. A series of ratios were calculated to examine relative allocation, including: reproductive effort (RE = reproductive dry weight/(vegetative dry weight + below ground dry weight)); reproductive dry

weight/total dry weight; below ground dry weight/total dry weight; and vegetative dry weight/total dry weight.

### **9.3.3. Resource allocation among flowering structures**

To investigate changes in the allocation of resources among structures within an inflorescence with change in altitude, 10 inflorescences were randomly selected at each site. Each inflorescence was separated into a terminal cluster of flowering heads (terminal corymb consisting of several flower heads and their stems), peduncles, and side clusters of flower heads (side corymbs including the stem and associated leaves). The number of individual flower heads was recorded for each terminal and side corymb. Dry weights were obtained for the terminal corymb and side corymbs.

### **9.3.4. Statistical analysis**

A series of linear regressions were performed to examine the effect of altitude on the dry weight of components of plants and inflorescences (SPSS Version 10.0 for Windows, Coakes and Steed 2000).

To satisfy assumptions of normality and homogeneity of variance for the linear regressions, natural log transformations were performed on reproductive allocation, below ground allocation, vegetative allocation, total biomass, dry weight of terminal flowers dry weight of entire bracts, and weight per flower for terminal inflorescence and bract. To allow log transformation for the dry weight (g) of terminal or side corymbs these values were multiplied by 1000 and for the dry weight per flower the value was multiplied by 10,000.

## **9.4. RESULTS**

### **9.4.1. Biomass allocation among plant structures**

The absolute allocation to reproductive structures, reproductive effort and the proportion of total resources allocated to reproduction all declined slightly with increasing altitude although there was considerable variation in biomass at each site, as often occurs in size measures for plants (Tables 9.2 and 9.3, Figures 9.1 and 9.2). There was also a trend for relative allocation to below ground biomass to increase

slightly with increasing altitude, with a P value of 0.051 for the regression, although the  $r^2$  was low (Table 9.2 and Figure 9.2). These changes with altitude did not affect the absolute allocation of biomass to total dry weight, below ground or vegetative structures (Table 9.2 and Figure 9.1).

Table 9.2. Results from linear regression testing the effect of altitude on reproductive, vegetative and underground biomass of *A. millefolium*. Data from 10 cm<sup>2</sup> quadrats of *A. millefolium* sampled from nine sites along an altitudinal gradient in Kosciuszko National Park, during February 2002. RE = reproductive dry weight/(vegetative dry weight + below ground dry weight).

y (g per 10 cm <sup>2</sup> )	F	P	r <sup>2</sup>	Regression formula
Reproductive structures	8.543	0.005	0.109	(ln (y * 10 <sup>-3</sup> ) = 11.8540 - 0.00126 * altitude
Below ground structures	0.000	0.983	0.000	(ln (y * 10 <sup>-3</sup> ) = 4.3050 - 0.00000511 * altitude
Vegetative structures	3.146	0.080	0.043	(ln (y * 10 <sup>-3</sup> ) = 4.2200 - 0.000303 * altitude
Total dry weight of plant	2.919	0.092	0.040	(ln (y * 10 <sup>-3</sup> ) = 5.1780 - 0.000297 * altitude
RE	4.477	0.038	0.060	y = 2.0290 - 0.00069 * altitude
Reproductive/total ratio	4.180	0.045	0.056	y = 71.8700 - 0.0182 * altitude
Below ground/total ratio	3.940	0.051	0.053	y = 14.6170 + 0.0186 * altitude
Vegetative/total ratio	0.010	0.921	0.000	y = 13.5130 - 0.000382 * altitude

y = predicted value of the dry weight of specified structure in g per 10 cm<sup>2</sup>. F = Test statistic from regression, based on F distribution. P = Significance level for statistical test. r<sup>2</sup> = adjusted coefficient of determination.

Table 9.3. Mean  $\pm$ SE of dry weight (g) of inflorescences, rhizomes, vegetative material, and total biomass of *A. millefolium*. Data from 10 cm<sup>2</sup> quadrats of *A. millefolium* populations sampled from nine sites along an altitudinal gradient in Kosciuszko National Park, during February 2002.

Altitude	Inflorescences (g)		Rhizomes (g)		Vegetative material (g)		Total biomass (g)	
	Mean	$\pm$ SE	Mean	$\pm$ SE	Mean	$\pm$ SE	Mean	$\pm$ SE
1252	46.7	9.9	21.2	4.3	12.4	3.6	80.3	12.4
1307	25.1	3.9	18.5	3.5	4.8	0.9	48.4	4.9
1383	23.1	5.6	46.3	9.9	7.5	1.2	76.9	11.5
1624	22.7	6.5	20.6	5.7	5.8	2.2	49.1	12.1
1627	29.6	6.1	33.1	16.3	6.8	0.4	69.4	21.5
1706	37.1	11.2	46.2	9.3	7.2	1.4	90.4	16.9
1770	7.0	1.3	14.8	6.9	3.3	0.7	25.1	8.2
1867	13.6	2.4	26.3	9.3	5.9	1.3	45.8	11.9
1872	36.7	14.6	57.4	8.6	9.7	2.9	103.8	27.6
Total	27.4	2.9	31.3	3.5	7.2	0.7	65.9	5.5

The average total biomass per 10 cm<sup>2</sup> quadrat of *A. millefolium* was of 65.9  $\pm$  5.5 g, with 27.4  $\pm$  2.9 g consisting of inflorescences and associated leaves (41.6% of total), 31.3  $\pm$  3.5 g of below ground material (47.5% of total) and 7.2  $\pm$  0.7 g (10.9% of total) in leaves not associated with the inflorescence (Table 9.3). The largest dry weight of inflorescences (46.7 g) occurred at the lowest altitude site samples (1252 m) while the largest dry weight of rhizome (57.4 g) occurred at the highest altitude site (1872 m). The plants observed at this highest site were smaller in height compared to the other sites but not necessarily lighter in weight. The largest overall

plants were sampled at the highest altitude site (1872 m) at an average of  $103.8 \pm 27.6$  g with the smallest average plants found at the 1770 m site at  $25.1 \pm 8.2$  g (Table 9.3).

#### 9.4.2. Resource allocation among flowering structures

There was a significant decrease in the total weight of an inflorescence with increasing altitude although again the  $r^2$  was low ( $p = 0.000$ , Tables 9.4 and 9.5). This may be simply due to the inflorescences being short at higher altitude, as there was no reduction in the number of side corymbs or overall number of flowering heads or number of flowering heads on the side corymbs with altitude. There was a slight decrease in the number of flowering heads on the terminal corymb (Tables 9.4 and 9.5). Overall individual inflorescences only weighed around  $2.0 \pm 0.16$  g but had around  $129 \pm 2$  flowering heads. They consisted of a terminal corymb with around  $69 \pm 2.6$  flower heads, and just over two ( $2.1 \pm 0.18$ ) side corymbs with around  $60 \pm 6.4$  flower heads in total.

Table 9.4. Results from linear regression testing the effect of altitude on the biomass of components of inflorescences of *A. millefolium*. Data from single inflorescences sampled from nine sites along an altitudinal gradient in Kosciuszko National Park, during February 2002. N = number of replicates. Weight per flowering head = weight of entire corymbs/number of flowering heads, # number. fl = flower.

y	F	P	$r^2$	Regression formula
<b>Terminal corymb</b>				
# of flowering heads	10.275	0.002	0.105	$y = 126.807 - 0.036250 * \text{altitude}$
Dry weight of terminal fl. heads	24.112	0.000	0.215	$(\ln(y * 10^{-3})) = 5.255 - 0.002274 * \text{altitude}$
Weight per flower head	7.179	0.009	0.075	$(\ln(y * 10^{-4})) = 6.401 - 0.000667 * \text{altitude}$
<b>Side corymb</b>				
# of flowering heads	1.508	0.223	0.017	
Dry weight of all side corymb	27.207	0.000	0.283	$(\ln(y * 10^{-3})) = 11.670 - 0.004120 * \text{altitude}$
Number of side corymbs	0.015	0.902	0.000	
Weight per flowering head	29.354	0.000	0.298	$(\ln(y * 10^{-4})) = 8.155 - 0.003014 * \text{altitude}$
<b>Inflorescence</b>				
# of fl. heads per inflorescence	0.976	0.326	0.011	$y = 178.828 - 0.003120 * \text{altitude}$
Total weight of inflorescence	24.261	0.000	0.216	$y = 7.030 - 0.000313 * \text{altitude}$

F = Test statistic from regression, based on F-distribution. P = Significance level for statistical test. It is the probability of committing a type I error.  $r^2$  = adjusted coefficient of determination

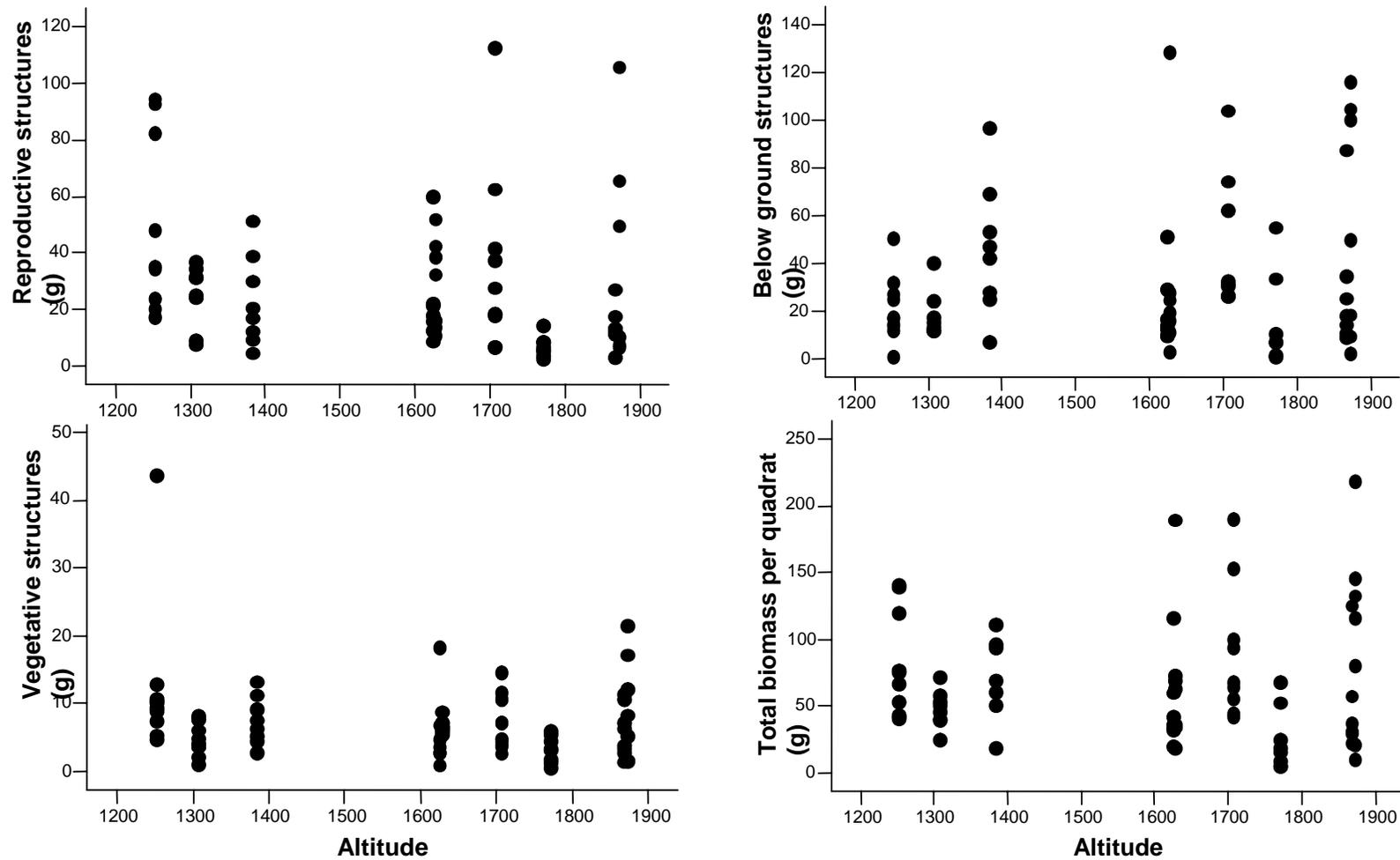


Figure 9.1. Relationship between altitude and biomass (g dry weight per 10 cm<sup>2</sup>) of *A. millefolium* reproductive structures (all inflorescences cut off at ground level), below ground structures (rhizomes and roots), vegetative structures (leaves not on inflorescence stem) and total dry weight.

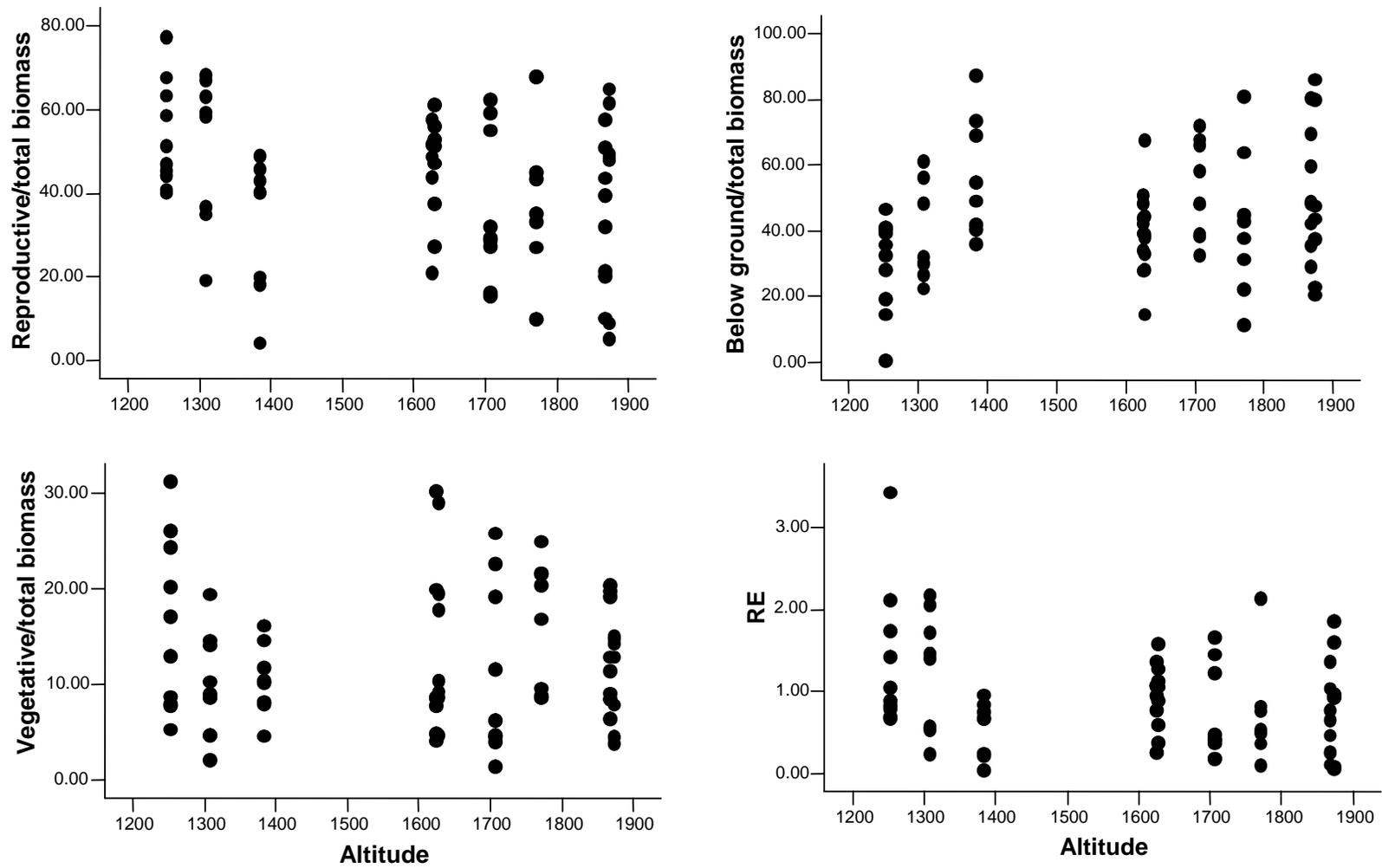


Figure 9.2. Relationship between altitude and relative allocation to reproductive, below ground and vegetative components and for reproductive effort (RE). Data from 10 cm<sup>2</sup> quadrats of *A. millefolium* sampled from nine sites along an altitudinal gradient in Kosciuszko National Park, during February 2002. RE = reproductive dry weight/(vegetative dry weight + below ground dry weight).

Table 9.5. Mean  $\pm$  SE for number and dry weight (g) of components of inflorescences for *A. millefolium*. Data from single inflorescences of *A. millefolium* sampled from nine sites along an altitudinal gradient in Kosciuszko National Park, during February 2002. N = number of replicates in mean. Weight per flowering head = weight of entire corymbs/number of flowering heads.

Altitude	N	Per Inflorescence				Terminal corymb						Side corymb								
		Number of flowering heads		Weight of inflorescence		Weight of terminal corymbs		Weight per fl. head for corymbs		Number of flowering heads		Number of flowering heads		Number of side corymbs		Weight of side corymbs		Weight per flowering head for corymbs		
		Mean	SE	Mean	SE	Mean	SE	Mean	SE	Mean	SE	Mean	SE	Mean	SE	Mean	SE	N	Mean	SE
1252	10	126	19	3.6	0.90	2.1	0.43	0.029	0.006	73	7.6	53	12.5	1.7	0.34	1.54	0.559	8	0.025	0.008
1307	10	146	17	3.3	0.55	3.2	0.51	0.033	0.005	96	5.9	110	23.4	3.1	0.50	0.71	0.215	9	0.005	0.001
1383	10	139	27	1.8	0.34	1.7	0.33	0.024	0.003	73	8.1	56	21.9	1.5	0.56	0.43	0.194	5	0.007	0.001
1624	10	123	17	1.5	0.22	1.4	0.19	0.022	0.003	60	7.4	25	8.3	1.1	0.31	0.14	0.081	7	0.005	0.002
1627	10	184	23	2.2	0.22	1.5	0.17	0.023	0.003	74	10.6	76	18.6	3.2	0.68	0.19	0.057	9	0.002	0.001
1706	10	83	13	1.2	0.25	1.1	0.19	0.019	0.003	57	6.2	64	14.3	2.6	0.50	0.18	0.061	9	0.002	0.001
1770	10	99	19	1.3	0.21	1.2	0.17	0.022	0.002	55	7.5	43	18.2	2.1	0.64	0.15	0.087	9	0.002	0.001
1867	10	148	19	1.5	0.21	1.3	0.21	0.017	0.002	72	4.3	66	26.4	1.8	0.55	0.13	0.063	7	0.001	0.001
1872	10	114	22	1.5	0.24	1.1	0.20	0.020	0.004	58	5.3	50	17.2	2.1	0.59	0.14	0.067	8	0.002	0.001
Total	90	129	7.0	2	0.16	1.6	0.12	0.023	0.001	69	2.6	60	6.4	2.1	0.18	0.40	0.084	71	0.006	0.001

## 9.5. DISCUSSION

*Achillea millefolium* is found at a range of altitudes in Kosciuszko National Park where it is observed to germinate, grow, flower and set seed (Chapters 3, 4, 5, 6 and 7). The resource allocation study here shows that the size (biomass) of these plants is large, with an average of 6.6 kg of dry weight of *A. millefolium* per m<sup>2</sup> at the sites sampled, consisting of 2.7 kg of inflorescences, 3.1 kg of rhizomes and roots and 0.7 kg of leaves not on inflorescences. Although individual inflorescences only weighed 2 g on average, they averaged 129 flowering heads.

The increasing severity of environmental conditions with altitude did affect biomass allocation in *A. millefolium*, including the absolute and relative allocation of resources to reproductive structures, but there were still large amounts of biomass even in the alpine zone. The reduction in biomass was of the order of 230 g of reproductive biomass (calculated per m<sup>2</sup> occupied by *A. millefolium*), with each 100 m increase in altitude based on the regression equation. This was associated with a decrease in the dry weight of inflorescences and a decline in the dry weight per flowering head but not a decline in the number of flowering heads, so it is not clear if the reduction in biomass equates to fewer seeds being produced by plants at higher altitudes.

The large amount of biomass of *A. millefolium* found along roadsides along with the high cover values found in the surveys of road verges (Chapters 3, 4 and 8) again suggest that this species is an important component of vegetation in many disturbed areas of Kosciuszko National Park. It also indicates that once established at a site the large biomass and dense spreading rhizome mat could limit the germination and establishment of other species. Studies in New Zealand found that *A. millefolium*'s extensive rhizome system is difficult to control (Bourdôt *et al.* 1979; Bourdôt 1984; Bourdôt and Butler 1985; Field and Jayaweera 1985a,b; Rutherford 1986; Bourdôt and Field 1988). This rhizome system can account for 57% of the total dry weight of the plant (Bourdôt *et al.* 1979). Vegetative spread of *A. millefolium* can be rapid, providing the plant with a competitive advantage in closed vegetation (Bourdôt *et al.* 1979; Warwick and Black 1982).

Although the absolute total, vegetative and below ground biomass of *A. millefolium* did not change significantly with altitude there was a trend for an increase in the relative allocation of resources to below ground structures. On average the allocation to underground biomass found over the altitude range examined here was 47.5%. These responses to altitude are similar to that of native plants in the European Alps which often allocate a higher portion of biomass to below ground organs, develop large reserve roots, and allocate fewer resources to reproduction (Grime 1977; Körner and Renhardt 1987; Körner 1999). For example, in a study comparing dry matter allocation for 49 species in the European Alps low altitude taxa were found to have a biomass division of; flowers 35%, leaves 22%, and below ground structures 42% (thick roots or storage 28%, and fine roots 14%). For their high altitude counterparts the division was: flowers 18%, leaves 24%, below ground structures 58% (thick roots or storage 28% and fine roots 30%) (Körner and Renhardt 1987; Körner 1999). This low shoot to root ratio is thought to be a response to low temperatures, low water and mineral nutrient supply and high light intensity (Körner and Renhardt 1987 and references therein).

In a study of ecotypes of the *A. millefolium* complex from climatically contrasting regions in the Sierra Nevada an inverse correlation between height of plant and altitude of habitat was found with the higher the altitude the smaller the stature of the plant and flowering stems (Clausen *et al.* 1958). This pattern was also observed in the plants studied in Kosciuszko National Park where those plants at 1872 m were smaller in stature than those plants at lower altitudes (Author obs.).

### **9.5.1. Conclusions**

This study shows that with increasing altitude there was a decrease in both the relative and absolute allocation of biomass to reproductive structures. However the total number of flowering heads was not affected by altitude. There was no effect of altitude on the absolute allocation to below ground structures or vegetative structures: though a trend for increased relative allocation to below ground structures with increasing altitude was observed. From the results it appears that the production of flowers, below ground and vegetative structures is not limited by the environmental conditions in the Australian Alps.

Populations of *A. millefolium* were found to have high cover values (Chapters 7 and 8) made up of extensive biomass of vegetative and reproductive material (this Chapter). The phenology study showed the potential for huge numbers of seed to be produced at a range of altitudes over an extended period from November to April. In this chapter the results again showed that there was a considerable allocation of resources to the production of inflorescences.

In the next chapter the potential seed production resulting from this investment is estimated as the total number of florets per inflorescences, along with the seed rain and the viability of stored and buried seed of *A. millefolium* along an altitudinal gradient

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## CHAPTER 10

### ASPECTS OF *ACHILLEA MILLEFOLIUM*

#### SEED ECOLOGY

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#### 10.1. SUMMARY

To study the seed ecology of *A. millefolium* potential seed production and seed viability was estimated over an altitudinal range from the montane to the subalpine zone in Kosciuszko National Park. Seed production was estimated in two ways; (1) by measuring the number of florets per inflorescence to obtain an estimate of the maximum potential seed that could be produced per inflorescence, and (2) by measuring seed rain per unit area collected after 12 months. Inflorescences were sampled at 17 sites from 1522 m to 1798 m altitude. The average number of florets per inflorescence was 1419 ( $\pm 83$  SE), thus the average maximum potential seed output per inflorescence would be  $\sim 1420$  seeds (one seed per floret). Seed rain was estimated by collecting all *A. millefolium* seed remaining on 50 cm<sup>2</sup> pieces of the artificial grass AstroTurf™ after one year at 12 sites at a range of altitudes. The results were highly variable ranging from one seed ( $\pm 0.7$  SE) to 275 ( $\pm 23$  SE) seeds per m<sup>2</sup>, with those sites at high subalpine and secondary roads sites having the lowest seed rain.

Viability of stored and buried *A. millefolium* seed was measured over time. To test the viability of stored seed, seed was collected from fruiting inflorescences at 13 sites along an 1140 m altitudinal gradient. The germination rate of this stored seed over two years was examined. To test the viability of buried *A. millefolium* seed, bags of seed and soil were buried with samples exhumed and then germinated each spring and autumn for two and a half years. Germination rates of stored seed varied among the 13 sites sampled ranging from 8.7% ( $\pm 2.4$  SE) to 88.7% ( $\pm 0.9$  SE). There were differences in viability of stored seed among sites and some changes over time but there was no consistent pattern. Of the buried seed there was an overall average loss of 45.7% ( $\pm 1.8$  SE). Of the remaining buried seed the average germination rate was 16.2% ( $\pm 7.8$  SE) with viability independent of time or site.

Although there was considerable variation in seed production, seed rain, and seed viability among sites the greater environmental stress with increasing altitude either did not affect or had a minor effect on the amount of seed produced, seed rain and the viability of stored and buried seed.

## **10.2. INTRODUCTION**

Previous chapters of this thesis have shown that *A. millefolium* occurs in many disturbed areas of Kosciuszko National Park and can be found in natural vegetation adjacent to disturbed areas particularly where there are increased nutrients and moisture (Chapters 4, 5, 7). Although *A. millefolium* only occurs in ~ 4% of natural sites sampled (Chapter 7), where it is found it can be highly competitive forming monocultures over limited areas (Chapters 4, 5). Experiments indicated that *A. millefolium* is present in the soil seed bank at least 10 m from road verges and accounted for 6% of all germinants from soil sampled one, five and 10 m from the verge (Chapter 5).

Seed rather than rhizome buds are thought to be the main mechanism by which this species expands its range (Bourdôt *et al.* 1979). Therefore its capacity to disperse or establish in new sites will be influenced by the amount of seed it produces and the viability of the seed. It is therefore important to quantify seed production and viability and to determine if increasing severity of conditions with increasing altitude affects seed production and viability.

### **10.2.1. Seed production**

Seed plays an important role in the capacity of species to colonise and establish in disturbed areas and enables plants to survive adverse environmental conditions (Hutchings 1986). *Achillea millefolium* is in general a prolific seed producer although the amount of seed produced is highly variable. Estimates of seed production vary from 500 to 4189 seeds per plant (Deschenes 1974; Bostock and Benton 1979; Kannangara and Field 1985). Environmental conditions (such as temperature and moisture) during the previous and current growing season and biotic conditions (such as availability of pollinators and predispersal predation) are some factors affecting seed production (Chapin and Chapin 1981; Chambers 1989; van der

Valk 1992; Cousens and Mortimer 1995; Walker *et al.* 1995; McGraw and Day 1997; Molau and Larsson 2000; Greilings and Kichanan 2002; Moles *et al.* 2003).

### *Seed rain*

The flux of seed into and out of the habitat can affect the density and spread of the plant population with seed rain (mature seed that is released from the parent) an important mechanism for expanding the range of species (Harper 1994). The seed rain falling per unit of land is a function of the height and distance of the source, the concentration of the seed, the dispersability of the seed, and the activity of distributing agents (Harper 1994). The small light *A. millefolium* seed is not particularly aerodynamic with most seed the falling to the ground within 2-3 m of the parent (Bostock and Benton 1979; Chandler *et al.* 1982; Warwick and Black 1982).

#### **10.2.2. Seed viability**

The viability of seed is the lifespan of a seed. *Achillea millefolium* seed has been found to be viable for several years with germination triggered by light, temperature and moisture, the effects of which depend on factors such as the age of the seed and burial depth (Robocker 1977; Bostock 1978; Field and Kannangara 1987). *Achillea millefolium* seed has been found to have high initial viability (96.9%), and stored viability (88.7% soil stored and 26.7% following storage at 27°C) (Bostock 1979). Its seeds were found to have a rapid water uptake capacity which is associated with better germination on drier substrate with  $2.3 \pm 0.22$  mean days to germination. The seed was found to have short period of after ripening with germination spread over months, partly after fruiting and partly in the following spring (Bostock 1979).

From the colonisation experiments during this research (Chapter 5) *A. millefolium* was found to be one of the most common species in the soil seed bank adjacent to road verges. *A. millefolium* germinated with an average density of 8.3 seedlings per m<sup>2</sup> of soil in samples (5 cm depth) taken one, five and 10 m from the road verge.

In order to investigate the importance of seed in the ecology of *A. millefolium* in Kosciuszko National Park this research determined; (1) the number of florets per *A. millefolium* inflorescence over an altitudinal range as a measure of maximum seed production; (2) the seed rain from established *A. millefolium* plants, (3) the viability

over time of stored *A. millefolium* seed produced over an altitudinal range, and (4) the viability and loss of seed over time of buried *A. millefolium* seed.

### **10.3. METHODS**

#### **10.3.1. *Achillea millefolium* seed production and seed rain**

The number of *A. millefolium* seed produced per inflorescence or per unit area was not determined in this study. This was in part due to the difficulty of estimating seed production for a species that produces numerous inflorescences over a long period of time, with seeds likely to be shed over months. Collecting seed from single inflorescences by bagging was considered, but rejected as bagging was likely to affect seed production. As the species is cross pollinated bagging would stop pollination of late opening florets at the centre of inflorescences. Also, bagging could damage inflorescences in high wind or wet conditions in the field. Therefore two other methods were used to assess how much seed could be dispersed by *A. millefolium*; (1) the maximum potential seed production based on the number of florets per inflorescence was estimated, and (2) the amount of seed collected per unit area at sites with *A. millefolium* (seed rain) was estimated.

##### *Maximum potential seed per inflorescence*

Like most Asteraceae, *A. millefolium* has one ovule per floret and so can produce a maximum of one seed from each floret (one achene). Therefore to estimate the maximum potential number of seed that could be produced per inflorescence the number of florets per *A. millefolium* inflorescence was determined. As altitude could affect the number of florets per inflorescence and hence the potential number of seed, 10 *A. millefolium* inflorescences were randomly sampled at each of 17 randomly selected road verge sites located along a 276 m altitudinal gradient from the high montane (Wilson's Valley) to the high subalpine zone (Charlotte Pass) along the Kosciuszko Road during mid-January 2005 (Table 10.1). The number of flower heads (capitula) were counted for each inflorescence, and the number of florets counted on one randomly selected flowering head per inflorescence.

Table 10.1. Location of 17 sites along Kosciuszko Road, Kosciuszko National Park from which *A. millefolium* inflorescences were collected during January 2005.

Site	Altitude	Northing	Easting
1	1522	5975900	636200
2	1537	5974670	634938
3	1548	5974809	633111
4	1581	5975054	634076
5	1607	5974174	632374
6	1612	5975815	630818
7	1641	5972155	629939
8	1666	5973360	631642
9	1680	5971519	629124
10	1694	5971201	628087
11	1741	5967451	622089
12	1749	5970331	627011
13	1752	5969640	625967
14	1755	5967788	623089
15	1788	5968432	624037
16	1797	5969041	625054
17	1798	5967247	619980

The more severe environmental conditions at higher altitudes could affect seed production by reducing the number of flowering heads per inflorescence, by reducing the number of florets per flowering head or the two in combination. Therefore linear regressions and One-Way ANOVA were performed in SPSS Version 10.0 on the number of flowering heads per inflorescence, the number of florets per flowering head and the total number of florets per inflorescence with altitude as the independent variable (Coakes and Steed 2000).

#### *Seed rain per unit area*

Seed rain per unit area can be used to estimate seed output. To measure seed rain of *A. millefolium* in Kosciuszko National Park eight seed traps were randomly placed at each of 12 sites where *A. millefolium* occurred along an altitudinal gradient from montane to high subalpine during February 2000 (Table 10.2). Sites were located close to primary roads, secondary roads or buildings. The seed traps were 50 cm<sup>2</sup> pieces of artificial grass Astroturf™. Astroturf™ has been used for measuring seed rain in arctic and alpine environments by the International Tundra Experiment (Molau 1993). At each site traps were randomly placed along a 20 m transect parallel to the road or building. The seed traps were left unattended for a year and then collected (February 2001) bagged and removed to the laboratory. The seed traps

were dried at ambient temperatures and then all *A. millefolium* seed on the trap was collected by combing and brushing the Astroturf™.

Seed rain values were expected to be lower than estimates based on the number of ovules/florets per inflorescence as not all seed set by a plant falls to the ground as seed rain due to predation of seed prior to release (Urbanska and Fattorini 2000). Also seeds that do fall to the ground may be lost due to on ground predation or they can be washed or blown away from the collection point.

Table 10.2. Location of sites where *A. millefolium* seed rain was measured in tableland, montane, subalpine and alpine climatic zones of Kosciuszko National Park in the 1999-2000 growing season.

Location	Climatic zone	Altitude (m)	Northing	Easting
Primary Road				
Berridale, Kosciuszko Rd	Mid montane	860	5973600	663600
Wilson's Valley, Kosciuszko Rd	High montane	1460	5975900	636300
Perisher Valley, Kosciuszko Rd	Low subalpine	1650	5969800	626300
Spencers Creek, Kosciuszko Rd	High subalpine	1760	5967700	620800
Secondary Rd				
Eucumbene Rd	Mid montane	900	5974100	650400
Schlinks Pass Rd	High montane	1440	5976400	626500
Schlinks Pass Rd	Low subalpine	1580	5980300	625400
Schlinks Pass Rd	High subalpine	1780	5982800	624400
Building				
Private Property	Mid montane	900	5974100	650400
Wilson's Valley Ranger Station	High montane	1460	5975900	636200
Perisher Lodge, Perisher Valley	Low subalpine	1650	5969400	626400
Charlotte Pass Resort	High subalpine	1760	5966800	619300

To determine if there was an effect of type of disturbance (primary road, secondary road or building) or altitude (mid montane, high montane, low subalpine and high subalpine) on the number of seed per unit area of Astroturf a Two-way ANOVA was performed on log transformed ( $\ln + 1$ ) data in SPSS (Version 10.0 for Windows, Coakes and Steed 2000).

### 10.3.2. *Achillea millefolium* seed viability

In addition to estimating potential seed output the viability of stored and buried seed over time was measured.

#### *Viability of stored seed*

Experiments were conducted to determine if there were changes in the percentage germination of stored *A. millefolium* seed with increased storage time. Seed was

collected from the locations where the seed rain experiments were conducted (Table 10.2). At each site ten *A. millefolium* inflorescences which had florets setting seed but had not yet lost seed were randomly collected between February 1999 and April 1999. Sites at lower elevations flowered earlier and thus were sampled earlier and sites at higher altitude were sampled later. Inflorescences from the same site were pooled, placed into paper bags and stored until all available seeds were released from the seed heads. Seeds were sieved from the chaff and stem using a mesh sieve and then stored in dark dry cool conditions until needed.

In order to measure decline in viability of stored seed over time three replicate samples of stored seed from each site were germinated in May 1999 (autumn, 1-3 months after collection), in May 2000 (autumn ~1 year after collection) and in May 2001 (autumn ~two years after collection). Seed were germinated at room temperature in 150 mm (diameter) plastic polystyrene Petri dishes with 20 seeds from each site placed on moist litmus paper. *Achillea millefolium* seed takes on average 2-4 days to germinate (Bostock 1978; Stock 1999) so seed that had not germinated after two weeks were classed as non-viable.

To determine if there was an effect of altitude or storage time on percentage germination of *A. millefolium* data were analysed using a Two-Way ANOVA in SPSS Version 10.0 for Windows. Differences between means were determined using Tukey's LSD tests. In order to satisfy assumptions of normality and homogeneity the data were transformed using an arcsine square root.

#### *Viability of and loss of buried seed*

A field experiment was conducted to determine if there were changes in: (1) percentage germination of buried *A. millefolium* seed over time; and (2) loss of buried seed over time. Loss of seed is defined here as the difference between the numbers of seed initially placed in bag for burial (in this case 100 seeds) and those remaining in exhumed bags. The specific reason for the loss of seed (e.g. predation, decay) was not determined in this experiment.

Mature *A. millefolium* seed was collected from 40 randomly sampled inflorescences located adjacent to infrastructure at three sites in Kosciuszko National Park during

February 1999 (Table 10.3). Seed from each site was stored separately and then buried at that site.

Table 10.3. Location of sites where mature *A. millefolium* seed was collected during February 1999 in Kosciuszko National Park for use in the seed burial experiments.

<b>Location</b>	<b>Altitude (m)</b>	<b>Northing</b>	<b>Easting</b>
Perisher Valley	1650	5969800	626300
Smiggin Holes	1734	5971816	628559
Charlotte Pass	1872	5967456	622010

At each site 50 muslin bags each containing 100 seed and 5 g of soil from that site were buried. At each site a 10 m<sup>2</sup> area was permanently marked and five holes dug at random locations within the area. Then 10 securely sealed seed bags were placed in each hole at a depth of 10 cm during April 1999. Fifteen control seed bags for each site were placed in cool dark dry conditions with 5 g of soil but not buried in the field.

Seed bags were exhumed from the field from one randomly selected burial hole at each site during spring 1999, autumn 2000, spring 2000, autumn 2001 and spring 2001. Viability of exhumed seed was measured using germination procedures as described in the preceding section. Seed from control samples were germinated alongside the exhumed samples at each time period.

To determine if seed loss (percentage of seed remaining in the seed bag) and seed viability (percentage of germinated seed) were affected by altitude/site or length of burial time data were analysed using Two Way ANOVAs with site and germination time as the independent variables and seed loss and percentage germination as the dependent variables (SPSS Version 10.0 for Windows, Coakes and Steed 2000). Differences between means were determined using Tukey's LSD Tests. To satisfy assumptions of normality and homogeneity percentage data were transformed using an arsine square root (SPSS Version 10.0 for Windows, Coakes and Steed 2000).

## 10.4. RESULTS

### 10.4.1. *Achillea millefolium* seed production

#### *Maximum potential seed per inflorescence*

The average number of flower heads per *A. millefolium* inflorescence was  $93 \pm 5$  (SE) and the average number of florets per flower head was  $15 (\pm 1.2 \text{ SE})$  (Table 10.4). There was considerable variation within and between sites in the number of flower heads per inflorescence, but less variation in the number of florets per inflorescence. The number of flower heads per inflorescence varied from 15 to 496 while the number of florets per flower head varied from 9 to 20. The average number of florets per inflorescence and hence the maximum potential seed that could be produced was 1419 ( $\pm 83 \text{ SE}$ ) with a range from 150 to 7786. Based on these results along with data from Chapter 9 (36.2 inflorescences per  $\text{m}^2$ ), gives an estimate of  $\sim 51\,4000$  seed per  $\text{m}^2$ .

Table 10.4. Mean  $\pm$  SE of the number of flowering heads per inflorescence ( $n = 10$ ) and number of florets per flowering head ( $n = 10$ ) at 17 sites along an altitudinal gradient in Kosciusko National Park, collected during January 2005.

Altitude	# flowering heads per inflorescence (mean $\pm$ SE)	# florets per head (mean $\pm$ SE)	# florets per inflorescence (mean $\pm$ SE)
1522	106 $\pm$ 13	15.4 $\pm$ 0.47	1661 $\pm$ 237
1537	74 $\pm$ 7	16.9 $\pm$ 0.46	1257 $\pm$ 125
1548	116 $\pm$ 19	15.8 $\pm$ 0.85	1841 $\pm$ 293
1581	88 $\pm$ 12	16.2 $\pm$ 0.55	1446 $\pm$ 223
1607	149 $\pm$ 37	14 $\pm$ 0.75	2252 $\pm$ 668
1612	142 $\pm$ 27	15.5 $\pm$ 0.82	2328 $\pm$ 530
1641	142 $\pm$ 44	15.3 $\pm$ 0.86	2008 $\pm$ 525
1666	170 $\pm$ 27	14.7 $\pm$ 1.11	2497 $\pm$ 506
1680	104 $\pm$ 16	16.2 $\pm$ 0.53	1651 $\pm$ 228
1694	63 $\pm$ 7	14.5 $\pm$ 0.62	914 $\pm$ 96
1741	47 $\pm$ 7	15.4 $\pm$ 0.81	730 $\pm$ 118
1749	76 $\pm$ 10	13.5 $\pm$ 0.89	1027 $\pm$ 160
1752	76 $\pm$ 10	13.6 $\pm$ 0.93	1003.8 $\pm$ 132
1755	33 $\pm$ 6	12.3 $\pm$ 0.76	419.7 $\pm$ 90
1788	67 $\pm$ 16	15.7 $\pm$ 0.39	1036.4 $\pm$ 237
1797	84 $\pm$ 14	15.6 $\pm$ 0.47	1322.2 $\pm$ 230
1798	60 $\pm$ 15	14.4 $\pm$ 0.56	891 $\pm$ 225
<b>Average</b>	<b>93 <math>\pm</math> 5</b>	<b>15 <math>\pm</math> 1.16</b>	<b>1419 <math>\pm</math> 83</b>

Table 10.5. Results of linear regressions of number of flower heads per inflorescence, number of florets per flower head and number of florets per inflorescence against altitude, and for One-Way ANOVA comparing low (<1960 m) and high altitude sites (>1690m altitude).

	<b>Regression formula</b>	<b>r<sup>2</sup></b>	<b>F</b>	<b>P</b>
# flower heads per inflorescence*	$y = 7.934 - 0.002 x$	0.093	19.407	0.000
# florets per flower head	$y = 26.561 - 0.007 x$	0.069	13.209	0.000
# florets per inflorescence*	$y = 11.419 - 0.003 x$	0.126	25.618	0.000
	<b>One-Way ANOVA</b>		<b>F</b>	<b>P</b>
# flower heads per inflorescence*			43.129	0.000
# florets per flower head			13.647	0.000
# florets per inflorescence*			51.858	0.000

- natural log transformed

There was a slight decrease in the number of flower heads, number of florets per flower head and the number of florets per inflorescence with increasing altitude, however the strength of each of the relationships was poor (Table 10.5).

There appears to be a threshold around 1680-1694 m altitude in the number of flowering heads per inflorescence (Table 10.4). If the data are therefore compared between sites below and above 1690 m altitude significant differences were found (Table 10.5), with lower altitude sites having an average of  $116 \pm 8$  flower heads per inflorescences  $15.7 \pm 0.2$  florets per flower head giving a total of  $\sim 1820 \pm 127$  ovules per inflorescences. In contrast higher altitude sites had average of  $63 \pm 4$  flower heads per inflorescences,  $14.4 \pm 0.3$  florets per flower head giving a total of  $\sim 918 \pm 94$  ovules per inflorescences.

#### *Seed rain per unit area*

The average number of seed collected on the 50 cm<sup>2</sup> Astroturf™ seed traps set out for the one year period was 11.8 ( $\pm 2.3$  SE) for the 12 sites, but varied widely among sites (Table 10.6). The altitudes and types of disturbance interaction was significant (Two-way ANOVA, Interaction,  $F = 115.8$ ,  $P = 0.00$ ), with the three high subalpine sites all having significantly lower seed rain than other sites. The mid montane, high montane and low subalpine sites only had low seed rain when they were adjacent to secondary roads. Mid montane, high montane and low subalpine sites adjacent to primary roads or buildings usually had significantly higher seed rain. There was little variation in seed rain among the eight pieces of Astroturf™ within sites (Table 10.6).

Table 10.6. Mean  $\pm$  SE of number of seed in seed rain for *A. millefolium*. Data are the total number of seeds remaining on 50 cm<sup>2</sup> artificial grass Astroturf™ (n = 8) at 12 sites along an altitudinal gradient in Kosciusko National Park during 1999 (spring) to 2000 (autumn).

Location	Climatic zone	Altitude (m)	Seed/50 cm <sup>2</sup>	Seed rain/ 1m <sup>2</sup>
<b>Primary Road</b>				
Berridale, Kosciuszko road	Mid montane	860	47.1 $\pm$ 4.4	189 $\pm$ 18
Wilson's Valley, Kosciuszko road	High montane	1460	0.38 $\pm$ 0.18	1.5 $\pm$ 0.7
Perisher Valley, Kosciuszko road	Low subalpine	1650	11.8 $\pm$ 1.33	47 $\pm$ 5
Spencers Creek, Kosciuszko road	High subalpine	1760	0.25 $\pm$ 0.16	1.0 $\pm$ 0.6
<b>Secondary Road</b>				
Eucumbene road	Mid montane	900	0.38 $\pm$ 0.18	1.5 $\pm$ 0.7
Schlinks Pass road	High montane	1440	0.25 $\pm$ 0.16	1.0 $\pm$ 0.7
Schlinks Pass road	Low subalpine	1580	0.75 $\pm$ 0.37	3.0 $\pm$ 1.5
Schlinks Pass road	High subalpine	1780	0.50 $\pm$ 0.38	2 $\pm$ 1.5
<b>Building</b>				
Private Property	Mid montane	900	1.50 $\pm$ 0.33	6 $\pm$ 1.3
Wilson's Valley Ranger Station	High montane	1460	68.8 $\pm$ 5.7	275 $\pm$ 23
Perisher Lodge, Perisher Valley	Low subalpine	1650	9.0 $\pm$ 1.9	36.0 $\pm$ 7.6
Charlotte Pass Resort	High subalpine	1760	0.38 $\pm$ 0.26	1.5 $\pm$ 1.1
Average			11.8 $\pm$ 2.3	47 $\pm$ 9

#### 10.4.2. *Achillea millefolium* seed viability

##### *Viability of stored seed*

Overall 60%  $\pm$  2.5 (SE) of stored *A. millefolium* seed germinated although there was considerable variation among sites (Table 10.7). There were also differences in germination rates over time for some sites, but not others (Table 10.7, Two-Way ANOVA, site \* time interaction, F = 2.302, P = 0.003). For example, for sites two, four and six the germination rate actually increased significantly between the first and second year. For 10 of the 13 sites sampled germination rates did not vary significantly over time. Two sites (5 and 11) had only ~ 10% germination compared to >48% for all other sites.

Table 10.7. Mean  $\pm$  SE percentage stored *A. millefolium* seed that germinated over time (1999 = 1-3 months, 2000 =  $\sim$  1 year and 2001 =  $\sim$ 2 years). Seed collected from 12 sites along an altitudinal gradient in Kosciuszko National Park in 1999.

Site	Altitude (m)	Mean $\pm$ SE germinated <i>A. millefolium</i> seed (%)			
		1999	2000	2001	Overall
1	860	57.0 $\pm$ 1.7	53.7 $\pm$ 5.0	59.7 $\pm$ 1.2	56.8 $\pm$ 1.8
2	900	24.0 $\pm$ 5.0	69.0 $\pm$ 6.7	68.0 $\pm$ 4.6	53.7 $\pm$ 7.9
3	1400	81.0 $\pm$ 7.1	89.7 $\pm$ 3.8	88.3 $\pm$ 1.5	86.3 $\pm$ 2.7
4	1401	34.7 $\pm$ 6.1	55.0 $\pm$ 6.7	56.0 $\pm$ 8.7	48.6 $\pm$ 5.0
5	1402	8.7 $\pm$ 2.4	13.3 $\pm$ 5.2	10.3 $\pm$ 4.4	10.8 $\pm$ 2.2
6	1600	61.3 $\pm$ 5.5	89.3 $\pm$ 5.5	88.0 $\pm$ 1.7	79.6 $\pm$ 5.0
7	1601	47.0 $\pm$ 3.5	50.7 $\pm$ 2.9	48.7 $\pm$ 2.2	48.8 $\pm$ 1.5
8	1602	69.7 $\pm$ 8.8	74.3 $\pm$ 7.3	73.0 $\pm$ 7.6	72.3 $\pm$ 4.0
9	1603	80.7 $\pm$ 6.8	73.0 $\pm$ 9.1	67.0 $\pm$ 6.0	73.6 $\pm$ 4.2
10	1700	88.7 $\pm$ 0.9	85.0 $\pm$ 7.0	80.7 $\pm$ 7.6	84.8 $\pm$ 3.2
11	1800	11.7 $\pm$ 1.2	8.3 $\pm$ 2.7	11.7 $\pm$ 2.8	10.6 $\pm$ 1.3
12	1801	74.7 $\pm$ 3.2	81.3 $\pm$ 2.6	73.7 $\pm$ 4.2	76.6 $\pm$ 2.1
13	2000	74.3 $\pm$ 1.7	76.0 $\pm$ 1.5	78.0 $\pm$ 5.1	76.1 $\pm$ 1.7
	Total	54.9 $\pm$ 4.4	63.0 $\pm$ 4.3	61.8 $\pm$ 4.1	59.9 $\pm$ 2.5

#### *Viability and loss of buried seed*

There was no appreciable loss of seed in the control bags over the three-year sampling period. Germination rates of the control seed for each site averaged 60%  $\pm$  3.4 (SE) with no reduction in germination percentage over time. This result is consistent with 10 of the 13 sites sampled in the stored germination experiment. It was therefore assumed that any seed loss or reduction in viability of buried seed compared to the control was due to burial conditions.

Overall the bags of buried seed lost an average of 45.7%  $\pm$  1.8 (SE) of the original 100 seed. There was significantly less seed lost from bags buried at Charlotte Pass than at the other two sites (between 41% and 51% Table 10.8) (Site F = 4.748, P = 0.016).

Table 10.8. Mean  $\pm$  SE percentage of seed lost following burial in subalpine soil at three locations in Kosciuszko National Park in April 1999 and then removal and germination in spring and autumn over three years (1999, 2000, 2001) (n = 10).

Site	Spring 1999	Autumn 2000	Spring 2000	Autumn 2001	Spring 2002	Overall
	$\sim$ 6 months	$\sim$ 1 year	$\sim$ 18 months	$\sim$ 2 years	$\sim$ 30 months	
Charlotte Pass	50.0 $\pm$ 10.5	54.3 $\pm$ 8.8	51.0 $\pm$ 5.4	41.0 $\pm$ 2.3	48.6 $\pm$ 3.0	49.0 $\pm$ 3.0
Perisher Valley	23.0 $\pm$ 6.3	34.6 $\pm$ 7.9	28.0 $\pm$ 6.6	60.3 $\pm$ 1.7	56.6 $\pm$ 2.7	40.5 $\pm$ 3.2
Smiggin Holes	38.2 $\pm$ 6.0	58.7 $\pm$ 5.4	28.1 $\pm$ 5.0	60.9 $\pm$ 5.7	52.2 $\pm$ 5.0	47.6 $\pm$ 2.9
Overall	37.1 $\pm$ 4.8	49.2 $\pm$ 4.6	35.7 $\pm$ 3.8	54.1 $\pm$ 2.7	52.5 $\pm$ 2.2	45.7 $\pm$ 1.8

Over time, more seed was lost (Time,  $F = 2.277$ ,  $P = 0.011$ ) with only 37% of seed lost in the spring of 1999 (~6 months after burial) compared to 54% after two years (autumn 2001) and 53% after ~30 months (spring 2002).

The viability of the remaining seed was independent of the time of exhumation (Two-Way ANOVA, Time,  $F = 1.137$ ,  $P = 0.362$ ) and the site ( $F = 0.486$ ,  $P = 0.628$ ) (Table 10.12). The average viability of *A. millefolium* seed post burial was  $16.2\% \pm 7.8$  across the three sites and five exhumation times.

Table 10.9. Mean  $\pm$  SE percentage viability of seed remaining in seed bags following burial in subalpine soil in April 1999 and then removal and germination in spring and autumn over three years (1999, 2000, 2001) ( $n = 10$ ).

Site	Spring 1999 ~6 months	Autumn 2000 ~1 year	Spring 2000 ~18 months	Autumn 2001 ~2 years	Spring 2002 ~30 months	Overall
Charlottes Pass	$24.2 \pm 19.2$	$5.6 \pm 8.2$	$13.5 \pm 12.4$	$13.2 \pm 10.9$	$20.9 \pm 16.6$	$15.3 \pm 4.4$
Perisher	$24.8 \pm 18.2$	$11.1 \pm 7.6$	$11.6 \pm 9.1$	$9.6 \pm 4.8$	$11.6 \pm 5.8$	$13.7 \pm 2.0$
Smiggin Holes	$44.3 \pm 25.4$	$21.0 \pm 17.3$	$4.7 \pm 4.7$	$12.4 \pm 15.1$	$14.5 \pm 18.1$	$19.4 \pm 6.1$
Overall	$31.1 \pm 11.5$	$12.6 \pm 7.8$	$9.9 \pm 4.6$	$11.7 \pm 1.9$	$15.4 \pm 4.4$	$16.2 \pm 7.8$

## 10.5. DISCUSSION

### 10.5.1. *Achillea millefolium* seed production

Using the data from Chapter 9 and the results reported in this chapter the estimate for the maximum number of *A. millefolium* seed produced per  $m^2$  was 51 400. This is lower than estimates for the amount of seed produced in arable land. For example, 900 000 seed per  $m^2$  was estimated for a population of *A. millefolium* in arable land in New Zealand (Bourdôt *et al.* 1979), and 243 000 seed per  $m^2$  for pure stands (58 plants per  $m^2$ ) of *A. millefolium* in agricultural land in temperate New Zealand (Kannangara and Field 1985).

The estimate here is for the maximum number of potential seed. It does not take into account how many ovules would develop into seed. Bostock and Benton (1979) estimated the mean percentage of ovules developing into seed as 55.4% accounting for losses due to abortion and predation. Using this value would reduce the estimate for seed production along roadsides and adjacent to buildings in Kosciuszko National Park to 28 460 per  $m^2$ .

### *Seed rain*

The seed rain found here was relatively consistent within site but varied considerably between sites, with seed rain not related to altitude but to other unidentified site specific factors. Seed rain is typically highly variable due to factors such as number of seed released, distance from the source (exponential reduction, with most seed falling within a few metres of the parental plant), weather conditions at the time of dispersal, on ground predation and post release dispersal (Bostock and Benton 1979; Chandler *et al.* 1982; Warwick and Black 1982). Other studies have also found considerable spatial and temporal variation in seed rain (Weaver and Cavers 1979; Urbanska *et al.* 1998; Molau and Larsson 2000; Urbanska and Fattorini 2000; Grace *et al.* 2002).

The results highlight that the reduction in the number of seed between that produced, and that left on a surface at ground level can be massive (from ~ 28 460 per m<sup>2</sup> to 47 per m<sup>2</sup>). It is likely that the seed rain in this study is an underestimate of the number of germinants in a disturbed area with the number of seedlings found in the colonisation experiment (Chapter 5) greater than the estimate of seed rain here.

#### **10.5.2. *Achillea millefolium* seed viability**

##### *Viability of stored seed*

There was considerable variation in the viability of *A. millefolium* stored seed collected from different sites in Kosciuszko National Park and surrounds, ranging from 8% to 89%. This variation was not related to the altitude of the site from which the seed was collected, and viability did not decline with time. The average germination rate was 60% over the 2.5 years tested. Similar results studying *A. millefolium* have been reported by Robocker (1977) who found a germination of 41% (loss of 59%) after nine years of dry storage with a relatively uniform decay rate. A comparison of the germination of Kosciuszko National Park native and exotic plant seed (Stock 1999) found *Achillea millefolium* germination from 10% to 37% under controlled temperature and moisture conditions. In a study of the germination strategies of five perennial weeds *A. millefolium* was found to have a fresh germination of 97%, soil stored 88%, and for 27°C stored seed a germination rate of

26% (Bostock 1978). The controlled germination rates however may not reflect those in the field. For example, for *Solidago altissima* in controlled conditions has a germination of 62% but in the field is reduced to 0.8% (Meyer and Schmid 1999).

#### *Viability and loss of buried seed*

Instead of germinating the seed may enter the seed bank. The fate of seed in the soil is difficult to study. Losses of seed in or on the soil include predation by birds, small mammals, earthworms, and seed eating insects, fungal attack, fire and natural deterioration due to environmental conditions (Harper 1994; Cousens and Mortimer 1995; Chadoeuf *et al.* 1998; Kostel-Hughes *et al.* 1998).

The overall average seed loss of *A. millefolium* over the three years of soil burial at a depth of 10 cm reported in this study was 45% with no significant change with length of time of burial (2 years in total). This result differs to those from temperate New Zealand where, for *A. millefolium* seed buried at 32 cm germination fell from 98% at three months to 67% by two years, and to 44% by four years (Kannangara and Field 1985). This difference in germination may be due to site specific biotic and abiotic conditions.

Maintenance of buried seed viability over time depends on many factors including species, soil type, depth of burial, management regimes etc, as well as internal physiological conditions in the soil (Reuss *et al.* 2001). In contrast to the seed found on the surface, buried seed have lower rates of seed predation and higher dormancy and viability due to a decrease in daily soil temperature fluctuations, with greater germination viability with increased burial depth (Weaver and Cavers 1979; Moles *et al.* 2000; Mennan 2003).

*Achillea millefolium* seeds are recorded to be easily incorporated into the soil where a significant proportion, once exhumed by disturbance may germinate to seedlings, based on fresh and buried seed germination percentages (Bostock 1978; Field and Kannangara 1987).

### 10.5.3. Conclusions

The results presented here and those of other field studies on *A. millefolium* show that this species invests considerable resources into the mass production of large number of seeds over an extended season (Bourdôt *et al.* 1979; Henskens *et al.* 1992; Johnston and Pickering 2004). Altitude had no, or limited, effect on allocation of resources in terms of the number of florets per flowering head, number of flowering heads per inflorescence, seed rain, and the viability of stored and buried seed.

Although *A. millefolium* mainly spreads to new sites via seed, rhizomes play an important role in its survival at a site and its capacity spread at that site as consequence of competition with other plants. Therefore the next chapter will examine how *A. millefolium* interacts with the dominant Australian Alps subalpine and alpine graminoid *Poa fawcettiae*. Competition between these two species is explored in a study of intraspecific, interspecific and root/shoot competitive interactions in a set of glasshouse experiments.



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# CHAPTER 11

## COMPETITION BETWEEN

### *ACHILLEA MILLEFOLIUM*

### AND THE NATIVE GRASS *POA FAWCETTIAE*<sup>10</sup>

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#### 11.1. SUMMARY

The effects of intra-specific competition, inter-specific competition, and root and shoot competition on the biomass of *A. millefolium* and *Poa fawcettiae* the dominant native snow grass in alpine and subalpine grasslands of Kosciuszko National Park, were examined in glasshouse experiments. Experiments in the natural grassland communities were not appropriate due to the invasive nature of *A. millefolium*.

Three competition experiments were conducted simultaneously in a glasshouse. The first experiment investigated the potential for intra-specific competition between plants by growing seedlings in single species pots at two densities. The second experiment examined the potential for inter-specific competition in mixed species pots at three densities. In the third experiment plants were grown in pots where either roots or shoots of the two species could compete.

*Achillea millefolium* plants after 12 weeks had four times the biomass of *P. fawcettiae* plants. As a result the two species responded differently to competition. In the *A. millefolium* monocultures the dry weight of roots and shoots per plant declined with increasing density. By contrast, *P. fawcettiae* biomass was not affected by density over the time tested possibly due to the small size of the grass plants. In mixed pots, *P. fawcettiae* had no effect on the biomass of *A. millefolium* plants, while *P. fawcettiae* shoot and root biomass per plant decreased with one or more *A. millefolium* plants. Root rather than shoot competition from *A. millefolium* appeared to be the main source of the decrease in biomass of *P. fawcettiae*.

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<sup>10</sup>Johnston, F.M. and Pickering, C.M. (Under Review) Effect of plant competition and density biomass of *Poa fawcettiae* and *Achillea millefolium*: a comparison between a native grass and herbaceous weed. *Australian Journal of Botany*.

The results indicate that *A. millefolium* may out-compete *P. fawcettiae* plants of the same age. Therefore in areas in Kosciuszko National Park where plants establish from seed it is likely *A. millefolium* may inhibit the growth and establishment of the dominant grass, *P. fawcettiae*. This may already be occurring in areas adjacent to roads after the 2003 bushfires where; (1) nearly all above ground vegetation was lost, (2) there is regeneration from seed, and (3) *A. millefolium* seed is already present in the seed bank.

## 11.2. INTRODUCTION

The competitive ability of *A. millefolium* is of particular concern after the extensive bushfires in the Australian Alps in January-February 2003. These fires burnt over 70% of the subalpine area above 1500 m with very little above ground vegetation found in the first few months post fire (Johnston and Johnston 2003; Growcock *et al.* 2004; Scherrer *et al.* 2004). Since the fires, *A. millefolium* has been found growing along with seedlings of natives such as *Poa* in the regenerating subalpine grasslands (Johnston and Johnston 2003).

Grasses are the dominant group of plants in the herbfield and grassland communities in alpine and subalpine areas (Costin 1954; Costin *et al.* 2000). *Poa* species, principally *P. fawcettiae*, are the most common grasses in these areas with high cover values (Costin *et al.* 2000; Chapters 4 and 5). Seed of *Poa* are found in the seed bank in subalpine areas adjacent to roads, and it is was one of the first species to colonise small gap disturbances in such sites (Chapter 5). Therefore in areas regenerating after disturbance there is likely to be competition between new plants of *A. millefolium* and *P. fawcettiae*.

Experimental competition experiments in the field could have indicated how the two species may be interacting in the Australian Alps. However, they were considered inappropriate by park agencies due to the invasiveness of *A. millefolium*. Therefore competition experiments were conducted under controlled glasshouse conditions on the two species at a range of densities. The limitations of the glasshouse trials are recognised, with factors such as climate, herbivores, pathogens, presence of other plant species, which could effect competition in the field not taken into account.

Therefore the experiments here provide a simplified scenario of interactions between *A. millefolium* and *P. fawcettiae* where the results, with caution, could be extrapolated to indicate how the two species may compete in natural conditions.

Competition has been defined as the negative effects that one organism has upon another by consuming, or controlling access to a resource that is limited in availability (Begon and Mortimer 1986; Keddy 1989). Plants can compete with each other in various ways, both above and below the ground. They may reduce light intensity and quality and compete for nutrients and water (Harper 1994; Tilman 1997; Watkinson 1997).

The potential for competition between the spreading environmental weed *A. millefolium* and the upright slower growing dominant native grass *P. fawcettiae* of the Australian Alps was examined in this study. Based on results for *A. millefolium* overseas in pasture (Bostock and Benton 1979; Warwick and Black 1982; Bourdôt and Field 1988) it was hypothesised that *P. fawcettiae* plants would experience competition due to *A. millefolium* rapid vegetative growth and extensive rhizome and root system. In contrast the smaller/slower growing native snowgrass (Atkin *et al.* 1996) would have little effect on the biomass of *A. millefolium*.

Three experiments were conducted simultaneously in a glasshouse. The first experiment examined the potential for intra-specific competition (plants grown in monocultures at two densities). This established the baseline response of the species to the glasshouse conditions and to density. The second experiment examined the potential for inter-specific competition between *A. millefolium* and *P. fawcettiae* at a range of densities. The third experiment examined the potential effects of above ground inter-specific competition (shoot) and below ground inter-specific competition (root) on the biomass of the two species. The densities of plants were selected to reflect densities that may occur in the field (Mallen-Cooper 1990, unpublished data).

## 11.3. METHODS

### 11.3.1. Experimental design and layout

A variety of methods have been used to examine competition between two species in glasshouse conditions including substitution designs, additive and response surfaces experimental designs (Inouye 2001). In this experiment a modified response surface experimental design was used where the densities of the two species were varied independently. This means that the inferences developed are not limited to any particular densities and therefore are particularly relevant to natural systems where densities of competitors may vary spatially and over time (Inouye 2001). The design of the shoot and root competition experiments were based on those used by Mallen-Cooper (1990) and Willis *et al.* (1998).

*Poa fawcettiae* and *A. millefolium* seed was collected from subalpine grassland communities in Kosciuszko National Park during the summer of 2001. The seed was stored in cool, dry conditions prior to use. It was sown into 5 mm vivo cells and grown until plants were approximately 5 cm in height. The seedlings were then transplanted into 20 cm diameter plastic pots containing a mixture of 10 parts standard potting mix soil to one part sand. The fertiliser Osmocote<sup>®</sup> was added at a rate of 150 g per 40 L of soil. Fungicide (Benomyl (2 g per 40 L soil)) was used to control fungal growth in the pots. The seedlings were randomly allocated a position in the pot and each was planted equidistant from adjacent plants. Plants for all experiments were grown at the same time in climate-controlled glasshouse conditions of 13 °C at night and 25 °C by day and watered daily. At the end of the experiments plants were harvested, separated into above and below ground material, dried at 70 °C for five days, and dry weights were recorded.

The biomass of all above ground structures is referred to as ‘shoot biomass’, and below ground structures (including rhizomes) referred to as ‘root biomass’. Tukeys post hoc tests were used to compare means among treatments. Data were subjected to natural log transformations when necessary to meet the assumptions of the analysis.

#### *Experiment one: intra-specific competition*

The effects of intra-specific competition on biomass were examined for *P. fawcettiae* and *A. millefolium* grown at two densities; (1) low density (one plant per pot) and (2) high density (10 plants per pot). Pots were planted with monocultures for each species with five replicates per treatment (two species at two densities giving four treatments). Plants were harvested after 12 weeks.

#### *Experiment two: inter-specific competition*

For each species the effects of inter-specific competition were determined by comparing the biomass of plants from pots that contained both species growing together. Three levels of density were tested; (1) low (one plant of each species per pot), (2) medium (one *P. fawcettiae* with five *A. millefolium* plants per pot, and conversely one *A. millefolium* with five *P. fawcettiae* per pot), and (3) high (one *P. fawcettiae* with 10 *A. millefolium* plants per pot and conversely one *A. millefolium* with *P. fawcettiae* plants in a pot) (Figure 11.1). There were 10 replicates for each treatment, and plants were harvested after 12 weeks. Replicates of all treatments were grown in the same glasshouse with treatments randomly allocated to positions on a single bench.

#### *Experiment three: root and shoot competition*

The potential effects of inter-specific competition from above and below ground structures on biomass of each species were examined by separating out root and shoot competition treatments. This experimental method has been used previously to examine competition between natives and weeds (Willis *et al.* 1998). Four treatments were established. (1) Monoculture control. For each species, pots were planted at a density of six plants per pot (10 replicates for each species). (2) Potential root competition only. Ten replicate pots were planted with six plants per pot (three *P. fawcettiae* and three *A. millefolium*). To limit the competitive effects of above ground plant parts shoots and leaves on each plant were kept separate using clear plastic tubes. (3) Potential shoot competition only. Ten replicates were established, each consisting of a pair of pots. One pot contained three *P. fawcettiae* plants and the other contained three *A. millefolium* plants. Pairs of pots were placed close together

so that shoots from one pot became intertwined with shoots from the other pot. This prevented any potential competition between roots, but allowed any shoot competition. (4) Potential root and shoot competition combined. Ten replicate pots were planted, each with three *P. fawcettiae* plants and three *A. millefolium* plants. Replicates of treatments were randomly assigned a position within the glasshouse and grown for 14 weeks prior to harvesting.

### **11.3.2. Statistical analysis**

#### *Experiment one: intra-specific competition*

To determine the effects of intra-specific competition, a series of Two-way ANOVAs in SPSS 10.1 were performed (Coakes and Steed 2000). Species and density (one plant per pot, and 10 plants per pot) were the independent variables with the total biomass (root + shoot biomass), root biomass, shoot biomass, and proportion of biomass allocated to roots (root biomass/total biomass) as the dependent variables.

#### *Experiment two: inter-specific competition*

To determine the effects of inter-specific competition on biomass of each species a series of One-way ANOVAs were run in SPSS 10.1 (Coakes and Steed 2000). The independent variables were intra- and inter specific density. The intra-specific competition treatments were included to act as controls for the inter-specific competition treatments. The dependent variables were as in Experiment one. Biomass was measured as the average biomass of plants per pot. For some of the biomass measurements a few outlier values exerted large leverage on the original ANOVA. They were removed and the analysis repeated.

#### *Experiment three: root and shoot competition*

To separate the effects of potential below ground competition from above ground competition on biomass of each species a series of One-way ANOVAs was conducted with 'competition treatment' (monoculture control; root competition; shoot competition; and whole plant competition) as the independent variable. The

dependent variables were as in Experiment one. There were two measures; (1) the average dry weight of a plant per pot and (2) the total dry weight of all plants per pot.

## 11.4. RESULTS

### 11.4.1. Experiment one: intra-specific competition

There was a significant difference in the response of the two species to density in the monocultures (Table 11.1). Density affected total, shoot and root measures of biomass for *A. millefolium* but not *P. fawcettiae* plants (Figure 11.2). Increasing the density from one *A. millefolium* plant per pot (density equivalent = 32 plants/m<sup>2</sup>) to 10 plants (320 plants/m<sup>2</sup>) caused a two and a half-fold decrease in both total biomass and root biomass (Figure 11.2a,b) and a three and a half-fold decrease in shoot biomass (Figure 11.2c). The greater effect of density on shoots compared to roots for *A. millefolium*, resulted in an apparent higher proportional allocation of biomass to roots for pots with 10 plants compared to pots with one plant (Figure 11.2d). There was no significant effect of density on any biomass measure for *P. fawcettiae* (Figure 11.2; Tukeys post hoc tests for pair wise comparisons were all non-significant).

Table 11.1. Experiment one: results of Two way ANOVAs comparing the biomass of low density (one plant per pot), and high density (10 plants per pot) monocultures of the exotic *A. millefolium* and the native grass *P. fawcettiae*. n = 5. P values in bold denote statistically significant differences at the  $\alpha=0.0125$  level (Bonferroni correction for multiple tests to significance level of 0.05).

	Species		Density		Interaction	
	F	P	F	P	F	P
Total dry weight <sup>a</sup>	94.741	<b>0.000</b>	228.268	<b>0.000</b>	10.678	<b>0.005</b>
Dry weight of shoots <sup>a</sup>	29.062	<b>0.000</b>	190.874	<b>0.000</b>	19.158	<b>0.000</b>
Dry weight of roots <sup>a</sup>	131.802	<b>0.000</b>	196.959	<b>0.000</b>	6.159	0.025
% allocation to roots	108.432	<b>0.000</b>	4.862	0.042	4.450	0.051

<sup>a</sup> Analysis performed on natural log transformed data.

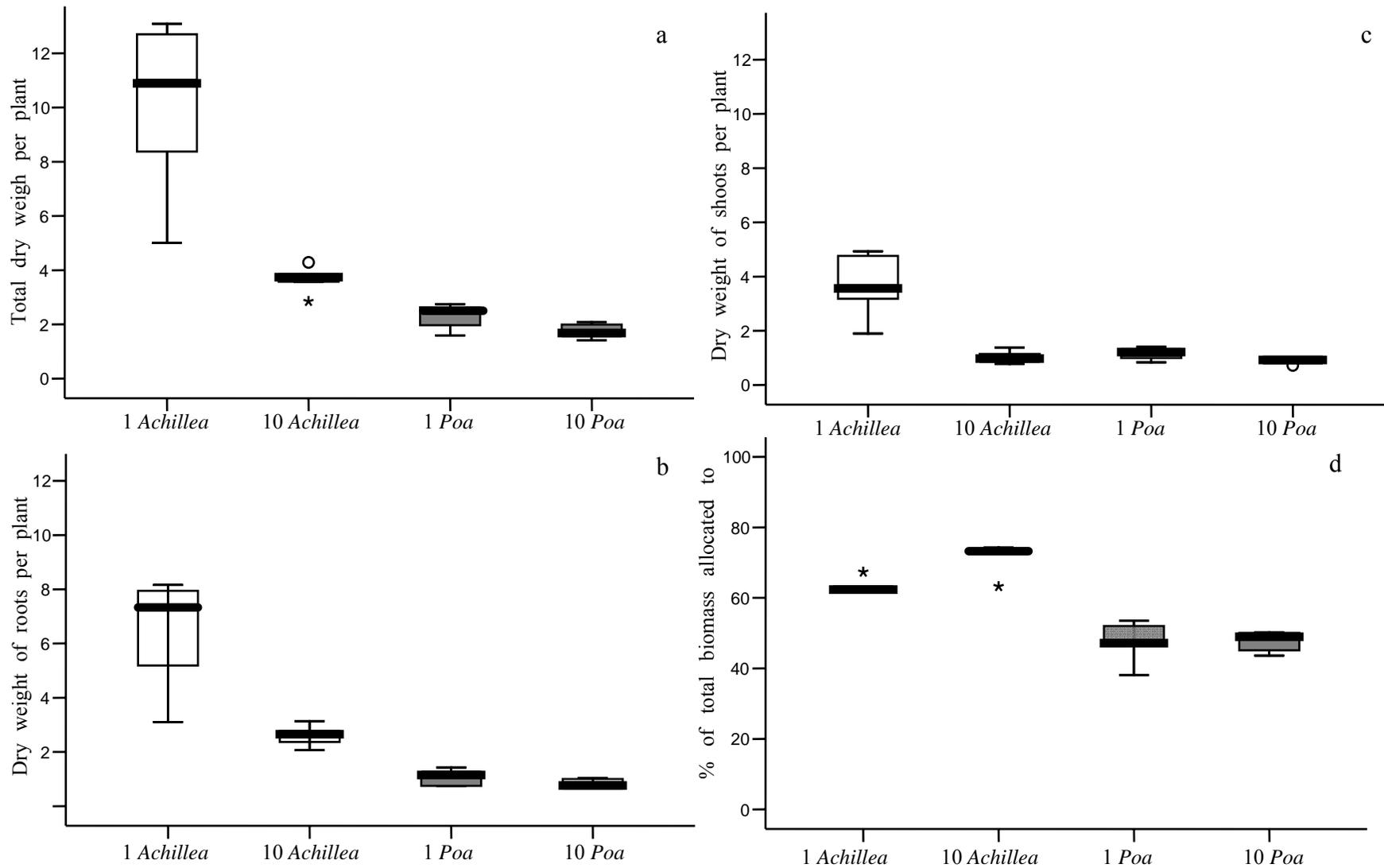


Figure 11.1. Experiment one. Box plots showing median, interquartile range, outliers and extreme values in biomass (g) of *A. millefolium* (clear boxes) and *P. fawcettiae* (grey boxes) in single species pots at different densities. a = total biomass, b = root biomass, c = shoot biomass and d = proportion of biomass allocated to roots.

### 11.4.2. Experiment two: inter-specific competition

#### *Per plant response of P. fawcettiae to A. millefolium*

Inter-specific competition had a significant effect on total and shoot biomass for *P. fawcettiae* (Table 11.2, Figure 11.3). The presence of any *A. millefolium* plants reduced the total biomass of *P. fawcettiae* in mixed pots compared with the low-density control (single *P. fawcettiae* plants in monoculture) (Figures 11. 2 and 3). Even one *A. millefolium* plant per pot reduced the total biomass of *P. fawcettiae* compared to the *P. fawcettiae* monoculture (Figures 11.2 and 11.3). Biomass of *P. fawcettiae* was reduced by a similar amount by low, medium and high densities of *A. millefolium* (Figure 11.3a).

Table 11.2. Experiment two: inter-specific competition results from One-way ANOVAs comparing the effect of different densities of the exotic *A. millefolium* and the native grass *P. fawcettiae* when grown in monoculture (control) and together. P values in bold denote statistically significant differences at the  $\alpha=0.0125$  level (Bonferroni correction for multiple tests to significance level of 0.05).

	Per <i>A. millefolium</i> plant		Per <i>P. fawcettiae</i> plant		Per pot (all plants combined)	
	F	P	F	P	F	P
Total dry weight	23.109	<b>0.000</b>	5.367	<b>0.000</b>	96.468	<b>0.000</b>
Dry weight of shoots	13.095	<b>0.000</b>	8.537	<b>0.000</b>	51.171	<b>0.000</b>
Dry weight of roots	20.672	<b>0.000</b>	2.487	0.035	106.115	<b>0.000</b>
% allocation to roots	0.748	0.606	1.222	0.310		

The only treatment in which the presence of *A. millefolium* did not affect *P. fawcettiae* biomass was when there were 10 *P. fawcettiae* plants per pot and just one *A. millefolium*. Under this condition there was no difference in total or shoot biomass compared to high density controls (10 *P. fawcettiae* plants in monoculture) (Figure 11.3 a,b,c,d, Tukeys post hoc tests were non-significant).

The magnitude of the response to *A. millefolium* was different for the shoots and roots of *P. fawcettiae*. Only when *A. millefolium* was in high density (10 *A. millefolium* plants in a pot with one *P. fawcettiae*) was there a trend for a decrease in the root biomass of *P. fawcettiae* compared to the low-density monoculture control (Figures 11.2b and 11.3b). The response was different for shoot biomass. Any *A. millefolium* in a pot reduced the shoot biomass of *P. fawcettiae* compared to the low-density monoculture control (Figures 11.2c and 11.3c). The difference in shoot and root responses, however, did not result in a significant effect on the proportion of

biomass allocated to roots due to the large variation among plants (Table 11.2, Figure 11.3).

*Per plant response of A. millefolium to P. fawcettiae*

The biomass of *A. millefolium* plants was not affected by density of *P. fawcettiae* (Table 11.2). Low, medium or high density of *P. fawcettiae* did not affect any measure of biomass of *A. millefolium* compared with the control (*A. millefolium* grown in a low-density monoculture) (Figures 11.2 and 11.3).

There was a significant decline in total and root biomass per plant with increasing density of *A. millefolium* irrespective of the number of *P. fawcettiae* plants in the pot (Figure 11.3a,b). For shoot biomass there was no significant difference between pots with 10 and five *A. millefolium* plants, but there was a difference between pots with one and five *A. millefolium* plants (Figure 11.3c). The relative allocation to roots did not change in *A. millefolium* as a result of intra- or inter-specific competition (Figures 11.2d and 3d).

**11.4.3. Experiment three: root and shoot competition**

*Poa fawcettiae* and *A. millefolium* responded differently to inter-specific root and shoot competition treatments (Table 3). *Poa fawcettiae* was affected by root but not by shoot competition treatments from *A. millefolium*, while *A. millefolium* was not affected by any of the mixed pot competition treatments (Figure 11. 4).

Table 11.3. Experiment three: root and shoot competition results from One-way ANOVAs comparing the effect of different densities of *A. millefolium* and the native grass *P. fawcettiae* when grown in root and shoot competition exclusion treatments. P values in bold denote statistically significant differences at the  $\alpha=0.0125$  level (Bonferroni correction for multiple comparisons to significance level of 0.05).

	Per <i>A. millefolium</i> plant		Per <i>P. fawcettiae</i> plant	
	F	P	F	P
Total dry weight	8.465	<b>0.000</b>	27.742	<b>0.000</b>
Dry weight of shoots	4.255	<b>0.011</b>	29.083	<b>0.000</b>
Dry weight of roots	8.272	<b>0.000</b>	5.548	0.030
% allocation to roots	1.718	0.181	5.560	0.030

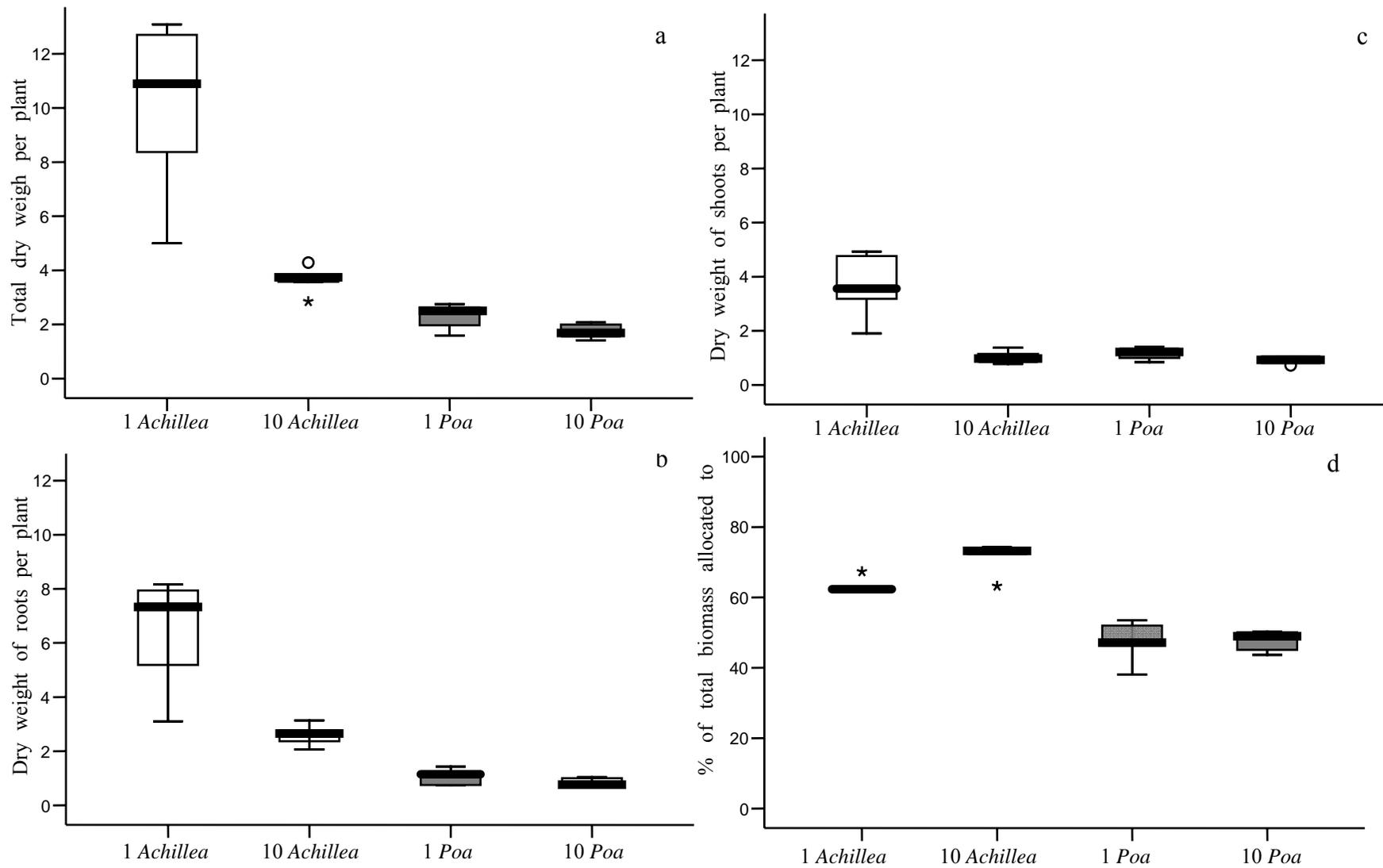


Figure 11.2. Experiment two. Box plots showing median, interquartile range, outliers and extreme values in biomass (g) of *A. millefolium* (clear boxes) and *P. fawcettiae* (grey boxes) in mixed pots at different densities. a = total biomass, b = root biomass, c = shoot biomass and d = proportion of biomass allocated to roots.

#### *Response of P. fawcettiae to A. millefolium root and shoot competition treatments*

There were significant effects of the root but not shoot competition treatments on the biomass of *P. fawcettiae* plants (Figure 11.4). The total biomass and shoot biomass per plant were lower for *P. fawcettiae* plants in the root competition treatment than when grown in a monoculture control (six plants per pot) (Figure 11.4a,b,c). Correspondingly, total and shoot biomass was lower for *P. fawcettiae* in the root competition treatment than in the shoot competition treatment (Figure 11.4a,b,c). This was because the shoot competition treatment had no effect on any measure of biomass (Figure 11.4).

#### *Response of A. millefolium to P. fawcettiae root and shoot competition treatments*

*Achillea millefolium* had similar total, root and shoot biomass irrespective of whether it was subjected to root, shoot or whole plant competition treatments from *P. fawcettiae* (Table 11.3, Figure 11.4). Biomass (total, shoot and root) declined however, when there were six *A. millefolium* plants in a pot, reflecting the effect of intra-specific competition among *A. millefolium* plants, rather than root or shoot competition from *P. fawcettiae*.

## **11.5. DISCUSSION**

### **11.5.1. Intra-specific competition**

The exotic *A. millefolium* and the native snowgrass *P. fawcettiae* responded differently to the intra-specific and inter-specific density experiments. Because of the small size of the *P. fawcettiae* plants increasing the density tenfold in a pot had no significant effect on the biomass per plant. In contrast intra-specific competition decreased dry weight of root, shoot and total biomass for *A. millefolium* with ten-fold changes in density leading to a 3.5-, 2.4- and 2.75-fold decrease in shoot, root, and total biomass weights respectively for individual plants.

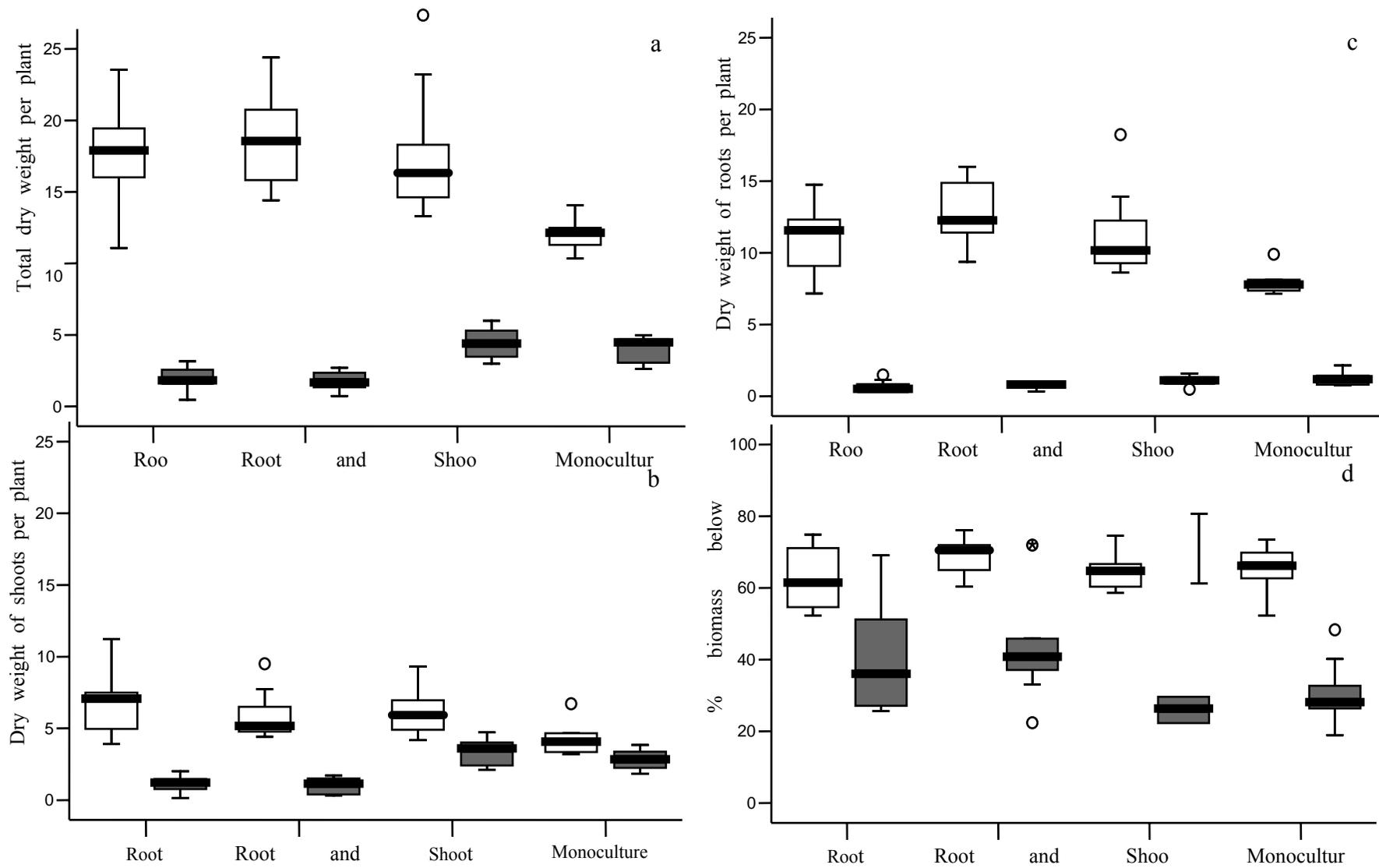


Figure 11.3. Experiment three. Box plots showing median, interquartile range, outliers and extreme values in biomass (g) of *A. millefolium* (clear boxes) and *P. fawcettiae* (grey boxes) in mixed pots at different densities. a = total biomass, b = root biomass, c = shoot biomass and d = proportion of biomass allocated to roots.

The effect of intra-specific competition on the biomass and mortality of *A. millefolium* under a range of densities (21, 96, 192, 288, 576 and 868 plants/m<sup>2</sup>) has been examined in another glasshouse experiment (Deschenes 1974). Intra-specific competition was observed through a reduction in biomass at low to medium density and through biomass reduction and mortality at high density, with seedlings unable to compete with established plants. In the glasshouse study in this thesis there was a 4.0-, 2.9- and 3.6- fold increase per pot in root, shoot and total biomass respectively between 32 plants/m<sup>2</sup> (one plant per pot) and 320 plants/m<sup>2</sup> (10 plants per pot) densities, and no plant mortality during the experiment.

For the smaller native grass, *P. fawcettiae*, there was no intra-specific competition over the time and densities sampled. This is likely to be due to differences in the form and growth rate of *P. fawcettiae* compared to that of *A. millefolium*. The growth of *A. millefolium* was rapid compared to that of *P. fawcettiae*, with the low growing *A. millefolium* rosettes and roots filling the pot after 12 weeks. *Poa fawcettiae*, with its upright tufted growth, did not become crowded after 12 weeks, with an average of 17.54 g of biomass of plants per pot. If the experiment had continued, or the *P. fawcettiae* plants had been at a higher density per pot, then intra-specific competition may also have occurred in *P. fawcettiae*.

The faster growth and larger final size of the weed *A. millefolium* compared to the native grass is consistent with results of a previous study of competitive interactions between exotic species and Australian high altitude native plants (Mallen-Cooper 1990). In that glasshouse study all the introduced species (*Agrostis capillaris*, *Dactylis glomerata*, *Poa pratensis*, *Rumex crispus*, *Hypochaeris radicata* and *Achillea millefolium*) had more rapid growth producing more shoot and root biomass over a 12-week period than any of the native species (*Poa costiniana*, *Poa fawcettiae*, *Craspedia* sp., *Celmisia* sp. and *Acaena* sp.).

### **11.5.2. Inter-specific competition**

Natural plant communities are usually mixtures of species with inter-specific competition a major ecological force (Begon and Mortimer 1986). The results of the current study indicate an asymmetric competitive relationship, with no effect of *P. fawcettiae* plants on *A. millefolium*, but a competitive effect of *A. millefolium* plants

on *P. fawcettiae*. Changes in the density of *P. fawcettiae* from one, five or 10 plants per pot had no effect on the root or total biomass growth of *A. millefolium*. Similarly, *P. fawcettiae* had no effect on the shoot growth of *A. millefolium* at one and five plants per pot. The growth of *P. fawcettiae* plants was negatively affected by a single *A. millefolium* plant in the pot, with some reductions in root biomass but even greater reductions in shoot biomass with increasing numbers of *A. millefolium* plants.

### **11.5.3. Root versus shoot competition**

Root and shoot allocation patterns differ among plant species (Zobel and Zobel 2002). As predicted in the current study, *P. fawcettiae* was adversely affected by root competition from *A. millefolium* but did not appear to be affected by shoot competition. *Achillea millefolium* suppressed the growth of *P. fawcettiae* when their roots were in the same pot, but the shoots had no effect on the growth of *P. fawcettiae* plants. This may be due to the growth form of the *A. millefolium* leaves, which, in spite of their larger biomass, did not overtop the more upright tufted native grass during the experiment.

In other glasshouse studies comparing the impact of root competition with shoot competition the response of each species depended on the mechanism of the competition, the limiting resources and the biological attributes of individual species (Donald 1958; Aspinall 1960; Harper and references therein 1994; Willis 1994). The impact of *A. millefolium* on *P. fawcettiae* in my study appears to be primarily due to below ground competition. The exotic produced more above and below ground material in the allocated experimental time. When the *A. millefolium* was removed from the pot the rhizome/root mass filled the pot and the above ground vegetative growth flowed over the edges of the pot. The vegetative reproductive effort of *A. millefolium* in container grown plants has been found to be very high in comparison with other perennial species (Henkens *et al.* 1992). The extensive rhizome system of *A. millefolium* is thought to be the major source of *A. millefolium*'s competitive ability in agricultural fields (Bourdôt *et al.* 1979).

The results from this glasshouse study indicate that if *A. millefolium* and *P. fawcettiae* germinated together in cleared areas the weed could out-compete the dominant native species in alpine and subalpine grasslands, when *Poa* is in low

densities. However, the results do not necessarily indicate what happens when *A. millefolium* germinants within an existing stand of *P. fawcettiae* or in a dense stand of *P. fawcettiae* seedlings or when *A. millefolium* competes with other native or exotic species that may have different growth rates and or morphologies to *P. fawcettiae*.

For example, the competitive interaction of weeds and natives found in the Kosciuszko National Park appears to vary among species combinations. Glasshouse experiments comparing the performance of *A. millefolium*, other exotics (*Hypochoeris radicata*, *Rumex crispus*, *Verbascum virgatum*), and two native forbs (*Celmisia* sp. and *Craspedia* sp.) from the Kosciuszko National Park indicated that although *A. millefolium* performed well in monoculture compared to the natives and other exotics, it did not dominate in mixed pots potentially due to competition from other exotics (Mallen-Cooper 1990).

In the field the effects of competition between *A. millefolium*, other exotic and natives is likely to depend on the species combinations, their relative density, specific environmental conditions such as shading and any management practices including the use of herbicides by park agencies. However the results presented here and those observed in the field (Chapters 4, 5, 9 10) indicate a capacity for *A. millefolium* to compete with native plants and to be a persistent exotic in both the rhizome bud and seed banks.

#### **11.5.4. Conclusions**

The results of this chapter show that in glasshouse conditions *A. millefolium* is able to out-compete the native grass *P. fawcettiae*, due to root competition. The interaction of these two species in the field may, of course, differ from the interactions in the glasshouse. However the glasshouse results do indicate that *A. millefolium* has the potential to out-compete the dominant native grass when both species germinate together in cleared areas in the absence of other potential competitors. This is an important consideration in areas of the Australian Alps subject to human disturbance and after the 2003 bushfires.

This section of the thesis has extended the ecology of *A. millefolium* in the Australian Alps. Results indicate that there are few climatic constraints to the establishment, flowering, and growth of *A. millefolium*. It would appear however that the prerequisite of disturbance and changes to soil properties may be necessary for its widespread introduction and establishment (Johnston and Johnston 2003; Johnston and Johnston 2004, Chapters 4 and 5).

The following part of this thesis, Section C, presents a life stage transition model using data collected in the field and in the glasshouse experiments (Chapters 7 to 11), together with data from the literature (Chapter 6). The thesis concludes with a comprehensive discussion including examining the diversity and distribution of exotics in the Australian Alps, and the ecology and management of the case study species, *A. millefolium*.



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## CHAPTER 12

# MODELLING POPULATION DYNAMICS OF *ACHILLEA MILLEFOLIUM* AND CONTROL STRATEGIES

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### 12.1. SUMMARY

The population dynamics of *A. millefolium* were modelled using a transition matrix model. This model collated information on the biology and ecology of *A. millefolium* into a discrete representation of this species' lifecycle which was used to explore the consequences of different management strategies. The life stages examined included seed (seed rain, seed bank, seed loss), seedling (emergence and survival), flowering adult (seed production), and vegetative adult plants. The data obtained from the literature and from this thesis were used to estimate baseline population parameters and life stage transition rates in Kosciuszko National Park which were then manipulated to simulate possible control strategies targeting specific life stages.

The results from the modelling indicate that without adequate control current populations of *A. millefolium* could, theoretically, increase exponentially with each generation, resulting in large numbers of seed and vegetative propagules. To contain or eradicate *A. millefolium* the most effective management strategy would require both the control of seed production (removing at least 999/1000th of all seed produced) and removal of the underground rhizome system. It is recommended that control be based on a landscape scale to incorporate as many sites of *A. millefolium* as feasible in the Australian Alps.

### 12.2. INTRODUCTION

Theoretical (qualitative models) and their parameterised versions (quantitative models) can be used to explain and represent plant population dynamics (Sharov 1996). Examples of theoretical models include exponential and logistic models with or without density dependence, regression models based on linear or polynomial relationships between the predicted value and other factors, and qualitative (non-

parametric) models which use no parameters but a set of conditions that equations should satisfy. Models which make a quantitative prediction are based on parameterised variables (Sharov 1996). Quantitative models can be used to investigate the effects of environment, time and intrinsic plant traits on growth, survival, probability of flowering, fruit production and vegetative reproduction (Buckley *et al.* 2002a). Examples of these quantitative models include phenological models, life history models based on the population change driven by different interrelating ecological processes, and object oriented programming models (Sharov 1996). Models can be static (i.e. single season or year), dynamic (i.e. multiple seasons or years), deterministic (i.e. no uncertainty) or stochastic (i.e. includes uncertainty). With increasing complexity the model may include more than one of these descriptions and can be simplistic or highly complex depending on the requirements of the modeller.

A life history model for an invasive plant can be used as a representation of the life cycle to organise, characterise and simplify information about the weed and the threatened ecosystem. Modelling the ecology and population dynamics of the weed can also provide an important tool for exploring the consequences of different management strategies such as the targeting of certain life stages of the weed to maximise the effect of any control method (Buckley *et al.* 2002 a,b). Two primary types of quantitative population models used to evaluate control strategies are sensitivity analysis which identify the life-history stages with the greatest impact on population growth rates, based on difference equations and matrix models and direct evaluation models of management impacts on target population dynamics (Buckley *et al.* 2002b).

To investigate the population dynamics of *A. millefolium* an established quantitative transition matrix model was used (Maxwell, B. (instructor) Montana State University Lab 3 Life history models LRES 543 Agroecology (<http://weedeco.msu.montana.edu/>)). The mathematical model was generated from the diagrammatic model of a perennial weed with both sexual and vegetative reproduction, as a series of equations representing the life history processes in the

model. The equations are solved in sequence to simulate natural population dynamics and the model parameterised for *A. millefolium*.

### 12.3. METHODS

The original transition matrix model for an established perennial weed (Figure 12.1) was parameterised for *A. millefolium* based on the research in this thesis and information from the literature and incorporates both density dependence and demographic stochasticity.

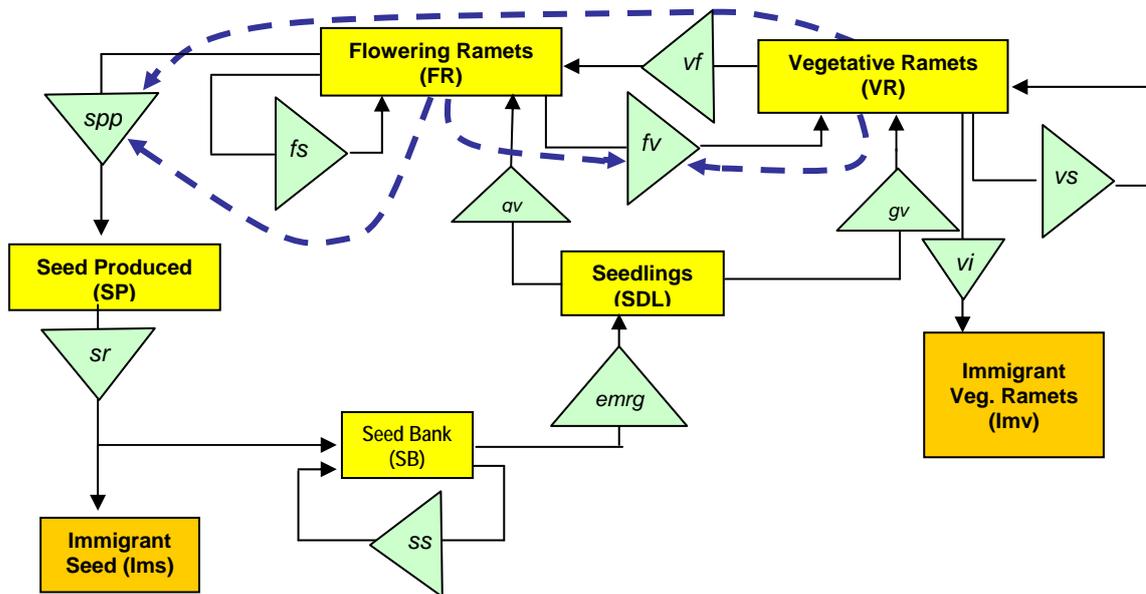


Figure 12.1. Proposed life history model of the perennial weed *A. millefolium* based on an established perennial weed model. Solid boxes represent the life stages and triangle arrows represent the transitions between these life stages. (Adapted from Maxwell, B. (instructor) Montana State University Lab 3 Life history models LRES 543 Agroecology <http://weedeco.msu.montana.edu/> Last update 15<sup>th</sup> January 2004).

**Model life cycle stage rates:** SP – seed produced per 1 m<sup>2</sup>; FR – number of flowering rosettes per 1 m<sup>2</sup>; SB – seed bank in the soil; SDL – number of seedlings per 1 m<sup>2</sup>; VR – number of vegetative rosettes per 1 m<sup>2</sup>; BB – rhizome bud bank per 1 m<sup>2</sup>.

**Model transition rates:** sl – seed loss; ss – seed remaining in seed bank; spp – number of seed produced from flowering rosettes per 1 m<sup>2</sup>; fs – proportion of times in one season that a flowering rosette flowers per 1 m<sup>2</sup> area per season; vf – proportion of the vegetative rosettes that form flowering rosettes per 1 m<sup>2</sup> area per season; fv – proportion of flowering rosettes that ‘revert’ to vegetative rosettes per 1 m<sup>2</sup> area per season; sr – seed rain per 1 m<sup>2</sup> area per season; emrg – proportion of seed which germinate each season (spring through to autumn) to form seedlings per 1 m<sup>2</sup> area per season; gv – proportion of seedlings which survive to become mature vegetative rosettes per 1 m<sup>2</sup> area per season; vs – proportion of vegetative rosettes that remain vegetative rosettes per 1 m<sup>2</sup> area per season; bs – proportion of dormant buds to total buds remaining in the bud bank per 1 m<sup>2</sup> area per season; bv – proportion of active buds to total buds which leave the bud bank to become rosettes per 1 m<sup>2</sup> area per season; bb – proportion of rhizome per 1 m<sup>2</sup> area per season; gf – proportion of seedlings which form flowering plants.

### 12.3.1. Determining the model input parameters for *A. millefolium*

The transition matrix model life stage default values are a seed bank (SB) of 50 seeds/m<sup>2</sup>, seedling density (SDL) of 18 seedlings/m<sup>2</sup>, flowering plants (FR) as 3/m<sup>2</sup> and the seed produced (SP) as 300 seeds/m<sup>2</sup> (Maxwell, B. (instructor) Montana State University Lab 3 Life history models LRES 543 Agroecology <http://weedeco.msu.montana.edu/>. Last update 15<sup>th</sup> January 2004). These initial default values were retained for the *A. millefolium* model as they were generic values for vegetative perennial plants, there were no available *A. millefolium* specific default values, and there was a reasonable expectation that actual *A. millefolium* values would fall within those specifications given for these population model parameters. Transition matrix model life stages and transition rates are displayed in Figure 12.1

Values for other life history stages and transition rates of *A. millefolium* were estimated based on the research in this thesis and information from the literature. The seed survival (ss) rate is defined as the seeds that do not germinate but remain in the soil from one generation to the next. The value of 0.55 (55%) was used for the model based on estimations from the seed burial experiment (Chapter 10) where this was the percentage of seed remaining in the buried sample bags after three years.

The seed that falls to the ground is seed rain (sr) and a value of 0.39 (39%) was estimated from seed rain results (Chapter 10) and the default value in the matrix transition model for perennial plants.

Seed loss (sl) is the loss of seed due to biotic and abiotic causes. This was estimated at 0.7<sup>11</sup> (70%) based on Bostock (1978) who found that 50% of ovules fail to develop to produce seed and the results in Chapter 10, this thesis where 40% of the seed was ‘lost’ in burial experiments.

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<sup>11</sup> Starting with 100 seeds, a 50% loss results in 50 seeds remaining of the initial 100 seeds. Of the remaining seed 40% are lost during seed burial equating to 30 seeds of the initial 100 seeds remaining – a total loss of 70%.

The value estimated for the seed survival in the soil (ss) was 0.6 (60%) from results in Chapter 10.

The parameter for emergence rate (emrg) is the proportion of seed that become new seedlings and was estimated at 0.43 (43%). This figure was derived from seed ecology studies in Chapter 6 reviewing the biology and ecology of *A. millefolium* from published literature and Chapter 11 reporting on the seed ecology of *A. millefolium* in Kosciuszko National Park.

The survival transition from seedlings to flowering plants (gf) was based on the succession data and phenology data (Chapter 5 and 8) and estimated at 0.1 (10%).

The proportion of seedlings which survive to become mature vegetative rosettes (gv) was estimated at 0.45 (45%) (Bourdôt and Hurrell 1984; Author obs.).

The mean seed produced per plant (spp) was estimated at 14000 based on phenology, resource allocation and seed data from this thesis and other literature sources (Bostock 1978; Kannangara and Field 1985; Johnston, unpublished data; Chapters 8, 9 and 10).

The number of times in one season that a rosette flowers (fs) in a season was estimated as one. The proportion of rosettes that 'revert' to vegetative rosettes (fv) was 0, based on samples of *A. millefolium* collected in subalpine sites (Author obs.).

The proportion of the vegetative rosettes that form flowering rosettes (vf) was 0.2 (20%) and the proportion of vegetative rosettes that remain vegetative rosettes (vs) was estimated at 0.8 (80%) (Author unpublished data). The values for vf and vs were estimated from 10 randomly selected samples (areas 30 m by 30 m by 10 cm depth) of *A. millefolium* collected from subalpine sites in Kosciuszko National Park during February 2002. The majority of the vegetative and flowering rosettes appeared to be part of a single genet interconnected by a rhizomatous mat.

These estimated values for *A. millefolium* life stages and transition rates were used to establish a baseline population. Each run of the model program was equivalent to one plant generation. The equations used to simulate the population dynamics of *A. millefolium* population growth are detailed in Table 12.1.

Table 12.1. Equations used in the matrix transition model to calculate the values of seed bank (SB), seedling (SDL), vegetative rosette (VR), flowering rosette (FR) and seed produced (SP) given the starting default values and estimated life stage transition rates. The equations are illustrated at time = 3.

<b>Equations used in the matrix transition model</b>
<b>1. Population density with time (<sup>1</sup> value is the mean value of the parameter)</b>
$SB_{t=3} = (SB_{t=2} - SDL_{t=2}) + (SP_{t=2} * sr^1) * ss^1$
$SDL_{t=3} = SB_{t=3} * emrg^1$
$VR_{t=3} = SDL_{t=2} * gv^1 + FR_{t=2} * fv^1 + VR_{t=2} * vs^1$
$FR_{t=3} = SDL_{t=3} * gf^1 + VR_{t=3} * vf^1 + FR_{t=2} * fs^1$
$SP_{t=3} = FR_{t=3} * spp^1$
<b>2. Population density over time with stochasticity (<sup>#</sup> value is the random number generated by the model for stochasticity)</b>
$SB_{t=3} = ((SB_{t=2} * sr^{\#}) + SB_{t=2} - SDL_{t=2}) * ss^{\#}$
$SDL_{t=3} = SB_{t=3} * emrg^{\#}$
$VR_{t=3} = SDL_{t=2} * gv^{\#} + FR_{t=2} * fv^{\#} + VR_{t=2} * vs^{\#}$
$FR_{t=3} = SDL_{t=3} * gf^{\#} + VR_{t=3} * vf^{\#} + FR_{t=2} * fs^{\#}$
$SP_{t=3} = FR_{t=3} * spp^{\#}$
<b>3. Density dependence model</b>
$SB_{t=3} = ((SB_{t=2} - SDL_{t=2}) + (SP_{t=2} * sr^1)) * ss^1$
$SDL_{t=3} = SB_{t=3} * emrg^1$
$VR_{t=3} = (SDL_{t=2} * gv^1 + FR_{t=2} * fvmax^1 * (1 - (c * (VR_{t=2} + FR_{t=2})) / (1 + c * (VR_{t=2} + FR_{t=2}) / d)) + VR_{t=2} * vs^1)$
$FR_{t=3} = SDL_{t=3} * gf^1 + VR_{t=3} * vf^1 + FR_{t=2} * fs^1$
$SP_{t=3} = FR_{t=3} * sppmax^1 * (1 - b * (VR_{t=3} + FR_{t=3})) / (1 + b * (VR_{t=3} + FR_{t=3}) / a)$
<b>4. Total ramet density versus fv: densities values in increments of 4 eg 0, 4, 8, 12</b>
$fv = (fvmax^1 * (1 - c * density\ value) / (1 + c * density\ value / d))$
<b>5. Total ramet density versus spp: densities values in increments of 4 eg 0, 4, 8, 12</b>
$spp = sppmax^1 * (1 - b * density\ value) / (1 + b * density\ value / a)$
<b>6. Density dependence with stochasticity</b>
$SB_{t=3} = SP_{t=2} * sr^{\#} + (SB_{t=2} - SDL_{t=2}) * ss^{\#}$
$SDL_{t=3} = SB_{t=3} * emrg^{\#}$
$VR_{t=3} = SDL_{t=3} * gv^{\#} + FR_{t=2} * (fvmax^{\#} * (VR_{t=2} + FR_{t=2})) / (1 + c^{\#} * (VR_{t=2} + FR_{t=2}) / d^{\#} + VR_{t=2} * vs^{\#} - (vi^{\#} * VR_{t=2}))$
$FR_{t=3} = SDL_{t=3} * gf^{\#} + VR_{t=3} + FR_{t=3} * fs^{\#}$

With the establishment of the baseline model, parameter values and transition rates were manipulated to reflect 12 possible management strategies on *A. millefolium* populations. The change to the parameter occurs once only at the beginning of the model run i.e. a single event (Table 12.2).

Table 12.2. Input parameters for the matrix transition model. The baseline population is Model 1. Models 2 to 12 represent possible management scenarios. The model descriptive in the table is an explanation of the possible management requirement or outcome. Bold figures are those manipulated from the baseline model.

Parameters	ss	emrg	gv	gf	vs	vf	spp	sr
<b>Model descriptive</b>								
1. Full flowering and rhizome growth and production – ‘stable population’	0.55	0.43	0.45	0.1	0.8	0.2	14000	0.39
2. 75% reduction in seed production with no change to seed rain or rhizome production	0.55	0.43	0.45	0.1	0.8	0.2	<b>3500</b>	0.39
3. 100% control of seed production and seed rain; rhizomes parameters as for baseline	0.55	0.43	0.45	0.1	0.8	0.2	<b>0</b>	<b>0</b>
4. 50% reduction in seed production with no change to seed rain or rhizome production	0.55	0.43	0.45	0.1	0.8	0.2	<b>7000</b>	0.39
5. 50% reduction in rhizome production with no changes to seed production	0.55	0.43	<b>0.225</b>	<b>0.05</b>	0.8	0.2	14000	0.39
6. 100% control of new rhizome production but existing rhizome remain intact from initial stable population. Seed production reduced to 1/1000 <sup>th</sup> with seed rain as for baseline	0.55	0.43	<b>0</b>	<b>0</b>	0.8	0.2	<b>14</b>	0.39
7. 100% control of new rhizomes but existing rhizomes remain intact from initial stable population. No changes to flowering (seed production and seed rain variables)	0.55	0.43	<b>0</b>	<b>0</b>	0.8	0.2	<b>14000</b>	0.39
8. 100% control of emerging seedlings with seed production and rhizome variables remain the same	0.55	<b>0</b>	0.45	0.1	0.8	0.2	14000	0.39
9. 100% control of emerging seedlings with seed production reduced to 1/1000 <sup>th</sup> . Rhizome variable remain the same as baseline	0.55	<b>0</b>	0.45	0.1	0.8	0.2	<b>14</b>	0.39
10. 100% control removal of rhizome system – both existing and potential with 100% of seed production	0.55	<b>0.43</b>	<b>0</b>	<b>0</b>	<b>0</b>	<b>0</b>	<b>0</b>	0.39
11. 100% control and removal of rhizome system. Seed production reduced to 1/1000 <sup>th</sup> of baseline. 100% control of emerging seedlings	0.55	<b>0</b>	<b>0</b>	<b>0</b>	0.8	0.2	<b>14</b>	0.39
12. 100% removal and control of seed production, seed rain and rhizome system. 100% control of emerging seedlings from seed bank.	0.55	<b>0</b>	<b>0</b>	<b>0</b>	<b>0</b>	<b>0</b>	<b>0</b>	<b>0</b>

Legend of table symbols: ss = seed survival rate is the proportion seeds that do not germinate and remain in the soil from one generation to the next, emrg = emergence rate is the proportion of seed that become new seedlings, vf= the proportion of the vegetative rosettes that form flowering rosettes, vs = the proportion of vegetative rosettes that remain vegetative, spp is the mean seed produced per plant, gv is the proportion of seedlings which survive to become mature vegetative rosettes, gf = the survival transition from seedlings to flowering plants; and sr = seed rain.

## 12.4. RESULTS

The simulated baseline population of *A. millefolium* with unlimited flowering and rhizome growth and production, predicted the number of seed in the seed bank, the number of seedlings, the number of flowering and vegetative ramets, the number of seed produced and the immigrating seed and rhizome material (population expansion) to rise exponentially with each generation (equations of the projected population parameters in Table 12.3).

With a 50% or a 75% reduction in seed production (with no change to seed rain or rhizome production) there was a considerable decline in the density of all parameters compared to the baseline population. However, although the rate of population growth was reduced, the counts of seed, seedlings and adult material continued to rise exponentially with time (Table 12.3).

The control of 100% of seed production and seed rain, however, significantly reduced the population growth, where within nine generations the seed bank was exhausted with no new seedlings appearing. However the rhizome system, unaffected by this management event, increased slowly with time (Table 12.3).

A management scheme of 50% reduction in new rhizome production with no changes to seed production had little effect on the growth of the population, with the predicted population's seed bank, seedlings, seed production and rhizome amounts still rising exponentially with time (Table 12.3). A strategy of 100% control of new rhizomes while existing rhizome remain as is, and no changes to seed production does reduce the level of the population considerably (Table 12.3).

A management strategy of 100% control of new rhizome production combined with a 999/1000<sup>th</sup> reduction in seed production was projected to cause a significant reduction in the population variables. Yet, even with this substantial control scenario *A. millefolium* populations will still be present in the environment after 50 years. Control of emerging seedlings was estimated to lead to a significant reduction in the density of the other life stages, particularly when coupled with a 100% reduction in seed production. But, without the removal of the rhizome system, the population was maintained at low levels.

Table 12.3. Equations generated from transition matrix modelling under different management scenarios. Equations are presented for the following model variables. The equation reported for the run represents the best fit for the data from the available trend lines estimates.  $r^2$  is a measure of the goodness of fit.

	<b>SB</b>	<b>SDL</b>	<b>VR</b>	<b>FR</b>	<b>SP</b>	<b>Ims</b>	<b>Imv</b>
1	$y = 84.149e^{2.062x}$ $r^2 = 0.9981$	$y = 284.46e^{2.062x}$ $r^2 = 0.9981$	$y = 172.83 e^{2.0536x}$ $r^2 = 0.9991$	$y = 39.703 e^{2.0517x}$ $r^2 = 0.9993$	$y = 40871 e^{2.0328x}$ $r^2 = 1$	$y = 26096 e^{2.7394x}$ $r^2 = 1$	$y = 0.4552 e^{2.742x}$ $r^2 = 1$
2	$y = 499.54e^{1.0322x}$ $r^2 = 0.9935$	$y = 214.8e^{1.0332x}$ $r^2 = 0.9935$	$y = 159.89 e^{1.0289x}$ $r^2 = 0.9966$	$y = 36.46 e^{1.0371x}$ $r^2 = 0.9972$	$y = 9917.4 e^{1.0055x}$ $r^2 = 1$	$y = 7127.2 e^{0.5047x}$ $r^2 = 0.9999$	$y = 5.8511 e^{0.5555x}$ $r^2 = 0.9742$
3	$y = 10e^{-1.16x}$ $r^2 = 1$	$y = 43e^{-1.16x}$ $r^2 = 1$	$y = 2.4937x + 16.187$ $r^2 = 0.9836$	$y = 3.6452 e^{0.0601x}$ $r^2 = 0.8915$	$y = 0$ $r^2 = n/a$	$y = -0.014x^2 - 0.2368x - 3.4223$ $r^2 = 0.978$	$y = 0.7793 e^{0.133x}$ $r^2 = 0.9782$
4	$y = 592.51e^{1.5062x}$ $r^2 = 0.9966$	$y = 254.78 e^{1.5662x}$ $r^2 = 0.9966$	$y = 167.58 e^{1.4993x}$ $r^2 = 0.9984$	$y = 38.386 e^{1.4974x}$ $r^2 = 1$	$y = 20120 e^{1.4776x}$ $r^2 = 1$	$y = 15103 e^{0.2316x}$ $r^2 = 0.999$	$y = 18.932 e^{0.3135x}$ $r^2 = 0.8523$
5	$y = 467.8e^{1.5104x}$ $r^2 = 0.9956$	$y = 467.8 e^{1.5104x}$ $r^2 = 0.9956$	$y = 167.54 e^{1.4993}$ $r^2 = 0.9984$	$y = 38.377 e^{1.4974x}$ $r^2 = 0.9987$	$y = 40230 e^{1.4766x}$ $r^2 = 1$	$y = 25341 e^{2.1581x}$ $r^2 = 1$	$y = 0.4818 e^{2.177x}$ $r^2 = 0.9995$
6	$y = 0.003x^2 + 0.0986x + 7.8744$ $r^2 = 0.7023$	$y = 0.0013x^2 + 0.0424x + 3.386$ $r^2 = 0.7023$	$y = 19.272 e^{0.0586x}$ $r^2 = 0.8765$	$y = 0.50598x + 2.5144$ $r^2 = 0.9877$	$y = -0.0051x^2 + 0.8279 + 22.489$ $r^2 = 0.6809$	$y = 19.17 e^{0.01882}$ $r^2 = 0.7167$	$y = 0.0003x^2 + 0.12422 + 0.4275$ $r^2 = 0.9994$
7	$y = 9.118x^2 + 548.64x + 4362.2$ $r^2 = 0.8468$	$y = -3.9207x^2 + 235.92x + 1875.8$ $r^2 = 0.8468$	$y = 2.5098x + 15.181$ $r^2 = 0.9853$	$y = 0.5069x + 2.5144$ $r^2 = 0.9877$	$y = -5.1151x^2 + 827.86x + 22.489$ $r^2 = 0.6809$	$y = 11828 e^{0.1296x}$ $r^2 = 0.8214$	$y = 1.34x^2 - 11.748x + 40.171$ $r^2 = 0.9929$
8	$y = 459.6x + 7593.1$ $r^2 = 0.8636$	$y = 0$ $r^2 = n/a$	$y = 2.5098x + 15.181$ $r^2 = 0.9853$	$y = 0.5069x + 2.5144$ $r^2 = 0.9877$	$y = 22955 e^{0.0229x}$ $r^2 = 1$	$y = 21200 e^{1.0791}$ $r^2 = 1$	$y = 1.368 e^{1.1054x}$ $r^2 = 0.9979$
9	$y = 0.009x^2 + 0.3944x + 10.023$ $r^2 = 0.911$	$y = 0$ $r^2 = n/a$	$y = 2.5098x + 15.181$ $r^2 = 0.9853$	$y = 0.5069x + 2.5144$ $r^2 = 0.9877$	$y = -0.0051x^2 + 0.8279x + 22.489$ $r^2 = 0.6809$	$y = 0.3119x + 15.844$ $r^2 = 0.5785$	$y = 0.0725x + 0.8285$ $r^2 = 0.9741$
10	$y = 10e^{-1.16x}$ $r^2 = 1$	$y = 4.3 e^{-1.16x}$ $r^2 = 1$	$y = 0.2847x^2 - 3.4293x + 9.176$ $r^2 = 0.8282$	$y = 0$ $r^2 = n/a$	$y = 0$ $r^2 = n/a$	$y = 8.0203e^{-1.2619x}$ $r^2 = 0.891$	$y = 0.0113x^2 - 0.1818x + 0.5775$ $r^2 = 0.851$
11	$y = 0.3363x + 10.159$ $r^2 = 0.9106$	$y = 0$	$y = 2.50982 + 15.181$ $r^2 = 0.9853$	$y = 0.5059x + 2.5144$ $r^2 = 0.9877$	$y = 0.6744x + 23.23$ $r^2 = 0.6784$	$y = 0.0026x^2 + 0.258x + 12.75$ $r^2 = 0.5668$	$y = 0.2716x - 0.0704$ $r^2 = 0.9913$

	<b>SB</b>	<b>SDL</b>	<b>VR</b>	<b>FR</b>	<b>SP</b>	<b>Ims</b>	<b>Imv</b>
12	$y = 10e^{-0.5978x}$ $r^2 = 1$	$y = 0$	$y = 0.0147x^2 -$ $0.5449x + 4.2508$ $r^2 = 0.4118$	$y = 0.0027x^2 -$ $0.1006x + 0.7676$ $r^2 = 0.2311$	$y = 0$	$y = 0$	$y = -0.0008x^2 +$ $0.0304x - 0.2517$ $r^2 = 0.2535$

Code: Variables estimated in the model; SB – Seed Bank variable; SDL – Seedling variable; VR – Vegetative Rhizome variable; FR – Flowering Rhizome variable; SP – Seed Produced variable; Ims – Immigrant seed; Imv – Immigrant vegetative rhizome.

## 12.5. DISCUSSION

The transition matrix model, as used here, incorporated the physiological information about the important life stages of *A. millefolium* – seed, seedling, adult (sexual and vegetative) – and the transition and survival rates between these life stages using data collected for *A. millefolium* populations in Kosciuszko National Park and from overseas studies. The transition matrix model predictions indicate that this species, without adequate control could theoretically expand exponentially. The potential number of seed and vegetative propagules produced are massive. The matrix model predicted that seed was the major source of increasing the population with the rhizome system maintaining the presence of *A. millefolium* in the environment.

However although *A. millefolium* is present in many areas of Kosciuszko National Park (Chapter 7) it is dominant in only a small number of areas, with the vast majority of these highly disturbed by human activity (roadsides, around buildings etc.). Therefore *A. millefolium* may be limited in its ability to expand to new sites (through the mechanisms of seed rain, and then seedling emergence etc.) by environmental conditions such as soil moisture, nutrients, lack of disturbance, and by competition with existing plants and thus exponential growth is not probable. Nevertheless due to its high amount of seed and rhizome presence (with the latter thought to be exploitative rather than reproductive unless the plant was disturbed (Warwick and Black 1982)), this species presents a difficult weed to control due to its persistence in the environment.

The model projections indicate that to eradicate *A. millefolium* from the Australian Alps management would need to involve both the control of the production of seed and the control and removal of the underground rhizome system. An approach of removing all flowering heads (either by hand removal or a combined hand removal with herbicide application) would deplete the seed bank. Hand removal, however, may not be a cost effective option due to the extent of the infestation and the presence of rhizomes. The modelling results suggest seed production needs to be reduced to 1/1000<sup>th</sup> of the potential in order to reduce the invasive impact of this weed in Kosciuszko National Park. Removal of 50 to 75% of the seed production does not appear to be adequate to deplete seed reserves from current populations.

### 12.5.1. Effectiveness of different control measures

Several herbicides have been trialled for control *A. millefolium* with varying success dependent on the herbicide and method of application (Aamisepp 1977; Robocker 1977; Bourdôt and Hurrell 1984; Field and Jayaweera 1985a,b). In Kosciuszko National Park herbicides are currently used to manage the roadside and resort populations for *A. millefolium*. They have been thought of as the only cost effective option available to control the widespread infestation of this weed, despite environmental issues associated with their use such as residues and lack of selectivity (Sanecki *et al.* 2003). Mixtures of dicamba and 2,4-D have been used to control *A. millefolium* but have been relatively ineffective (Sanecki and Knutson 1998; Sanecki 1999; Sanecki *et al.* 2003). For example, field trials evaluating herbicides for use on *A. millefolium* roadside infestations have shown low efficacy of dicamba/2,4-D mixes (Sanecki *et al.* 2003). Dicamba/2,4-D treated plants actually showed an increase in flowering post herbicide application (Sanecki *et al.* 2003). Alternative herbicides (metsulfuon-methyl and triclopyr/picloram) were shown to be significantly more effective in trials, with both herbicides reducing plant biomass 12 months post treatment (Sanecki *et al.* 2003). Currently Grazon\* DS (picloram) is being trialed for use as a high volume spraying herbicide on late vegetative to flowering *A. millefolium* plants at a rate of one application per year with follow up application to control regrowth and germinating seedlings in subsequent years (Dave Woods pers. comm. NSW NPWS 2005).

The effect of herbicides on the underground rhizome system has not been studied in the Australian Alps (Dave Woods pers. comm. NSW NPWS 2005). At present the chosen herbicides are applied in early to late summer at the peak of flowering. However, the efficacy of any translocated herbicides would be greatest if it were applied in the autumn when the movement of assimilate into the rhizomes is at its most active during vigorous extension growth (Bourdôt *et al.* 1979), with the best development stages for herbicide applications at pre-rhizome or plants with only a small developing rhizome system (Bourdôt and Field 1988). These results suggest two herbicide applications per year to be applied – one in summer to control flowering (seed) and one in autumn for rhizome control.

In crop/pasture agricultural systems a combination of multiple cultivations and herbicide application have been effective at controlling rhizomes for *A. millefolium* (Bourdôt *et al.* 1982; Bourdôt 1984; Bourdôt *et al.* 1984; Field and Jayaweera 1985; Field and Jayaweera 1985). To stimulate the maximum number of buds to grow, the rhizome system needed to be reduced to the smallest fragments possible, such as rotary hoeing rather than grubbing or ploughing. Subsequent cultivations were used to destroy the primary regrowth shoots before they formed new rhizomes and to release more buds from apical dominance. Without follow up, however, cultivation may only result in more *A. millefolium* plants, not less (Bourdôt *et al.* 1982; Bourdôt and Butler 1985).

The physical removal of *A. millefolium* plants, including rhizomes, may only be possible along the road verges and around highly disturbed infrastructure such as building sites in the Australian Alps. Physical removal has been tested in the Australian Alps only for small clumps of *A. millefolium*. Given its capacity for vegetative reproduction great care would be needed to removal all fragments of root and rhizome material (Bourdôt *et al.* 1979; Sanecki *et al.* 2003). Control measures would have to be repeated to exhaust underground resources of the rhizome. Rhizome removal would have to be carried out in conjunction with rehabilitation work to prevent reestablishment by *A. millefolium* and/or other exotic species.

Alternatives to herbicides and mechanical removal of plants could be fire and biological control. Biological agents have not been investigated for control of *A. millefolium* (S. Corey, pers. comm. CSIRO Division of Entomology 1999). Fire is likely to be ineffective as the plant has low ignitability (Bourdôt *et al.* 1985; Stickney 1989; Howe 1994; Hogenbirk and Sarrazin-Delay 1995), the rhizome can resprout post fire, and seedlings can germinate from soil seed banks.

*Achillea millefolium* often appears in the first stages of succession post fire (Howe 1994; Stickney 1989; Bourdôt *et al.* 1985) including in the Australian Alps after the most recent fires (Johnston and Johnston 2003). In post-fire Montana (U.S.A.) grasslands, *A. millefolium* regenerated rapidly from rhizomes and wind dispersed seeds from adjacent unburnt areas (Volland *et al.* 1981; Howe 1994). In the Australian Alps many *A. millefolium* plants along road verges survived the large

scale bushfires in January-February 2003 as the roads tended to act as fire breaks (Johnston and Johnston 2003). Four weeks post-fire seedlings of *A. millefolium* were already found in newly burnt natural areas (Johnston and Johnston 2003). Control of *A. millefolium* and other weeds in areas regenerating from the fires will be important as exotics along road verges have the potential to colonise these burnt areas (Johnston and Johnston 2003; Scherrer *et al.* 2004).

Control of *A. millefolium* in the Australian Alps, including Kosciuszko National Park, must be on a landscape scale rather than just focusing on local populations. The isolated populations of *A. millefolium* that occur in different sites throughout the Australian Alps are part of a larger metapopulation. Individual populations can act as source or sink populations. If one population goes 'extinct' due to control measurements it may be later recolonised by surviving populations (Moody and Mack 1988).

#### **12.5.2. Further modelling**

To increase the predictive power of the model used here, density dependence relationships and the demographic and environmental conditions experienced by *A. millefolium* plants growing in the Australian Alps could be integrated. The clonal parameters of *A. millefolium* could also be included in an expanded form of the model to include ramet life span (the replacement rate and speed of spatial dynamics), mean annual extension of the rhizome (the speed of vegetative mobility), frequency of rhizome branching (intensity of vegetative reproduction), branching angle, ramet density and ramet size (Aavikoo *et al.* 1995).

An expanded model could include the figures: proportion of dormant buds to total buds remaining in the bud bank (bs) at 97% (Bourdôt 1984; Bourdôt and Butler 1982); proportion of active buds to total buds which leave the bud bank to become rosettes (bv) at 3% (Bourdôt 1984; Bourdôt and Butler 1982) to ascertain the bud bank (BB) in the model. The proportion of rhizome which produces further rhizomes (buds) per 1 m<sup>2</sup> area per season (bb) needs to be further researched. Furthermore to increase the validation and predictive capacity of this model further research into the factors which affect the transition rates between life stages under natural Australian Alps conditions would be required.

In addition to this matrix transition model type the quantitative physiological research on *A. millefolium* could be incorporated into other models types such as DYMEX™ to enable more *A. millefolium* specific predictions about the population dynamics and the effect of different control events on the invasion and control strategies on this species. DYMEX™ combines life stage-based transition matrix with Markov chain population modelling frameworks and individual-based models. Life stage transfer processes can be defined using any combination of functions of age or other cohort characteristics, or environmental factors. DYMEX™ modelling incorporates life stage level stochasticity in terms of deterministic functions (Kriticos *et al.* 2003). A preliminary model using DYMEX™ was constructed (Sutherst *et al.* 2000). However due to time constraints and lack of resources the DYMEX™ model was only partially completed.



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## **CHAPTER 13**

### **GENERAL DISCUSSION**

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#### **13.1. PLANT INVASIONS IN THE AUSTRALIAN ALPS**

Invasion by exotic plants is both a symptom and a consequence of the changes to natural Australian ecosystems since European settlement (Low 1999; Williams and West 2000; Muyt 2001; Booth *et al.* 2003). Anthropogenic disturbance compromises the capacity of natural areas to resist weed invasion (Williams and West 2000; Muyt 2001). The natural ecosystems of the Australian Alps have been modified by human disturbance such as livestock grazing, fire and the construction of roads, tracks, buildings and other infrastructure (ISC 2004). These disturbances have provided the opportunity for the introduction of new plant species into the Australian Alps, both deliberately and accidentally (Johnston and Pickering 2001a; Chapter 3). Some of these exotics have become environmental weeds and can be found in areas relatively undisturbed by human activities (Sainty *et al.* 1998; Chapters 3, 4, 5 and 7).

#### **13.2. STATUS OF EXOTICS IN THE AUSTRALIAN ALPS**

Over 175 species of exotic plants have been recorded above 1500 m in the Australian Alps, representing 41 families and 122 genera (Johnston and Pickering 2001a, Chapter 3). They are predominantly associated with human introductions and/or are in areas that have been modified by human activities. These exotics have been introduced as a result of livestock grazing practices and subsequent soil and vegetation rehabilitation activities as well as deliberately planted in gardens or accidentally introduced as contaminants of construction materials (Costin 1954; Costin and Wimbush 1963; Bryant 1971; Good 1976; McDougall 1982; Walsh *et al.* 1984; Mallen-Cooper 1990; Pearson 1997; McDougall and Appleby 2000; Johnston and Pickering 2001a). Eighty percent of the exotics in the Australian Alps were recorded along roads and paths with 58% found in and around resorts and other infrastructure (Chapter 3). A large number of these exotics (20%) can be considered naturalised in the protected areas of the Australian Alps (Johnston and Pickering 2001a; Chapter 3).

In addition to examining the status of exotic plants in the Australian Alps including the largest protected area, Kosciuszko National Park, this thesis explored the impact of road disturbance and plant colonisation adjacent to roads following disturbance.

### **13.3. ROAD DISTURBANCE AND EXOTICS**

A relationship was found between exotic and native plant species composition and soil properties in the study of three subalpine microsites associated with road disturbance. Differences in the chemical and physical properties of the soil after the removal of native vegetation during construction and use of the roads may contribute to continuing differences in vegetation at these sites. The road verges were dominated by exotics (64% cover comprising four species), particularly the grass *Anthoxanthum odoratum* and the widespread naturalised herb *Acetosella vulgaris*, growing on a soil characterised by low organic matter, coarse texture and low nutrient availability (compared to the other two microsites). Road verges were also characterised by the largest amount of bare ground (29%). The adjacent natural area with its fine textured rich organic soil had a wide range of native plant species with only a few exotic species: 92% cover of native vegetation cover comprising 31 species and 6% cover of exotic vegetation comprising just three species. The road drainage areas were unique as they were dominated by only one exotic, *A. millefolium* (77% cover) growing on soil with high water, sediment and nutrient loads (total species composition was three native species and five exotic species).

The colonisation of small gap disturbances by exotics and natives along an exotic dominated subalpine roadside showed that road verge quadrats are largely recolonised by exotic species (73% relative cover and 51% absolute cover, comprised of four exotic species and 10 native species) with vegetation approaching pre-disturbance composition after 21 months. Quadrats five metres from the road were recolonised by both native and exotic species (51% and 49% relative cover respectively, comprising 22 native species and three exotic species) while quadrats ten metres from the verge were dominated by natives (75% relative cover comprised of 22 native species and 3 exotic species). Both the five and ten metre quadrats had increased relative cover of exotics after disturbance compared with that prior to disturbance.

Soil samples from natural areas adjacent to sources of exotics (such as roadsides) contained both native and exotic seeds. Generally the diversity and abundance of seedlings matched the post disturbance vegetation composition i.e. exotics were more common in soil from the one metre quadrats and the natives in soil from the five and the ten metre quadrats. However two exotics *Acetosella vulgaris* and *Achillea millefolium* and a suite of native species (*Luzula* spp., *Poa* spp. *Olearia phlogopappa*, *Geranium potentilloides* var. *potentilloides*, *Asperula gunnii* and *Stellaria pungens*) had seedlings germinate in soil from most quadrats irrespective of distance from the road.

These studies highlight that post disturbance colonisation in the presence of exotic propagules will not necessarily end with a native climax community but a community where both natives and exotics are present and with potentially greater cover and diversity of exotics post disturbance.

This thesis also examined the ecology of the environmental weed *Achillea millefolium* including the risk this species poses to the natural vegetation communities of Kosciuszko National Park.

#### **13.4. STATUS OF *A. MILLEFOLIUM* IN THE AUSTRALIAN ALPS**

*Achillea millefolium* appears to be a ‘sleeper’ weed (Groves 1999) in that the size, number and extent of populations appears to have had a slow rate of increase for several decades after it was first recorded, until around 10 years ago when roadside populations increased dramatically and isolated plants were found in adjacent natural communities (Costin 1954; Johnston and Pickering 2001b; Chapter 7). The change in status of *A. millefolium* from an exotic to an environmental weed over a short period of time is documented in its control management status. In 1995 it was considered just an ‘other weed’ among many (NSW NPWS 1995) but by 2003 it was listed as a ‘major consideration weed to the conservation of alpine floral communities’ in the Snowy Mountains Region Pest Management Strategy 2003-2006 (NSWNPWS 2003).

The assessment of *A. millefolium* using standard weed assessment methodologies (Chapter 6) indicated the ecological traits that make this species a potential threat to both the natural environment and agriculture. If this species were evaluated for importation today it would be rejected.

Modelling the potential worldwide and Australian distribution of *A. millefolium* indicated that areas with Mediterranean climates or cool temperate climates (such as the Australian Alps) are highly suitable for *A. millefolium* while areas with high temperatures and low rainfall or high temperatures combined with wet periods (such as the tropics) are unsuitable (CLIMEX<sup>®</sup> model; Chapter 6). These predictions are consistent with the broad range of habitats where *A. millefolium* was found in Kosciuszko National Park, that is from the tableland to the alpine zone (Chapters 3 and 7). Within this range the areas where *A. millefolium* was most common (the montane to subalpine zone) had the cool temperate climates predicted by the CLIMEX<sup>®</sup> model (Chapter 6). Modelling the distribution of *A. millefolium* under a conservative climate change scenario of + 2°C indicated that high altitude areas of the world including the Australian Alps would become more suitable for this species (Chapter 6).

### **13.5. EFFECTS OF DISTURBANCE ON *A. MILLEFOLIUM***

Disturbance regimes are important in the establishment and spread of exotic taxa in Australia including the Australian Alps (Williams and West 2000; Johnston and Pickering 2001a, Chapter 3). The relationship between anthropogenic disturbance and the presence of *A. millefolium* is clear from this research (Johnston and Pickering 2001a,b; Johnston and Johnston 2004; Chapters 4, 5 and 6, 7, 8 and 10).

In Kosciuszko National Park *A. millefolium* occurs primarily in disturbed areas particularly along roads and around other infrastructure. It was recorded at 300 disturbed sites in specific surveys conducted during this research and in 9% of all sites where exotics were recorded in 18 general vegetation surveys in Kosciuszko National Park (total of 363 sites with exotics; Bear *et al.* Under review). *Achillea millefolium* is uncommon in natural vegetation – just 4% of sites in natural areas where other exotics were recorded also contained *A. millefolium* (Bear *et al.* Under review; Chapter 7). Where it occurs in natural vegetation *A. millefolium* can be small (isolated plants <5 cm diameter) but much larger plant/s (>70 cm diameter) have also been recorded. These together with populations on road verges are sources of propagules which may enable this species to establish or spread further into natural areas, particularly where disturbed (Bourdôt *et al.* 1979; Warwick and Black 1982; Bourdôt and Field 1988; Henskens *et al.* 1992; Chapter 4 and 5).

Once established *A. millefolium* can have high cover and exclude other species (Chapters 4 and 7). Similar patterns of establishment, exclusion of other taxa and potential for spread have been found for *A. millefolium* overseas (Bourdôt *et al.* 1982; Bourdôt *et al.* 1984; Bourdôt and Butler 1985; Field and Jayaweera 1985a,b).

The road impact study (Chapter 4) showed that soil-plant assemblages on road verges differed from those in natural vegetation. The road verge was dominated by exotics with only a few natives, while in adjacent undisturbed areas vegetation was diverse with few exotics. Soil from these areas had higher humus levels, less gravel and sand, higher levels of nutrients, and higher pH and electrical conductivity than soil from road verges. A different soil-plant assemblage was found in the drainage areas along roads. This microsite had soils characterised by high water and sediment, significantly higher pH and exchangeable levels of calcium and potassium than natural areas and disturbed areas without *A. millefolium*. These drainage areas were dominated by *A. millefolium* (70-100%) to the exclusion of nearly all other species. The road impact study (Chapter 4) confirms that exotics are the dominant vegetation in disturbed sites such as roads, and that the soils in these disturbed sites are very different to those in adjacent native vegetation.

In the field experiment examining colonisation following small scale disturbance (Chapter 5) the suite of species recolonising small gaps created in the vegetation differed depending on the distance of the gap from the road. Gaps closest to road verges were colonised predominantly by exotic species while sites further away from verges were colonised predominantly by natives. *Achillea millefolium* plants were, however, found at a distance of 10 m from the road both pre and post disturbance.

Disturbance type also appears to affect reproduction in *A. millefolium*. For example when flowering phenology and the number of reproductive structures were compared among sites located near buildings, primary and secondary roads, the number of flowering structures was three times greater around buildings than along roadsides (Johnston and Pickering Under Review; Chapter 7). Therefore disturbance type and its associated characteristics, such as nutrient enrichment and soil moisture may influence the distribution and abundance of *A. millefolium*.

### **13.6. EFFECT OF ALTITUDE/CLIMATE ON *A. MILLEFOLIUM***

In addition to disturbance, climate is another important factor that can affect weed invasions. A 'successful' invasion requires that the species arrive, establish, reproduce and spread (Booth *et al.* 2003). Climate can affect weeds by directly influencing establishment, growth and reproduction as well as indirectly affecting establishment through changes to soils, changes to herbivore and pathogen ecology (Prentice 1992). The results in this study indicate that *A. millefolium* does not appear to be principally limited by altitude/climatic conditions in the Australian Alps but by other factors that vary among sites such as water, nutrients, soil type and disturbance regimes.

Data on the distribution of *A. millefolium* indicate that it is already found in all climatic zones in Kosciuszko National Park (Chapter 7). The results from the phenology, resource allocation and seed studies (Chapters 8, 9, and 10) confirm that *A. millefolium* has the ability to not only survive but to successfully reproduce sexually via seed over a range of altitudes in the Park (Johnston and Pickering 2001b; Johnston and Johnston 2003; Johnston and Pickering 2004). Vegetative biomass, both above and below ground was not affected by altitude, indicating that altitude was not having a significant effect on vegetative growth (Johnston and Pickering 2004; Chapter 9).

More severe climatic conditions associated with higher altitudes, however, may be influencing some aspects of reproduction in *A. millefolium*. For example, flowering phenology of *A. millefolium* was affected by altitude, with plants at higher altitude sites flowering for a shorter time: flowering was initiated later and finished earlier than in plants at lower altitudes. Altitude affected the biomass of inflorescences with their dry weight decreasing with increasing altitude (Chapter 9). However the number of flowering heads and florets per inflorescence and the number of inflorescences produced per m<sup>2</sup> during a flowering season either were not affected by altitude, or there was only a weak relationship (Chapters 7 and 8).

The number of flower heads and florets varied among populations. Seed germination and viability of seed produced at a range of altitudes varied due to individual site characteristics rather than altitude. The average germination of seed was high at 60%

across the sites sampled (Chapter 10). The presence of suitable insect pollinators also does not appear to be restricted in Kosciuszko National Park (Appendix 3).

If the climate of the Australian Alps becomes warmer and there is less snow cover as has been predicted (Whetton 1998; Pickering *et al.* 2003a) then *A. millefolium* may benefit in terms of reproduction. Currently plants growing at lower altitude in Kosciuszko National Park flower for longer periods producing larger flowering structures (Johnston and Pickering 2004). The CLIMEX<sup>®</sup> modelling (Chapter 6) indicates that climate change would benefit *A. millefolium* growth in high altitude sites in the Australian Alps.

### **13.7. EFFECTS OF *A. MILLEFOLIUM* ON NATIVE VEGETATION**

Examination of the competitive interactions between *A. millefolium* and the dominant native graminoid, *Poa fawcettiae* indicated that if *A. millefolium* and *P. fawcettiae* germinate together in cleared areas the weed may out-compete the grass in alpine and subalpine grasslands. The main source of the competitive advantage of the weed over the native appears to be from root interactions (Johnston and Pickering Under Review; Chapter 9). *Achillea millefolium* has the potential to readily colonise areas subjected to vegetation and soil disturbance (Johnston and Johnston 2003; Chapter 5). Additional research would be required to quantify the ecological consequences of *A. millefolium* populations on the structure, processes and functions of subalpine and alpine ecosystem of the Australian Alps.

### **13.8. RECOMMENDATIONS FOR THE MANAGEMENT OF *A. MILLEFOLIUM***

*Achillea millefolium* was introduced to the Australian Alps deliberately as an ornamental garden plant and accidentally as a contaminate of hay or gravel used in the rehabilitation or construction work (Johnston and Pickering 2001a; GT Wright, NSW NPWS 2002 pers. comm.). In reference to the five stages of plant invasion (introduction, establishment, survival, production of numerous propagules and widespread dispersal, (Humphries *et al.* 1991; Scott 2000; Kolar and Lodge 2001; Booth *et al.* 2003) it would appear that *A. millefolium* is a species that has reached the stage of potential widespread dispersal.

*Achillea millefolium* is already well established in a wide range of areas in Kosciuszko National Park so eradication or containment may not be feasible. Therefore a combined weed led and site led ecosystem approach management strategy (Owen 1998) would tackle both the causation factors (e.g. disturbance) and the symptoms (the exotics) with the input of adequate resources and sustained long term control measures (Hobbs and Humphries 1995; Slocombe 1998).

An ecosystem approach that addresses causation factors needs to focus on limiting, as far as possible, additional disturbance to the natural vegetation in the Australian Alps, as well as actively restoring sites already disturbed. This type of approach would also assist in limiting the spread of other exotics in the Park, and ensuring that removal of *A. millefolium* from a site does not just lead to the establishment of, or increase in, one or more other invasive species. Thus eradication and containment of exotics at any site must also be followed by active and ongoing restoration of that site or risk the reestablishment of an exotic flora (Goodall and Naude 1998; Panetta 1999).

In terms of a weed led approach, the population dynamics modelling (Chapter 11) using physiological data from the literature and this thesis (Chapters 4, 5, 6, 7, 8, 9, and 10) indicated that removing *A. millefolium* from sites where it already occurs will be difficult. A reduction of 50% in the amount of seed shed is likely to have little impact on populations with the seed bank, seedlings, vegetative and flowering rhizomes increasing with each generation. A reduction of 75% may stabilise the population, although it would not result in a reduction in the current levels of infestation. The prevention of seed production, removing 99.9% of the seed production could control the seed bank and number of seedlings emerging with each generation. However, there would still be a steady increase in the underground rhizome system. These rhizomes may be able to grow, spread vegetatively, flower and produce seed. An effective control strategy for this species at sites where it occurs must include both the removal of flowers to decrease the input of seed into the seed bank, the removal of the underground rhizome system, as well as limiting the establishment of any seedlings.

Past and current chemical control programs for *A. millefolium* in the Kosciuszko National Park primarily focused on the prevention or reduction in flowering and thus seed production (Sanecki *et al.* 2003). These chemical programs will continue to be

important for the long-term control of *A. millefolium* with this study indicating that at high altitudes *A. millefolium* still has large numbers of flower heads and large underground mass of rhizomes. In addition to herbicide applications the periodic removal of the flower heads by mowing/slashing of the roadside populations would assist in the reduction of the amount of seed entering the seed soil bank.

Further research on *A. millefolium* should examine biological control and the use of competitive rehabilitation native species in both tube stock and seed either as control strategies or combined with herbicide application. Finding the Achilles heel of *A. millefolium* appears to be a huge task in that nearly all seed and vegetative material must be removed to control the spread of this species.

### **13.9. THE THREAT OF ENVIRONMENTAL WEEDS IN THE AUSTRALIAN ALPS**

A large number of exotic plants have been recorded in subalpine and alpine regions of the Australian Alps (Chapter 3, Godfree et al. 2004, McDougall et al. 2005). The majority of these are only found in areas affected by human disturbance such as roadsides, tracks, around building, dams etc. as well as in gardens in resorts where they have been deliberately introduced. For example of the 175 exotic taxa recorded in above 1500 m (Chapter 3), 136 could be found along roads and trails, but only 36 could be found in natural areas. Some of these naturalized exotics such as *Acetosella vulgaris* are not considered to be environmental weeds as they are easily overgrown by natives. Others, however, such as *Achillea millefolium*, *Trifolium repens*, *Hypochaeris radicata*, and *Agrostis capillaris* are considered to be a threat to the native biodiversity (Coyne, 2000). In response to this the National Parks and Wildlife Service currently spends \$400,000 per year controlling weeds in Kosciusko National Park. However the biological and ecological characteristics of most of the exotics in the Australian Alps have not been investigated to determine the extent to which they are threat.

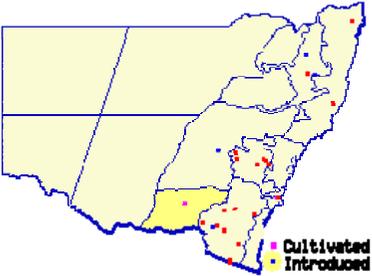
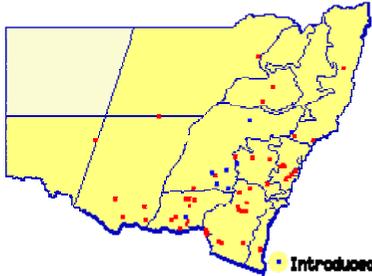
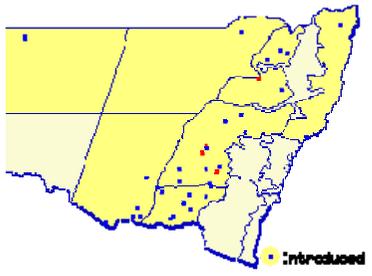
The species *A. millefolium*, which was examined in this dissertation, is regarded as a major weed in alpine and subalpine regions of the Australian Alps (Johnston and Pickering 2001b; Sanecki et al. 2003). Based on the weed risk assessment (Chapter 6), it would be considered to be risk for introduction to Australia. Field research

presented in this dissertation also indicates that *A. millefolium* is predominantly associated with anthropogenic disturbance through changes to soil, moisture and nutrients (Chapters 3, 4, 5 and 7). However, small areas of *A. millefolium* were also found in undisturbed natural vegetation (Chapters 3, 4, 5 and 7). This observed distribution, along with the research on the phenology (Chapter 8), resource allocation (Chapter 9), seed ecology (Chapter 10) and competitive characteristics (Chapter 11) demonstrates that *A. millefolium* is able to survive and reproduce in the Australian Alps without human induced changes to the environment. These results raise the possibility that *A. millefolium* is a sleeper weed in the early stage of its spread. Certainly it has been found to be very difficult to remove once established (Sanecki et al. 2003). With increasing pressures from tourism use of the Australian Alps, along with predicted climatic change (Chapter 7), it appears that the risk of *A. millefolium* becoming a serious threat to natural values of the Australian Alps is likely to increase.

#### **13.10. COMPARING *ACHILLEA MILLEFOLIUM* WITH OTHER PERENNIAL WEEDS**

One of the best indicators of invasive ability is information about the species' characteristics (Roy 1990; Thompson *et al.* 1995; Muyt 2000), with some traits common to many environmental weeds (Booth *et al.* 2003). This can be seen when the characteristics of *Achillea millefolium* are compared with two other important perennial weeds in south-eastern Australia; *Chondrilla juncea* (Rush skeleton weed) and *Solanum elaeagnifolium* (Silver leaved nightshade, Table 13.1).

Table 13.1. Distribution, ecological characteristic and management options for the three environmental weeds *A. millefolium*, *C. juncea* and *S. elaeagnifolium* in south-eastern Australia.

Characteristics	<i>Achillea millefolium</i>	<i>Chondrilla juncea</i>	<i>Solanum elaeagnifolium</i>
Common name	Yarrow	Skeleton weed	Silver-leaved nightshade
Taxonomy	Asteraceae	Asteraceae	Solanaceae
Origin	Europe	Mediterranean, Central Europe and West Asia	North and South America
Distribution in Australia	Victoria, NSW	NSW Queensland, Western Australia, South Australia	NSW, Queensland, Western Australia, South Australia, Northern Territory.
Distribution - In NSW <sup>1</sup>			
Worldwide, weed in....	Canada, New Zealand and Australia <sup>2</sup>	USA and Australia <sup>3</sup>	Australia, India, Middle East, Africa and Europe <sup>4</sup>
In Australia, weed in.... <sup>5</sup>	NSW, ACT and Victoria	NSW, Victoria and Tasmania	NSW, Victoria, Tasmania, South Australia, and Western Australia
Lifecycle	Perennial <sup>6</sup>	Perennial <sup>7</sup>	Perennial <sup>8</sup>
Flowering in NSW <sup>1</sup>	November to April	December to April	Late spring to summer
Form	Stoloniferous forb, deep rooted, 0.1-1 m high <sup>6</sup>	Basal rosette forb, 0.5-1m high <sup>7</sup>	Erect forb to 1 m <sup>8</sup>
Domestication/cultivation	Cultivated in many countries including Australia <sup>9</sup>	n/a	n/a
Climate tolerance	Broad – temperate <sup>6</sup>	Mediterranean - temperate - steppe <sup>7</sup>	Semi-arid – temperate <sup>8</sup>
Seed production	- photoperiod 12-18 hours <sup>10</sup> - self incompatible <sup>12</sup> - insect pollinated <sup>12</sup> - seed output 900 000/ m <sup>2</sup> <sup>15</sup>	- photoperiod 12-14 hours <sup>11</sup> - self compatible <sup>13</sup> -insect pollinated <sup>13</sup> - seed output 70 000/ m <sup>2</sup> <sup>16</sup>	-self incompatible <sup>14</sup> - insect pollinated <sup>14</sup> - seed output 5 million to 1000 million/acre <sup>17</sup>
Vegetative reproduction	- rhizome system <sup>12</sup> - rhizome extension rate estimated at 7 to	- adventitious buds on vertical and lateral roots <sup>18</sup> - spread up to 0.6 m per year <sup>20</sup>	- rhizome and root fragments <sup>14</sup>

Dispersal mechanisms	20 cm per year <sup>19</sup> - wind <sup>21</sup> - animal faeces <sup>21</sup> - contaminate of plant material <sup>21</sup> - rhizome <sup>21</sup>	- wind <sup>22</sup> - external attachment to animals <sup>22</sup> - contaminate of plant material <sup>22</sup> - rhizome <sup>22</sup>	- wind <sup>23</sup> - animal faeces <sup>23</sup> - tillage or harvesting equipment <sup>23</sup> - animals <sup>23</sup> - contaminate of plant material <sup>23</sup> - water <sup>23</sup> - rhizome <sup>23</sup>
Response to disturbance	Positive <sup>21</sup>	Positive <sup>22</sup>	Positive <sup>23</sup>
Propagule bank	- seed <sup>21</sup> - rhizomes <sup>21</sup>	- seed <sup>22</sup> - rhizomes <sup>22</sup>	- seed <sup>23</sup> - rhizomes <sup>23</sup>
Impacts <sup>5</sup>	- agricultural weed - environmental weed	- agricultural weed - environmental weed	- agricultural weed - environmental weed
Management options	1. Herbicides <sup>24</sup> 2. Multiple cultivation <sup>24</sup> 3. No effective biological control <sup>24</sup> 4. Rehabilitation work; limit disturbance to root system <sup>24</sup>	1. Herbicides <sup>25</sup> 2. Mowing <sup>25</sup> 3. Biological control by gall midge ( <i>Cystiphora schmidtii</i> ), gall mite ( <i>Eriophyes chondrillae</i> ) and rust fungus ( <i>Puccinia chondrillina</i> ) <sup>25</sup> 4. Limit disturbance to root system <sup>25</sup>	1. Herbicides; soil fumigation <sup>26</sup> 2. Hand pulling or hoes; mowing <sup>26</sup> 3. Herbivores <sup>26</sup> 4. Limit disturbance to root system <sup>26</sup>

<sup>1</sup>PlantNet (2005); <sup>2</sup>Holm et al. 1979; <sup>3</sup>McVean 1966; Panetta and Dodd 1987; <sup>4</sup>Boyd 1984; <sup>5</sup>Groves et al. 2003; <sup>6</sup>Chandler et al 1982; Mitich 1990; <sup>7</sup>McVean 1966; <sup>8</sup>Roche 1991; <sup>9</sup>Anon 1998; <sup>10</sup>Chandler et al. 1982; Zhang et al 1996; <sup>11</sup>Caso and Kefford 1968; <sup>12</sup>Warwick and Black 1982; <sup>13</sup>McVean 1966; <sup>14</sup>Boyd and Murray 1982a; <sup>15</sup>Bourdôt et al. 1979; <sup>16</sup>Panetta and Dodd 1987; <sup>17</sup>Cooley and Smith 1971; <sup>18</sup>Cullen and Groves 1977; Panetta and Dodd 1987; <sup>19</sup>Bostock and Benton 1970; <sup>20</sup>Old 1990; <sup>21</sup>Warwick and Black 1882; Bourdôt et al. 1979; <sup>22</sup>Piper and Coombs 1996; Panetta and Dodd 1987; <sup>23</sup>Boyd and Murray 1982a, b; Roche 1991; <sup>24</sup>Aamissepp 1977; Robocker 1977; Warwick and Black 1982; Bourdôt et al. 1984; Bourdôt and Hurrell 1984; Field and Jayaweera 1985 a, b; Bourdôt 1984; Kannangara and Field 1985 <sup>25</sup>Cullen and Groves 1977; McLennan 1991; Old 1992; Sheley et al. 1999; <sup>26</sup>Richardson 1979; Waphere 1988; Roche 1991.

Although these three species originate from different regions they have many ecological traits in common (Table 13.1). They have a wide climatic tolerance and all benefit from human disturbance and hence can be found in agricultural fields, roadsides and construction sites in south-eastern Australia (Holm *et al.* 1979; Warwick and Black 1982; Panetta and Dodd 1987; Panetta 1989; Roche 1991). They all have extensive and/or deep root system with vegetative regeneration a primary means by which local populations spread (Cuthbertson 1972; Cullen and Groves 1977; Bostock and Benton 1979; Bourdôt *et al.* 1982; Boyd and Murray 1982a; Kannangara and Field 1983; Field and Jayaweera 1985b; Panetta and Dodd 1987; Old 1990). Disturbance to these root/rhizome systems stimulates an increase in the population rosette density as each rhizome/root fragment can development into a new plant (Cullen and Groves 1997; Bourdot *et al.* 1982; Boyd and Murray 1982a; Kannangara and Field 1983; Field and Jayaweera 1985b; Panetta and Dodd 1987). The rhizomatous root system is difficult to control by herbicides, therefore minimising disturbance to the root system is critical to the control of population density (McVean 1966; Volland and Dell 1981; Bourdôt *et al.* 1982; Boyd and Murray 1982b; Bourdôt *et al.* 1984; Bourdôt and Butler 1985; Field and Jayaweera 1985a,b; Howe 1994).

In addition to vegetative spread the three species produce large amounts of seed which can be dispersed by a number of vectors (McVean 1966; Cooley and Smith 1971; Bourdôt *et al.* 1979; Boyd and Murray 1982a,b; Panetta and Dodd 1987, Liao 1996; Liao *et al.* 2000). These vectors include animals (internal), wind, water and human disturbance.

The management of these three species depends on the integration of various strategies involving early detection and implementation of an eradication programs for small infestations (Hobbs and Humphries 1995; Owen 1998; Slocombe 1998; Sheley *et al.* 1999). For larger established populations control involves the combinations of introduction of competitive plants, physical (hand pulling, digging, cutting, mowing, plowing, cultivation), chemical (herbicides) and biological (such as viral particles, fungi, and insects) agents, in order to be effective (Robocker 1977; Aamissepp 1977; Richardson 1979; Bourdôt *et al.* 1982; Bourdôt 1984; Bourdôt *et al.*

1984; Bourdôt and Hurrell 1984; Field and Jayaweera 1985a,b; Wapshere 1988; McLennan 1991; Roche 1991; Sheley *et al.* 1999; Sanecki *et al.* 2003). Biological control has only been used for *C. juncea* with the use of gall midge (*Cystiphora schmidtii*), gall mite (*Eriophyes chondrillae*) and rust fungus (*Puccinia chondrillina*) used to control populations of Skeleton weed in Australia (Cullen and Groves 1977; McLellan 1991; Piper and Coombes 1996; Harris 2003; Zouhar 2003). Further research is required to investigate potential agents for the biological control of *A. millefolium* and *S. elaeagnifolium*.

### **13.11. CONCLUSIONS**

This thesis has shown that the Australian Alps, including Kosciuszko National Park, contain a large number of exotic species, including the case study species *A. millefolium*. It has also demonstrated that *A. millefolium* has the capacity to establish, grow and reproduce in natural and disturbed sites at a range of altitudes in Kosciuszko National Park. It has a high seed output, high seed viability, and an extensive rhizome system.

Based on the research in this thesis it is clear that: (1) there are a wide range of exotic taxa in the Australian Alps; (2) the distribution of exotics including *A. millefolium* in the Alps is strongly associated with human disturbance; (3) although altitude has some effect on reproduction in *A. millefolium* it does not appear to be limiting its distribution; (4) under climate change predictions it is likely that the species may become even more abundant; (5) it appears to be able to compete with native taxa, particularly after disturbance; (6) it, as with other exotics, it will be difficult to control; and (7) limiting human disturbance in natural ecosystems combined with ongoing revegetation is important in maintaining the natural values of the ecosystems and limiting the further spread of exotics.

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## **APPENDIX 1**

Plant species recorded in the general area of the small gap disturbance and soil seed bank field experiments conducted along Schlunks Pass Road in 2001-2002 (Chapter 5). The area surveyed covered 300 m<sup>2</sup> including a distance of 100 m along both sides of Schlunks Pass Road and 15 m into the natural vegetation

Common names and nomenclature are cited for each species. Taxonomy according to Harden (1992) Duncan (1998) and Costin *et al.* (2000).

Api = Apiaceae, Ast = Asteraceae, Brass = Brassicaceae, Camp = Campanulaceae, Cary = Caryophyllaceae, Ona = Onagraceae, Cyp = Cyperaceae, Fab = Fabaceae, Jun = Juncaceae, Lam = Lamiaceae, Orch = Orchidaceae, Poa = Poaceae, Hal = Haloragaceae, Res = Restionaceae, Poly = Polygonaceae, Prot = Protaceae, Ran = Ranunculaceae, Ros = Rosaceae, Rub = Rubiaceae, Rut = Rutaceae, Sty = Stylidiaceae, Viol = Violaceae, Wint = Winteraceae, Thy = Thymelaeaceae, Scr = Scrophulariaceae, Ger = Geraniaceae, Euphorb = Euphorbiaceae.

Species	Common name	Family	Category	Life form	Reproductive mode	Notes
<i>Acaena novae-zelandiae</i> Kirk	Bidgee-widgee	Ros	Native	Perennial herb	Root nodes (rhizomes), seed	Fruit an achene tightly enclosed in the spiny hypanthium; hypanthia clustered <sup>1</sup> ; good coloniser of disturbed sites; generally replaced by <i>Acaena</i> sp. A in high subalpine and alpine areas <sup>DW</sup> .
<i>Acetosella vulgaris</i> Fourr. sens. lat.	Sheep Sorrel	Pol	Weed	Perennial herb	Root stock (Rhizomes), seed	Dioecious; widespread across the Park; often classed as naturalised <sup>DW</sup> ; seed dispersed by wind and animal <sup>5</sup> .
<i>Achillea millefolium</i> L.	Yarrow	Ast	Weed	Perennial herb	Rhizomes, seed	Herbaceous perennial; achene dispersed by wind; major weed in disturbed subalpine and alpine sites <sup>2</sup> ; invasive.
<i>Aciphylla simplicifolia</i> (F. Muell.) Benth.	Mountain Aciphyll	Rub	Native	Perennial herb	Seed	Dioecious <sup>10</sup> ; common in alpine and subalpine tussock grassland and tall alpine herbfield <sup>DW</sup> .
<i>Agrostis capillaris</i> L.	Brown-top bent	Poa	Weed	Perennial grass	Seed, rhizomes and sometimes stolons <sup>8</sup>	Tufted or rhizomatous, or sometimes spread by stolons; a major weed of pastures and areas of low soil fertility, particularly on poor, acidic soils <sup>7</sup> ; a well distributed exotic throughout the Park particularly along roadsides and resorts; also a concern because it appears to invade native vegetation in higher areas <sup>DW</sup> ; seed dispersed by wind and animal <sup>5</sup>
<i>Anthoxanthum odoratum</i> L.	Sweet Vernal Grass	Poa	Weed	Perennial grass	Seed, occasionally short rhizomes <sup>4</sup>	Tufted perennial <sup>8</sup> ; widespread in KNP particularly in heavily disturbed areas – montane and subalpine <sup>DW</sup> ; often grows on potassium deficient soils <sup>7</sup> .
<i>Asperula gunnii</i> Hook.f.	Mountain Woodruff	Rub	Native	Perennial herb	Seed, rhizomes	Dioecious; ascending or decumbent perennial herb <sup>10</sup> ; a good primary coloniser of moist & shaded sites, including inter-tussock spaces; mostly alpine to subalpine <sup>DW</sup> .
<i>Asperula pusilla</i> Hook. f.	Alpine Woodruff	Rub	Native	Perennial herb	Seed, rhizomes	Prostrate dioecious perennial; sometimes erect to decumbent <sup>1</sup> ; alpine and subalpine although less common above the treeline <sup>10</sup> .
<i>Asperula scoparia</i>	Prickly	Rub	Native	Perennial	Rhizomes, seed	Dioecious ascending or decumbent perennial herb <sup>1</sup> ;

Species	Common name	Family	Category	Life form	Reproductive mode	Notes
Hook. f. <i>Cardamine astoniae</i>	Woodruff Aston's Bitter-cress	Brass	Native	herb Perennial herb	Stolons, seed	Moist areas
<i>Carex appressa</i> R.Br.	Sedge	Cyp	Native	Perennial sedge	Short rhizomes, seeds <sup>1</sup>	Monoecious; moist areas and can survive periodic inundation <sup>11</sup>
<i>Carex breviculmis</i> R.Br.	Short- flowered Dryland Sedge	Cyp	Native	Perennial sedge	Rhizomes short <sup>10</sup> , seed	Common and occurs in drier sites of sod tussock grassland and tall herbfields <sup>10</sup>
<i>Carex</i> sp.	Knob Sedge	Cyp	Native	Perennial sedge	Rhizomes, seeds	
<i>Cassinia monticola</i> Orchard		Asteraceae	Native	Shrub	Root stock, seeds	Widespread throughout the subalpine area; was not long ago separated from the <i>C. uncata</i> complex <sup>DW</sup>
<i>Cerastium vulgare</i> Hartm. (syn. <i>Cerastium fontanum</i> Baumg subsp. <i>trivale</i> (Link) J alas)	Common Mouse Ear Chickweed	Car	Weed	Biannual or perennial herb	Seeds	Animal and water dispersed seeds <sup>5</sup> ; Occasionally noted in disturbed environments in higher elevated areas within the park such as along roadsides; seeds of this and <i>C. glomeratum</i> noted to be eaten by Crimson Rosellas <sup>DW</sup>
<i>Craspedia aurantia</i> Everett & J. Thompson	Orange Billy-button	Ast	Native	Perennial herb	Rootstock, Seed	Common in dry and rocky areas in alpine and subalpine areas <sup>DW</sup> Dry areas
<i>Craspedia jamesii</i> Everett & J. Thompson	Billy-button	Ast	Native	Perennial herb	Roostock, Seed	Widespread in grasslands of lower subalpine areas <sup>DW</sup>
<i>Dactylis glomerata</i> L.	Cocksfoot	Poa	Weed	Perennial grass	Seed, tussock forming	Widespread throughout KNP, particularly in disturbed areas like roadside corridors; seems to be quite resilient in both dry and moist sites <sup>DW</sup>
<i>Austrodanthonia pencillata</i> (Labill.) H.P. Linder	Slender Wallaby Grass	Poa	Native	Perennial grass	Seed, tussock forming	Tends to be more common in montane and tableland areas of KNP, though occasionally present in subalpine areas <sup>DW</sup>
<i>Deyeuxia brachyanthera</i> (Stapf) Vickery	Bent-grass	Poa	Native	Perennial grass	Seed, loose tussock	Occasional above the treeline but more common at lower zones like montane and tableland, particularly in moist or shaded sites <sup>DW</sup>
<i>Deyeuxia quadriseta</i> (Labill.) Benth.	Bent-grass	Poa	Native	Perennial grass	Seed, tussock	Usually damp and moist areas. Occasional in subalpine area, but appears more common lower down <sup>DW</sup>

Species	Common name	Family	Category	Life form	Reproductive mode	Notes
<i>Dichelachne crinita</i> (L.) Hook. f.	Longhair Plume-grass	Poa	Native	Perennial grass	Seed, tussock	Distributed throughout KNP but tends to be occasional in higher subalpine areas <sup>DW</sup>
<i>Empodisma minus</i> (Hook. f.) L.A.S. Johnson & D.F. Cutler	Spreading Rope-rush	Res	Native	Perennial rush	Rhizomes, seed	Dioecious; wet areas like bogs but also sod tussock grassland and tall alpine herbfields; widespread and common throughout subalpine and alpine areas <sup>DW</sup> .
<i>Epilobium gunnianum</i> Hausskn.	Gunn's Willow Herb	Ona	Native	Perennial herb	Stolons, seed	Wet areas like seepages and soaks but also common in moist areas including the dampness of intertussock spaces <sup>DW</sup>
<i>Eucalyptus pauciflora</i> Sieber ex Sprengel subsp. <i>niphophila</i> (Maiden & Blakely) L. Johnson	Snow Gum	Myrtaceae	Native	Tree	Seed, some epicormic and coppicing	Most dominant tree of the subalpine zone that grows on various soils and substrates in both dry and damp areas.
<i>Euphrasia collina</i> R. Br. subsp. <i>paludosa</i>	Eye Bright	Scr	Native	Perennial herb	Seed, rhizomes <sup>DW</sup>	Wet areas? A range of habitats that tend to be dry such as grassland and Snowgum woodlands, although occasionally in moist areas (intertussock) <sup>DW</sup> .
<i>Galium proprinquum</i> l.c.	Maori Bedstraw	Rubiaceae	Native	Perennial herb	Seed, rhizomes	Shaded areas including intertussock and under shrubs
<i>Geranium potentilloides</i> L'Herit. ex DC var <i>potentilloides</i>	Alpine Swamp Crane's Bill	Ger	Native	Perennial herb	Taproot, seed	Woodlands, grasslands, tall alpine herbfields and sod tussock grasslands.
<i>Gonocarpus montanus</i> (Hook. f.) Orch.	Mat Raspwort	Hal	Native	Perennial herb	Seed, woody rootstock	
<i>Grevillea australis</i> R.Br.	Alpine Grevillea	Prot	Native	Shrub	Seed, rootstock	Very common species in alpine and subalpine heaths throughout KNP
<i>Helichrysum scorpioides</i> Labill.	Button Everlasting	Ast	Native	Perennial herb	Seed, rhizomes	Widespread grasslands, woodlands and forests in KNP, from alpine to tableland <sup>DW</sup>
<i>Hovea montana</i> (Hook. f.) J. Ross	Alpine Hovea	Fab	Native	Shrub	Seed, rootstock	Very common in heaths of the subalpine zone <sup>DW</sup>
<i>Hymenanthera dentata</i> R.Br. ex Ging ( <i>Melicytus</i> sp.)	Tree Violet or Woody Violet	Vio	Native	Shrub	Berry fruit, seed, rootstock	A very variable species across KNP.

Species	Common name	Family	Category	Life form	Reproductive mode	Notes
<i>Hypochoeris radicata</i> L.	Cat's Ear	Ast	Weed	Perennial herb	Rootstock (taproot), seed	Widespread throughout all of KNP and is able to respond to small amounts of disturbance <sup>DW</sup> ; seed wind dispersed <sup>5</sup>
<i>Isolepis subtilissima</i> Boeck.	Dwarf Club-rush	Cyp	Native	Perennial	Rhizomes, seed	Damp areas
<i>Leptorhynchos squamatus</i> (Labill.) Less. s.l.	Scaly Buttons	Ast	Native	Perennial herb	Seed, rootstock	
<i>Luzula novae-cambriae</i> Gand.	Rock Woodrush	Jun	Native	Perennial rush	Seed, short rhizomes <sup>1</sup>	Prefers drier alpine and subalpine areas, hybridises
<i>Luzula modesta</i>	Bog Woodrush	Jun	Native	Perennial rush	Seed, rhizomes <sup>10</sup>	Associated with bogs, hybridises
<i>Malus x domestica</i> Borkh.	Apple	Ros	Weed	Tree	Seed	
<i>Microseris lanceolata</i> (Walp.) Schultz-Bip.	Native Dandelion	Ast	Native	Perennial herb	Tuberous root, Suckers, seed	The species on site tended to have a tuberous root, an ecotype described in Kosciuszko Alpine Flora but not that typical of the alpine track.
<i>Olearia algida</i> N.A. Wakefield	Alpine Daisy Bush	Ast	Native	Shrub	Seed	Common in the subalpine zone, not sure if it vegetates – probably does <sup>DW</sup>
<i>Olearia phlogopappa</i> (Labill.) DC	Dusty Daisy Bush	Ast	Native	Shrub	Seed, rootstock	Both <i>flavescens</i> and <i>subrepandra</i> varieties were present on site though not separated during survey; this is the most common daisy bush throughout KNP <sup>DW</sup> . Generally grows in drier sites.
<i>Oreomyrrhis eriopoda</i> (DC.) Hook. f.	Australian Caraway	Api	Native	Perennial herb	Seed, taproot	
<i>Ozothamnus secundiflorus</i> (Wakef.) C. Jeffrey	Cascade Everlasting	Ast	Native	Shrub	Seed, rootstock	Common shrub throughout the subalpine and montane zones in KNP <sup>DW</sup>
<i>Leionema phylicifolium</i> (F. Muell.) Paul G. Wilson	Mountain Phebalium	Rut	Native	Shrub	Seed, rootstock	Mostly subalpine and occasionally alpine
<i>Phleum pratense</i> L.	Timothy Grass	Poa	Weed	Perennial grass	Seeds, tufted	Occasionally in wet or damp disturbed sites in KNP <sup>DW</sup> ; seed dispersed by wind and water <sup>5</sup> .

Species	Common name	Family	Category	Life form	Reproductive mode	Notes
<i>Picris angustifolia</i> DC. subsp. <i>merxmuelleri</i> Lack & S. Holzapfel	Mountain Picris	Ast	Native	Biennial herb	Seeds, rootstock (simple or branched taproot <sup>10</sup> )	Fairly common in KNP, <i>P. hieracoides</i> revised a few years ago <sup>DW</sup>
<i>Pimelea alpina</i> F.Muell.ex Meisn.	Alpine Rice-flower	Thy	Native	Sub-shrub	Seed, rootstock?	Reasonably common throughout the alpine and subalpine zone in heath, grasslands and woodlands <sup>DW</sup>
<i>Pimelea ligustrina</i> Labill. subsp. <i>ciliata</i> Threlfall	Kosciuszko Rose	Thy	Native	Shrub	Seed	
<i>Poa annua</i> L.	Winter Grass	Poa	Weed	annual grass	Seed	Former constituent of 'Alpine Mix' that was used extensively across KNP, particularly in higher elevated areas <sup>DW</sup>
<i>Poa costiniana</i> Vickery	Prickly Snow Grass	Poa	Native	Perennial grass	Seed	Wetter areas
<i>Poa fawcettiae</i> Vickery	Smooth- blue Snow- grass	Poa	Native	Perennial grass	Seed	Drier areas
<i>Poa helmsii</i> Vickery	Broad- leaved Snowgrass	Poa	Native	Perennial grass	Seed, rootstock evident <sup>8</sup>	Wet areas like streams and soakage areas <sup>DW</sup>
<i>Poa hiemata</i> Vickery	Soft Snow Grass	Poa	Native	Perennial grass	Seed, rhizomes <sup>8</sup>	Moist areas. <i>Poa hiemata</i> also occurs in dry alpine herbfields.
<i>Poa pratensis</i> L.	Kentucky Bluegrass	Poa	Weed	Perennial grass	Seed, rhizomes	Well distributed along roadsides in KNP <sup>DW</sup> , seeds dispersed by animal, wind and water <sup>5</sup> .
<i>Podolepis robusta</i> (Maiden & E. Betcher) J.H. Willis	Alpine Podolepis	Ast	Native	Perennial herb	Seed, rootstock	Reasonably common in the sub-alpine zone.
<i>Prasophyllum alpestre</i>	Highland Leek-orchid	Orch	Native	Herb	Seed, tuber	Damp areas
<i>Poranthera microphylla</i> Brongn.	Small Poranthera	Euphorb	Native	Annual herb	Seed	Monoecious; Common in subalpine zone and lower elevations
<i>Ranunculus graniticola</i> Melville	Granite Buttercup	Ran	Native	Perennial herb	Seed	Fairly common in a range of damp and dry environments across the alpine and subalpine zone <sup>DW</sup>

Species	Common name	Family	Category	Life form	Reproductive mode	Notes
<i>Ranunculus</i> sp.	Buttercup	Ran	Native	Perennial herb	Seed	
<i>Rumex crispus</i> L.	Curled Dock	Pol	Weed	Perennial herb	Seed	Water dispersed seed <sup>5</sup> ; favours wet areas.
<i>Scleranthus biflorus</i> (Forst. & Forst.f) Hook.f.	Twin-flower Knawel	Cary	Native	Perennial herb	Seed	Mat-forming
<i>Senecio gunnii</i> (Hook. f.) Belcher	Gunn's Groundsel	Ast	Native	Perennial herb	Rootstock, seed	Widespread in alpine and subalpine areas.
<i>Stellaria pungens</i> Brongn.	Prickly Starwort	Cary	Native	Perennial Herb	Seed	Very common in woodlands throughout the park, often growing at the base of trees or scrambling over other vegetation <sup>DW</sup>
<i>Styloidium montanum</i> Raulings & Ladiges	Alpine Trigger-plant	Sty	Native	Perennial herb	Rootstock, seed	Widespread alpine and subalpine
<i>Taraxacum officinale</i> Weber	Dandelion	Ast	Weed	Perennial herb	Rootstock (taproot), seed	Seeds dispersed by wind <sup>5</sup> ; widespread
<i>Tasmannia xerophila</i> (Parm.) M. Gray	Alpine Pepper	Wint	Native	Shrub	Root suckers, rhizomes, seed	Mainly moist sites
<i>Trifolium arvense</i> L.	Haresfoot Clover	Fab	Weed	Annual herb	Seed	Seeds may have prolonged dormancy <sup>5</sup> , widespread
<i>Trifolium pratense</i> L.	Red Clover	Fab	Weed	Perennial herb	Seed, rhizomes	Former constituent species of 'alpine mix' <sup>DW</sup> ; seeds may have prolonged dormancy <sup>5</sup>
<i>Trifolium repens</i> L.	White Clover	Fab	Weed	Perennial herb	Seed, rhizomes, occasionally stolons <sup>4</sup>	Former constituent of 'alpine mix' and widespread throughout KNP <sup>DW</sup> ; seeds may have prolonged dormancy <sup>5</sup> ; seeds spread by animals (internal & external) and water <sup>4</sup>
<i>Trisetum spicatum</i> ssp. <i>australiense</i> (L.) A.G. Richter	Brittle Grass	Poa	Native	Perennial grass	Seed and rhizomes	Damp areas
<i>Viola betonicifolia</i> Sm. subsp. <i>betonicifolia</i>	Showy Violet	Viol	Native	Perennial herb	Rootstock, seed	Herbfield and grasslands
<i>Wahlenbergia ceracea</i> Lothian	Waxy Bluebell	Camp	Native	Perennial herb	Rhizome, seed	Sod tussock and wet areas

- <sup>1</sup>Harden, G. J. (1990-1993) *Flora of New South Wales*, Volumes 1–4. New South Wales University Press, Sydney.
- <sup>4</sup>Blood, K. (2001) *Environmental Weeds – A Field Guide for SE Australia*, C.H. Jerram and Associates, Melbourne.
- <sup>5</sup>Swarbrick, J. T. and Skarratt, D. B. (1994) *The Bushweed 2 Database of Environmental Weeds in Australia*, The University of Queensland, Brisbane.
- <sup>7</sup>Lamp, C. A., Forbes S. J. and Cade, J. W. (1990) *Grasses of Temperate Australia – A Field Guide*. Inkata Press, Melbourne.
- <sup>8</sup>Sharp, D. and Simon, B.K. (2002), *AusGrass: Grasses of Australia*. CD-ROM, Version 1.0 Australian Biological Resources Study, Canberra, and Environmental Protection Agency, Brisbane.
- <sup>10</sup>Costin, A.B., Gray, M., Totterdell, C.J., and Wimbush, D.J. (2000) *Kosciuszko Alpine Flora*. CSIRO and William Collins, Sydney.
- <sup>11</sup>Sainty, G. R. and Jacobs, S. W. L. (1981) *Waterplants of New South Wales*, Water Resources Commission of New South Wales, Sydney

## **APPENDIX 2**

Details of the 18 general vegetation surveys of 363 sites conducted between 1986 and 2004 in Kosciuszko National Park, Australia. The 1228 records of 173 exotic taxa identified in these 18 surveys are collated in a database. Also identified are 136 surveyed sites where only native species were recorded (Bear *et al.* Under Review). These data were used in Chapter 7 together with specific surveys in determining the distribution of *A. millefolium* in Kosciuszko National Park.

	Source of data	Type/location of survey	Sampling unit/method
1	Hill, W. Pickering, C.M. Effect of drought and fire on alpine and subalpine vegetation in Kosciuszko National Park: severity of initial impact and predictions for recovery. Unpublished data.	1. All species 2. Alpine & subalpine zone 3. Natural areas only	Sites ~30*20 m 200 points quadrats in each site
2	Pickering, C.M., Growcock, A., Hill, W., Banks, J., Field, J., (b) Long Plain disturbed. Unpublished data	1. All species 2. Montane zone only 3. Natural and disturbed areas	6 x 1* 1 m quadrat
3	Pickering, C.M., Growcock, A., Hill, W., Banks, J, Field J (a) Long Plain natural. Unpublished data	1. All species 2. Montane zone only 3. Natural only	6 x 1* 1 m quadrat
4	Pickering, C., Appleby, M., Good, R., Hill, W., McDougall, K., Wimbush, D., and Woods, D. (2002). Plant diversity in subalpine and alpine vegetation recorded in the Kosciuszko Biodiversity Blitz. In: <i>Biodiversity in the Mountains</i> . (ed. K. Green). Australian Institute of Alpine Studies, Canberra.	1. All species 2. Alpine – subalpine 3. Natural and disturbed areas	Had a good look around large sites
5	Pickering, C.M, Growcock, A., Hill, W., Banks, J., Field, J., (c) Long Plain Transgrid. Unpublished data	1. All species 2. Montane zone 3. Disturbed areas	6, 1 x 1 m quadrats.
6	Pickering, C.M. and Hill, W. (In Press 2005) Vegetation associated with different walking track types in the Kosciuszko alpine area, Australia. <i>Journal of Environmental Management</i> .	1. All species 2. Alpine 3. Disturbed and adjacent natural areas	3 * 50 x 50 cm quadrats
7	Mallen-Cooper, J. (1990) Exotic Plants in the High Altitude Environments of Kosciuszko National Park, Southeastern Australia. PhD thesis, Department of Biogeography and Geomorphology, Research School of Pacific Studies, Australian National University, Canberra.	1. All species 2. Alpine – montane zone 3. Disturbed road verges and nearby natural areas	20 x 6 m sampling plots
8	Global Research Initiative in Alpine Environments GLORIA (2004 sampling) Unpublished data.	1. All species 2. Alpine 3. Natural only	Large sampling plots and 16, 1*1 m quadrats intensively sampled for each site
9	Bear, R. (2004) Comparing Unburnt and Burnt Subalpine Grasslands One Year after Wildfire. Honours thesis, School of Environmental and Applied Sciences, Griffith University, Gold Coast.	1. All species 2. Subalpine only 3. natural areas only	6 m * 20 /m plots, 5 line transects 1.5m apart, sampled with point quadrats every 50 cm.
10	Campbell M (2004) Vegetation Associated with the Latest Lying Snowbanks in Australia. Honours thesis, School of Environmental and Applied Sciences, Griffith University, Gold Coast.	1. All species 2. Alpine zone 3. Natural areas only	One site = 68*03 x 05 m photoquadrats Other sites: 30*03 x 05 m photoquadrats = 4.5 sq m 40 point quadrats for each photoquadrat

	<b>Source of data</b>	<b>Type/location of survey</b>	<b>Sampling unit/method</b>
11	Scherrer P (2003a) Ch 4 Long term vegetation transects in the Kosciuszko alpine zone. In: Monitoring Vegetation Change in the Kosciuszko Alpine Zone, Australia. PhD thesis, School of Environmental Sciences Griffith University, Gold Coast.	1. All species 2. Alpine zone only 3. Natural areas only	Transect of ~12 x 15.25 m sections = 182.4 m. (1200 points per section).
12	Scherrer, P. Wimbush, D. Wright, G. (2004) <i>The assessment of pre and post 2003 wildfire data collected from subalpine transects in Kosciuszko National Park</i> . Report for the Department of Environment and Conservation, National Parks and Wildlife Division.	1. All species 2. Subalpine only 3. Natural areas only	Transects: 320 m (2100 points); and 503 m (3300 points)
13	Growcock, A. (2005) Trampling Impacts in Kosciuszko National Park, Australia. PhD thesis, School of Environmental Sciences, Griffith University, Gold Coast.	1. All species 2. Alpine and subalpine 3. Natural areas only	2.16 sq m quadrat/site
14	Scherrer, P. (2003b) Ch 5 Long Term photoquadrats in the Kosciuszko alpine zone. In: Monitoring Vegetation Change in the Kosciuszko Alpine Zone, Australia. PhD thesis, School of Environmental Sciences Griffith University, Gold Coast.	1. All species 2. Alpine zone only 3. Natural areas only	0.7 x 0.9 m photoquadrats, 30 in total; 18 Mt Gungartan; 12 Mt Kosciuszko
15	Scherrer, P. (2003c) Ch 6 Restoration of alpine herbfield on a closed walking track in the Kosciuszko alpine zone. In: Monitoring Vegetation Change in the Kosciuszko Alpine Zone, Australia. PhD thesis. School of Environmental Sciences Griffith University, Gold Coast.	1. All species 2. Alpine only 3. Disturbed and adjacent natural	1 x 1 metre quadrats
16	Johnston F Ch 5 this thesis	1. All species 2. Subalpine only 3. Disturbed adjacent and nearby natural vegetation	0.5 x 1 m quadrat
17	Bear, Z. and Pickering, C.M. Impacts of fire on road verges and adjacent natural areas (unpublished data).	1. All species 2. Subalpine zone 3. Disturbed road verge and adjacent natural vegetation	Each treatment has 3, 5x20 m line transects with 40 point quadrats (ie every 50 cm)
18	Johnston, F. and Johnston, S.W. (2004). Impacts of road disturbance on soil properties and on exotic plant occurrence in subalpine areas of the Australian Alps. <i>Arctic, Antarctic and Alpine Research</i> <b>36</b> , 201-207.	1. All species 2. Subalpine zone 3. Disturbed road verge and adjacent natural areas	1 x 1 m quadrats



## **APPENDIX 3**

Arthropods found on *Achillea millefolium* plants in a snapshot survey during February 2000 in Kosciuszko National Park and surrounding areas. (Arthropod identification kindly provided by Australian National Insect Collection staff at the Division of Entomology, Canberra).

**Arthropods found on *Achillea millefolium* plants in February 2000**

Altitude	Class	Order	Family	Genus	Species	Common Name
800	Insecta	Coleoptera	Scarabaeidae	<i>Pseudoheteronyx</i>	<i>P. creber</i>	scarab beetle
800	Insecta	Coleoptera	Scarabaeidae	<i>Pseudoheteronyx</i>	<i>P. creber</i>	scarab beetle
800	Insecta	Hemiptera	Pentatomidae			shield bug
900	Insecta	Diptera	Acroceridae			small-headed fly
900	Insecta	Hemiptera	Pentatomidae			shield bug
900	Insecta	Hemiptera	Reduviidae	<i>Gminatus</i>	<i>G. australis</i>	assassin bug
900	Insecta	Mecoptera	Choristidae	<i>Chorista</i>	<i>C. australis</i>	scorpion fly
1440	Insecta	Diptera	Muscidae	<i>Musca</i>	<i>M. vetustissima</i>	bush fly
1440	Insecta	Hymenoptera				bee
1440	Insecta	Diptera	Calliphoridae			blowfly
1440	Insecta	Hymenoptera	Tiphidae			flower wasp
1440	Insecta	Orthoptera	Tettigoniidae	<i>Conocephalus</i>		katydid
1460	Insecta	Lepidoptera	Hesperiidae			skipper butterfly
1460	Insecta	Orthoptera	Tettigoniidae	<i>Conocephalus</i>		katydid
1460	Insecta	Diptera	Syrphidae	<i>Eristalis</i>	<i>E. tenax</i>	drone fly
1460	Insecta	Hymenoptera	Apidae	<i>Exoneura</i>		reed bee
1460	Insecta	Hymenoptera	Apidae	<i>Exoneura</i>		reed bee
1460	Insecta	Diptera	Culicidae			mosquito
1460	Arachnia	Araneae	Salticidae			jumping spider
1460	Insecta	Diptera	Lauxaniidae			fly
1580	Insecta	Hemiptera	Cicadellidae			leafhopper
1580	Insecta	Diptera	Chironomidae			midge
1580	Insecta	Diptera	Chironomidae			midge
1580	Insecta	Diptera	Dolichopodidae			long legged fly
1580	Arachnia	Araneae				spider
1580	Insecta	Coleoptera	Mordellidae			pintail beetle
1580	Insecta	Diptera	Tachinidae			bristle fly
1650	Arachnia	Araneae	Araneidae	<i>Eriophora</i>		orb-weaving spider
1650	Arachnia	Araneae	Araneidae			orb-weaving spider
1650	Arachnia	Araneae	Araneidae			orb-weaving spider
1650	Insecta	Hymenoptera	Ichneumonidae			ichneumon wasp
1650	Insecta	Diptera	Chironomidae			midge
1650	Insecta	Coleoptera	Mordellidae			pintail beetle
1650	Arachnia	Araneae				spider
1650	Insecta	Lepidoptera				moth
1650	Insecta	Hymenoptera	Apidae	<i>Exoneura</i>		reed bee
1650	Insecta	Hymenoptera	Apidae	<i>Exoneura</i>		reed bee
1650	Insecta	Hymenoptera	Apidae	<i>Exoneura</i>		reed bee
1650	Insecta	Diptera	Calliphoridae			blowfly
1650	Insecta	Diptera	Calliphoridae			blowfly
1650	Insecta	Coleoptera	Cantharidae	<i>Chauliognathus</i>	<i>C. lugubris</i>	plague soldier beetle
1650	Insecta	Hymenoptera	Apidae	<i>Exoneura</i>		reed bee
1650	Insecta	Hemiptera	Pentatomidae			shield bug
1650	Insecta	Coleoptera	Mordellidae			pintail beetle
1650	Arachnia	Araneae	Araneidae			orb-weaving spider
1650	Insecta	Hemiptera	Reduviidae			assassin bug

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**Arthropods found on *Achillea millefolium* plants in February 2000**

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1650	Insecta	Coleoptera	Mordellidae			pintail beetle
1650	Insecta	Coleoptera	Chrysomelidae	<i>Monolepta</i>		leaf beetle
1650	Insecta	Hemiptera	Tingidae			lace bug
1650	Insecta	Coleoptera	Mordellidae			pintail beetle
1650	Insecta	Diptera	Lauxaniidae			fly
1650	Insecta	Hemiptera	Cicadellidae			leafhopper
1650	Insecta	Hymenoptera	Apidae	<i>Exoneura</i>		reed bee
1650	Insecta	Hymenoptera	Apidae	<i>Exoneura</i>		reed bee
1650	Insecta	Hymenoptera	Apidae	<i>Exoneura</i>		reed bee
1760	Insecta	Hemiptera	Reduviidae	<i>Gminatius</i>	<i>G. australis</i>	assassin bug
1760	Insecta	Diptera	Empididae			fly
1760	Insecta	Hemiptera	Pentatomidae			shield bug
1760	Insecta	Diptera	Calliphoridae			blowfly
1760	Insecta	Diptera	Calliphoridae			blowfly
1760	Insecta	Diptera	Calliphoridae			blowfly
1760	Insecta	Hymenoptera	Colletidae	<i>Leioproctus</i>		bee
1760	Insecta	Orthoptera	Acrididae			grasshopper
1760	Insecta	Hymenoptera				bee
1780	Insecta	Diptera	Tachinidae			bristle fly
1780	Insecta	Coleoptera	Buprestidae	<i>Castiarina</i>	<i>C. flavoviridis</i>	jewel beetle
1780	Insecta	Coleoptera	Buprestidae	<i>Castiarina</i>	<i>C. flavoviridis</i>	jewel beetle
1780	Insecta	Lepidoptera	Nymphalidae	<i>Oreixenica</i>	<i>O. orichora</i>	spotted alpine xenica
1780	Insecta	Orthoptera	Acrididae			grasshopper
1780	Insecta	Orthoptera	Acrididae			grasshopper
1780	Insecta	Orthoptera	Acrididae			grasshopper

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