Annotated Bibliography on the Ecology and Management of Invasive Species:

Hedgehog Dogtail (*Cynosurus echinatus*)

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For the Garry Oak Ecosystems Recovery Team
and the Nature Conservancy of Canada
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AgWest and Hawaiian Ecosystems at Risk Project 2001. Global Compendium of Weeds. Website: www.hear.org/gcw/index.html. Accessed: November 7, 2002.

The information on this website is still being compiled and updated. It currently gives details on nomenclature (including an extensive list of alternate common names), the origin of the species (Eurasia) and a list of data sources that refer to this species.

Adkins, S. W., S. Tanpipat, J. T. Swarbrick and M. Boersma. 1998. The influence of soil moisture content on glyphosate efficacy for the control of annual grasses in fallow land. Weed Research 38 (2): 119-127.

Authors' abstract: In order to determine the effects of soil moisture content on the efficacy of glyphosate, field experiments were conducted on three annual grass weeds (*Avena fatua* L., *Urochloa panicoides* Beauv. and *Echinochloa colona* L. (Link)). The soil moisture conditions were as follows: absence of rainfall using a rain-out shelter, natural rainfall and natural rainfall plus irrigation (2.5 cm week-1). These conditions were selected as they are representative of those in winter and summer fallows in the north-east grain region of Australia and had been previo usly identified by glasshouse experiments to be conditions that influence glyphosate efficacy. As predicted, efficacy of 360 g acid equivalent ha-1 glyphosate when applied to all three species was greatest under the irrigated and normal rainfall conditions and significantly less under the exclusion of rainfall condition. This response was the same for all near-isogenic lines of *A. fatua* and *U. panicoides* studied. As mild and severe forms of water stress are common events in the region, it is highly likely that soil moisture level will interfere with efficacy of glyphosate application in summer and winter fallows.

Belnap, J. and S. L. Phillips. 2001. Soil biota in an ungrazed grassland: Response to annual grass (*Bromus tectorum*) invasion. Ecological Applications 11 (5): 1261-1275.

Authors' abstract: *Bromus tectorum* is an exotic annual grass that currently dominates many western U.S. semi-arid ecosystems, and the effects of this grass on ecosystems in general, and soil biota specifically, are unknown. *Bromus* recently invaded two ungrazed and unburned perennial bunchgrass communities in southeastern Utah. This study compared the soil food-web structure of the two native grassland associations (*Stipa* (S) and *Hilaria* (H)), with and without and presence of *Bromus*. Perennial grass and total vascular-plant cover were higher in S than in H plots, while quantities of ground litter were similar. Distribution of live and dead plant material was highly clumped in S and fairly homogenous in H. Soil food-web structure was different between H and S, with lower trophic levels more abundant in H and higher trophic levels more abundant in S. In *Bromus*-invaded plots, the quantity of ground litter was 2.2 times higher in *Hilaria-Bromus* (HB) than in H plots, and 2.8 times higher in *Stipa-Bromus* (SB) than in S plots. Soil biota in HB generally responded to the *Bromus* invasion in an opposite manner than in SB, e.g., if a given component of the food web increased in one community, it generally decreased in the other. Active bacteria decreased in H vs. HB, while increasing in S vs. SB. Soil and live plant-infecting fungi were the exception, as they increased in both types of invaded plots relative to uninvaded plots. Dead-plant-infecting fungi decreased in H vs. HB and increased in S vs. SB. Most higher-trophic-level organisms increased in HB relative to H, while decreasing in SB relative to S. Given the mixed response to invasion, the structure of these soil food webs appears to be controlled by both plant inputs and internal dynamics between trophic levels. When compared to non-invaded sites, soil and soil food-web characteristics of the newly invaded sites included: (1) lower species richness and lower absolute numbers of fungi and invertebrates; (2) greater abundance of active bacteria; (3) similar species of bacterial and fungi as those found in soils invaded over 50 yr ago; (4) higher levels of silt (thus greater fertility and soil water-holding capacity); and (5) a more continuous cover of living and dead plant material (thus facilitating germination of the large-seeded *Bromus*). These results illustrate that (1) soil food-web structure can vary widely within what would generally be considered one vegetation type (semi-arid grassland), depending on plant species composition within that type, and (2) addition of a common resource can evoke disparate responses from individual food-web compartments, depending on their original structure.

Brown, C. S. and K. J. Rice. 2000. The mark of zorro: Effects of the exotic annual grass *Vulpia myuros* on California native perennial grasses. Restoration Ecology 8 (1): 10-17.

Authors' abstract: Native perennial grasses were once common in California prairies that are now dominated by annual grasses introduced from Europe. Competition from exotics may be a principal impediment to reestablishment of native perennial grasses. Introduced annual grasses, such as *Vulpia myuros* (zorro fescue), are often included with native perennial species in revegetation seed mixtures used in California. To examine the potential suppressive effect of this graminoid, we evaluated the growth and performance

of a mixture of California native perennial grasses and resident weeds when grown with varying densities of *V. myuros*. The annual fescue exhibited a strongly plastic growth response to plant density, producing similar amounts of above-ground biomass at all seeding densities. Perennial grass seedling survival and above-ground biomass decreased and individuals became thinner (i.e., reduced weight-to-height ratio) with increasing *V. myuros* seeding density. *V. myuros* also significantly suppressed above-ground biomass and densities of weeds and had a more negative effect on weed densities than on native perennial grass densities. Biomass of native grasses and weeds was not differentially affected by increasing densities of *V. myuros*. Overall, because *V. myuros* significantly reduced the survival and performance of the mixture of native perennial grasses and this effect increased with increasing *V. myuros* density, we conclude that including this exotic annual in native seed mixtures is counterproductive to restoration efforts.

Carlsen, T. M., J. W. Menke and B. M. Pavlik. 2000. Reducing competitive suppression of a rare annual forb by restoring native California perennial grasslands. Restoration Ecology 8 (1): 18-29.

Authors' abstract: Populations of the rare annual forb *Amsinckia grandiflora* may be declining because of competitive suppression by exotic annual grasses, and may perform better in a matrix of native perennial bunchgrasses. We conducted a field competition experiment in which *Amsinckia* seedlings were transplanted into forty 0.64-m2 experimental plots of exotic annual grassland or restored perennial grassland. The perennial grassland plots were restored using mature 3 cm-diameter plants of the native perennial bunchgrass *Poa secunda* planted in three densities. The exotic annual grassland plots were established in four densities through manual removal of existing plants. Both grass types reduced soil water potential with increasing biomass, but this reduction was not significantly different between grass types. Both grass types significantly reduced the production of *Amsinckia* inflorescences. At low and intermediate densities (dry biomass per unit area of 20-80 g/m2), the exotic annual grasses reduced *Amsinckia* inflorescence number to a greater extent than did *Poa*, although at high densities (>90 g/m2) both grass types reduced the number of *Amsinckia* inflorescences to the same extent. The response of *Amsinckia* inflorescence number to *Poa* biomass was linear, whereas the same response to the annual grass biomass is logarithmic, and appeared to be related to graminoid cover. This may be because of the different growth forms exhibited by the two grass types. Results of this research suggest that restored native perennial grasslands at intermediate densities have a high habitat value for the potential establishment of the native annual *A. grandiflora*.

Cenci, C. A., A. Candolini and V. Verona. 1998. Preliminary research on the urban flora of Udine (NE Italy). Societa Veneziana di Scienze Naturali Lavori 23 (0): 69-74.

Authors' abstract: The description of the area surveyed and the research methods utilized in the study of the spontaneous flora in the town of Udine (NE Italy) are presented here. The results indicate the presence of some new species as well as others, previously thought as extinct in both the province and region, which have been found in town during the first stage of the research, namely: *Aegilops geniculata, Brachypodium distachyon,*

Bromus rigidus, Centaurea calcitrapa, Cynosurus echinatus, Dasyphyrum villosum, Herniaria hirsuta, Linaria repens, Sideritis romana.

Ceska, A. 2002. *Personal communication.* Botanist. Victoria, BC. October 10, 2002.

Ceska has observed hedgehog dogtail in shallow soiled sites. He notes the species is pervasive, prolific and has an abundant seed bank. For these reasons, management of this species will be very difficult, if not hopeless. He states that it is difficult to gauge the effect of this species on Garry oak ecosystems because the original understory composition of the ecosystems is not known.

Cione, N. K., P. E. Padgett and E. B. Allen. 2002. Restoration of a native shrubland impacted by exotic grasses, frequent fire, and nitrogen deposition in southern California. Restoration Ecology 10 (2): 376-384.

Authors' abstract: Natural ecosystems globally are often subject to multiple human disturbances that are difficult to restore. A restoration experiment was done in an urban fragment of native coastal sage scrub vegetation in Riverside, California that has been subject to frequent fire, high anthropogenic nitrogen deposition, and invasion by Mediterranean annual weeds. Hand cultivation and grass-specific herbicide were both successful in controlling exotic annual grasses and promoting establishment of seeded coastal sage scrub vegetation. There was no native seedbank left at this site after some 30 years of conversion to annual grassland, and the only native plants that germinated were the seeded shrubs, with the exception of one native summer annual. The city green-waste mulch used in this study (C:N of 39:1) caused short-term N immobilization but did not result in decreased grass density or increased native shrub establishment. Seeding native shrubs was successful in a wet year in this Mediterranean-type climate but was unsuccessful in a dry year. An accidental spring fire did not burn first-year shrubs, although adjacent plots dominated by annual grass did burn. The shrubs continued to exclude exotic grasses into the second growing season, suggesting that successful shrub establishment may reduce the frequency of the fire return interval.

Claassen, V. P. and M. Marler. 1998. Annual and perennial grass growth on nitrogen-depleted decomposed granite. Restoration Ecology 6 (2): 175-180.

Authors' abstract: Decomposed granite (DG) is often difficult to revegetate because of its low nitrogen (N) content and poor physical properties. Use of soluble fertilizers on DG sites increases plant-available N but may encourage invasive annuals to grow rapidly and exclude perennial species. This study evaluates the effect of N availability on two potential DG revegetation species: an invasive, exotic annual grass (*Bromus mollis*) and a native perennial grass (*Elymus glaucus*). Plants in 10-L pots filled with DG were irrigated with all essential elements except N, which was provided in treatments ranging from zero to 1000 muM NO3-N. Shoot biomass and root distribution were measured in monocultures and in mixtures of annual and perennial plants, both when the two species were seeded simultaneously and when the perennials were seeded 50 days prior to the annuals. At the higher N treatments, growth of annuals exceeded that of perennials. At

solution N concentrations lower then the 50-100 muM treatments, however, growth of the perennial grasses equalled or exceeded that of the annuals. When seeded simultaneously, both species showed reduced biomass in mixtures to an extent similar to that when each species grew alone. When the perennials were already established, the biomass of annuals was reduced proportionately more than that of perennials, even at the highest N treatment. At low and medium N treatments, root placement of the perennial was deeper than that of the annual. At high N treatments, however, root distribution of both species was similar, and the deep rooting characteristic of the perennial was no longer observed.

Cristi, L. A. and J. M. Duran. 1984. The seeds of the phytocenosis hayedo de Montejo de la Sierra Madrid and their germination under controlled conditions. Phyton Buenos Aires 44 (1): 17-24.

Authors' abstract: The results obtained from seed germination under controlled conditions of humidity, darkness and temperature (15.degree., 20.degree. and 25.degree. C) from 50 taxa of the phytocenosis of "Montejo de la Sierra (Madrid [Spain])" are given. Between 15.degree. and 25.degree. C, 58% of the lots showed a germinative capacity < 25%; 15% germinated better at the lower temperature (*Aira caryophyllea, Geum sylvaticum, Rumex acetosa*, etc.); 17% germinated better at the intermediate temperature (*Epilobium montanum*) or showed an indifferent response (*Cynosurus echinatus, Hordelymus europaeus*, etc.) and the remaining 10% reached the best germination percentage at the highest temperature (*Mycelis muralis, Tordylium maximum*, etc.). Germination with different abscisic acid (ABA) concentrations shows the existence of seeds with different sensitivity to this inhibitor. The allelopathic effect of ABA is discussed.

Cullington and Associates. 2001. Invasive species in Garry oak and associated ecosystems in British Columbia. Fact sheets: *Anthoxanthum odoratum* and *Dactylis glomerata*. Garry oak ecosystems recovery team, Victoria, BC.

The fact sheets state “Non-native grasses such as sweet vernalgrass [orchard grass] are present in most Garry oak ecosystems and may comprise over 30 percent of the vegetation”. This inoformation was included in the current fact sheets but the original source of the information is not known.

Dear, B. S. and P. S. Cocks. 1997. Effect of perennial pasture species on surface soil moisture and early growth and survival of subterranean clover (*Trifolium subterraneum* L.) seedlings. Australian Journal of Agric ultural Research 48 (5): 683-693.

Authors' abstract: Subterranean clover seedling numbers and growth in swards containing 1 of 5 perennial pasture species (phalaris (*Phalaris auatica*) cv. Sirolan, cocksfoot (*Dactylis glomerata*) cv. Currie, lucerne (*Medicago sativa*) cv. Aquarius, wallaby grass (*Danthonia richardsonii*) cv. Taranna, and lovegrass (*Eragrostis curvula*) cv. Consol) were compared with those in typical annual pastures and pure clover swards in the wheatbelt of eastern Australia. Presence of a perennial species or the volunteer annual grass (*Eragrostis cilianensis*) increased the rate of drying of the soil surface (0-5

cm) after late February and May rain, compared with subterranean clover swards. Perennials differed in the rate they dried the soil surface, with the more summer-active lucerne and consul lovegrass drying the profile more rapidly than phalaris. The amount of water in the surface 5 cm, 6 days after the rainfall event on 27-28 February, was strongly negatively correlated (r = -0.75, P lt 0.01) with the amount of green perennial biomass, but not related to standing dead material or surface residues. Where perennials were present, a smaller proportion (2-4%) of the clover seed pool produced seedlings in response to late summer rain, compared with pure clover swards (18%). A higher proportion of the seed pool produced seedlings (19-36%) following rain in late autumn but there was no difference between species. The more summer-active perennials (cocksfoot, danthonia, and lucerne) markedly depressed the survival of emerged clover seedlings following both germinations. Of the seedlings that emerged in early March, the proportion remaining by 29 March was 57% in phalaris, 21% in lucerne, 13% in danthonia, and 1% in cocksfoot, compared with a 78% increase in seedlings in pure subterranean clover swards. By 15 May, all perennials had lt 2 clover seedlings/m-2 surviving, compared with 37 in the annual pasture and 964 plants/m-2 in pure subterranean clover. Following the May germination, the highest proportion of emerged seedlings surviving until 29 May was in the phalaris swards (40%) and least in the cocksfoot and danthonia swards (2-4%). Presence of a perennial or annual grass decreased (P lt 0.05) relative water content of clover seedlings on 15 March from 74% in pure clover swards, to 48% in annual pasture, 34% in phalaris, and 29% in lucerne swards. Clover seedlings growing in pure subterranean swards on 15 March (17 days after germinating rain) were 4 times larger than those in lucerne and twice as large as those in either phalaris or annual pasture. Seed size did not differ between treatments, but available mineral soil nitrogen was significantly higher (P lt 0.001) in pure subterranean clover swards (32 mu-g N/g) compared with perennials (3-13 mu-g N/g). Strategies such as heavy grazing in late summer to reduce green biomass of the perennials or sowing the perennials at lower densities may reduce the adverse effects that perennials have on subterranean clover seedlings in these drier environments.

Douglas, G. W., D. Meidinger, and J. Pojar (eds.). 2001. Illustrated Flora of British Columbia, Volume 7: Monocotyledons (Orchidaceae through Zosteraceae). Ministry of Sustainable Resource Management, British Columbia Ministry of Forests, Victoria, BC.

This comprehensive reference has excellent identification keys and detailed technical descriptions of vegetative and sexual morphology. This flora is the taxonomic authority for the invasive species fact sheets (unless otherwise indicated). Douglas *et al.* describe the habitat of hedgehog dogtail as "mesic, sandy shores, Garry oak woodlands, grassy rock outcrops and disturbed sites in the lowland, steppe and montane zones". This species has been introduced from Europe and is infrequent in southwest British Columbia and rare in southeast British Columbia.

Dowling, P. M., A. R. Leys and B. Plater. 1997. Effect of herbicide and application of superphosphate and subterranean clover seed on regeneration of vulpia in pastures. Australian Journal of Experimental Agriculture 37 (4): 431-438.

Authors' abstract: The annual grass vulpia has become one of the main weed problems in permanent pasture and cropping areas across southern Australia. The effect of herbicides and management (application of superphosphate and subterranean clover seed) on regeneration of vulpia in pasture was evaluated over a 2 year period at 6 sites in central and southern New South Wales (Beckom, Wagga Wagga, Eugowra, Bathurst, Holbrook and Millthorpe) during 1989-91. Four herbicide strategies (nil, spraytopping with paraquat in spring 1989, winter cleaning with simazine in winter 1990, and spraytopping with paraquat in spring 1989 followed by winter cleaning with simazine in 1990) were evaluated at a low (no added superphosphate or subterranean clover seed) and high level (250 kg/ha additional superphosphate applied in autumn 1989 and again in autumn 1990, plus 10 kg/ha subterraean clover seed broadcast in 1989) of management. Herbicides decreased the incidence of vulpia (as assessed from seedling density and pasture composition measurements) at low and high levels of management, with simazine and the combined paraquat plus simazine treatment providing more effective control than paraquat. The population of vulpia, however, increased rapidly on both the simazine and paraquat treatments with time. On the paraquat plots, this resulted in a similar or greater vulpia density as the unsprayed control within 2 years of application. The higher level of management encouraged greater density of subterranean clover and nitrophilous species (e.g. barley grass where present), resulting in greater competition against vulpia, and extending the period of control conferred initially by the herbicides. Control of vulpia over the longer term will require integration of herbicides with other management strategies (e.g. superphosphate, additional seed, careful grazing management). Such an approach needs to be implemented on a more regular basis than is currently practiced if the impact of vulpia in pastures is to be minimized.

Dunn, P. 1998. Prairie habitat restoration and maintenance on Fort Lewis and within the South Puget Sound prairie landscape: Final report and summary of findings. Report for the Nature Conservancy of Washington. February 1, 1998.

The report summarizes ongoing restoration efforts in prairie grasslands at Fort Lewis, Washington. This site is one of few active restoration sites in ecosystems similar to Garry oak ecosystems in Canada and provides a valuable resource for effective control methods. Invasive species management used at Fort Lewis includes prescribed burning, mechanical control and herbicides. Native species have also been replanted to this site. Non-selective herbicides were not used at Fort Lewis because they kill native grasses and forbs in addition to the target species. Selective herbicides such as Fusilade (containing fluazifop) and Poast (containing sethoxydim) have been used with some success to control colonial bentgrass. These herbicides kill broad leaved exotic grasses but do not harm fine leaved grasses such as *Festuca idahoensis*, sedges or dicotyledonous wildflowers. Herbicide application reduced the percent cover of bentgrass and prevented flowering the year the herbicide was applied. However, bentgrass flowered the season following application. Transplanted *Festuca idahoensis* plugs had greater survival when planted on sites that had exotic grasses controlled by a smothering mulch or herbicides. Application of fertilizer favoured invasive grasses and should not be used for restoration in Garry oak ecosystems.

Dyer, A. R. and K. Rice. 1999. Effects of competition on resource availability and growth of a California bunchgrass. Ecology 80 (8): 2697-2710.

Authors' abstract: In California, little is known about the sensitivity of native bunchgrasses to competition or to changes in resource availability. We investigated the effect of nonnative annual vegetation on resource availability and growth of a native bunchgrass, *Nassella pulchra*, in a pair of factorial field experiments that incorporated effects of both interspecific and intraspecific competition as well as variation in soil depth. Plots of differing target densities and neighborhoods were used to assess changes in aboveground (light) and below ground (water) resource availability over multiple seasons in two sites with differing soil depth. *N. pulchra* grown without interspecific competitors grew larger and produced more culms at all planting densities compared to plants in plots with interspecific competitors. Intraspecific competition significantly influenced growth only in the absence of interspecific competition. Reproductive effort, as measured by flowering culm production was more sensitive than vegetative growth to both forms of competition. Light availability and variability at the soil surface was greatly reduced by the nonnative annual neighborhood. As expected, soil moisture was rapidly depleted by annuals to 30 cm in all plots. In deep-soil plots, soil moisture was reduced at 60-150 cm depths only when annual vegetation was removed, and depletion was correlated with *N. pulchra* basal area. This result suggests that the interspecific neighborhood reduced root growth in *N. pulchra* and its subsequent ability to use deep moisture. Within California's inland grasslands, nonnative annual vegetation has changed seasonal patterns of resource availability. We conclude that (1) increased competition for light during the spring, when growth of annuals is most rapid, suppresses growth and reproduction of *N. pulchra*; (2) by suppressing bunchgrass growth, annual grasses reduce access to belowground resources by competitive interference; and (3) the loss of perennial grasses in California grasslands and the general dominance by nonnative annual species results in the relative underutilization of deep soil resources. These conclusions suggest that the dominance of California grasslands by nonnative annual vegetation has shifted the primary limiting resource from soil moisture to light and the timing of resource limitation from summer to winter and spring.

Eliason, S. A. and E. B. Allen. 1997. Exotic grass competition in suppressing native shrubland re-establishment. Restoration Ecology 5 (3): 245-255.

Authors' abstract: Disturbance of coastal sage scrub in southern California has led to extensive displacement of native shrubs by exotic annual grasses. The initial conversion from shrubland to exotic grassland is typically associated with disturbance caused by intense grazing, high fire frequency, or mechanical vegetation removal. While native shrubs have been shown to recolonize annual grasslands under some conditions, other annual grasslands are persistent and show no evidence of shrub recolonization. This study examined the mechanisms by which annual grasses may exclude native shrubs and persist after release from disturbance. Grass density was manipulated in experimental plots to achieve a series of prescribed densities. *Artemisia californica*, a dominant native shrub, was seeded or planted into the plots and responses to the grass density treatments were measured over two growing seasons. *A. californica* germination, first season growth, and

survival were all negatively related to the density of neighboring annual grasses. The most probable mechanism underlying the reduction of first season growth and survival was depletion of soil water by the grasses. The effects of the grasses on *A. californica* were no longer significant in the second season. The results of this study indicate that Mediterranean annual grasses reduce recruitment and can persist by inhibiting postdisturbance establishment of *A. californica* from seed. Although succession alone may not return disturbed annual grasslands to their former shrubland composition, the results suggest that restoration can be achieved by using container plantings or grass removal followed by seeding.

Erickson, W. 2002. *Personal communication*. Botanist, Ministry of Forests, Victoria, BC. October 10, 2002.

Erickson has observed hedgehog dogtail throughout the entire range of Garry oak ecosystems and notes that the species has heavily invaded large areas. It is an early invader, primarily on shallow soils and slopes where resources are scarce. It impacts rare and common native species by occupying space, commanding resources and acting as a physical barrier to distribution. Erickson suggests that it is worth investigating whether *C. echinatus* impacts ecosystems in the same manner as *Bromus tectorum*, a winter annual with similar ecological characteristics. *Bromus tectorum* germinates in the fall and impacts native species by competing for water early in the spring. During his research on Garry oak plant communities, Erickson found *Cynosurus echinatus* occurred frequently and was found in association with *Bromus sterilis, Bromus tectorum, Cytisus scoparius, Poa pratensis, Aira praecox* and *Aira caryophyllea*. In one location *C. echinatus* occurred as a post-burn community.

Evans, R. D., R. Rimer, L. Sperry and J. Belnap. 2001. Exotic plant invasion alters nitrogen dynamics in an arid grassland. Ecological Applications 11 (5): 1301-1310.

Authors' abstract: The introduction of nonnative plant species may decrease ecosystem stability by altering the availability of nitrogen (N) for plant growth. Invasive species can impact N availability by changing litter quantity and quality, rates of N2-fixation, or rates of N loss. We quantified the effects of invasion by the annual grass *Bromus tectorum* on N cycling in an arid grassland on the Colorado Plateau (USA). The invasion occurred in 1994 in two community types in an undisturbed grassland. This natural experiment allowed us to measure the immediate responses following invasion without the confounding effects of previous disturbance. Litter biomass and the C:N and lignin:N ratios were measured to determine the effects on litter dynamics. Long-term soil incubations (415 d) were used to measure potential microbial respiration and net N mineralization. Plant-available N was quantified for two years in situ with ion-exchange resin bags, and potential changes in rates of gaseous N loss were estimated by measuring denitrification enzyme activity. *Bromus* invasion significantly increased litter biomass, the *Bromus* litter had significantly greater C:N and lignin:N ratios than did native species. The change in litter quantity and chemistry decreased potential rates of net N mineralization in sites with *Bromus* by decreasing nitrogen available for microbial activity. Inorganic N was 50% lower on *Hilaria* sites with *Bromus* during the spring of

1997, but no differences were observed during 1998. The contrasting differences between years are likely due to moisture availability; spring precipitation was 15% greater than average during 1997, but 52% below average during spring of 1998. *Bromus* may cause a short-term decrease in N loss by decreasing substrate availability and denitrification enzyme activity, but N loss is likely to be greater in invaded sites in the long term because of increased fire frequency and greater N volatilization during fire. We hypothesize that the introduction of *Bromus* in conjunction with land-use change has established a series of positive feedbacks that will decrease N availability and alter species composition.

Fleming, T. 2002. *Personal communication*. Ecologist, CRD Parks, Victoria, BC. October 25, 2002.

Fleming has observed hedgehog dogtail growing on colluvial veneer slopes, usually over broken rock. In some places it is as abundant as sweet vernal grass (*Anthoxanthum odoratum).* It grows in sites that are wet in the spring and it is often found in association with *Trifolium depauperatum*. CRD Parks has not tried any forms of management to control this species.

Gayton, D. 2002. *Personal communication*. Grasslands Ecologist, Ministry of Forests, Nelson, BC. October 10, 2002.

Gayton was only slightly familiar with hedgehog dogtail from various casual trips to Garry oak ecosystems and he had no direct knowledge of autecology or control. However, he suggested that hedgehog dogtail may occupy a roughly analogous niche to the various annual bromes in the grasslands of the interior of British Columbia. Minimising soil disturbance may help prevent invasion and limit the spread of the species. Gayton also speculated as to whether tree and shrub encroachment could be tipping the balance in favour of introduced annuals and away from the perennial native grasses. The annual grasses seem to have a lower light saturation threshold which allows them to thrive with overstory canopy closure. Tree and shrub infilling may also be affecting the water balance to favour exotic annual grasses. Invasion is also affected by fire suppression.

Gordon, D. R. and K. J. Rice. 1993. Competitive effects of grassland annuals on soil water and blue oak (*Quercus douglasii*) seedlings. Ecology 74 (1): 68-82.

Gordon and Rice experimentally tested the impact of four nonnative annual plants on soil water availability and the growth of adjacent blue oak seedlings. Two forbs (*Erodium botrys* and *Hemizonia luzulaefolia*) and two grasses (*Bromus diandrus* and *B. mollis*) were sown at different densities around one acorn. Gordon and Rice found that survivorship of oak seedlings was negatively impacted by soil water depletion. Nonnative annuals had varying degrees of impact on oak seedlings depending on the phenology and root length of the annual.

Hamilton, J. G., C. Holzapfel and B. E. Mahall. 1999. Coexistence and interference

between a native perennial grass and non-native annual grasses in California. Oecologia 121 (4): 518-526.

Authors' abstract: Little is known about the potential for coexistence between native and non-native plants after large-scale biological invasions. Using the example of native perennial bunchgrasses and non-native annual grasses in California grasslands, we sought to determine the effects of interference from non-native grasses on the different life stages of the native perennial bunchgrass *Nassella pulchra*. Further, we asked whether *N. pulchra* interferes with non-native annual grasses, and whether competition for water is an important component of these interspecific interactions in this water-limited system. In a series of field and greenhouse experiments employing neighbor removals and additions of water, we found that seedling recruitment of *N. pulchra* was strongly seed-limited. In both field and greenhouse, natural recruitment of *N. pulchra* seedlings from grassland soil was extremely low. In field plots where we added seeds, addition of water to field plots increased density of *N. pulchra* seedlings by 88% and increased total aboveground *N. pulchra* seedling biomass by almost 90%, suggesting that water was the primary limiting resource. In the greenhouse, simulated drought early in the growing season had a greater negative effect on the biomass of annual seedlings than on the seedlings of *N. pulchra*. In the field, presence of annuals reduced growth and seed production of all sizes of *N. pulchra*, and these effects did not decrease as *N. pulchra* individuals increased in size. These negative effects appeared to be due to competition for water, because *N. pulchra* plants showed less negative pre-dawn leaf water potentials when annual neighbors were removed. Also, simply adding water caused the same increases in aboveground biomass and seed production of *N. pulchra* plants as removing all annual neighbors. We found no evidence that established *N. pulchra* plants were able to suppress non-native annual grasses. Removing large *N. pulchra* individuals did not affect peak biomass per unit area of annuals. We conclude that effects of interference from non native annuals are important through all life stages of the native perennial *N. pulchra*. Our results suggest that persistence of native bunchgrasses may be enhanced by greater mortality of annual than perennial seedlings during drought, and possibly by reduced competition for water in wet years because of increased resource availability.

Hitchcock, C. L. and A. Cronquist. 1973. Flora of the Pacific Northwest: an illustrated manual. University of Washington Press, Seattle and London.

This comprehensive reference provides keys for identification and detailed, technical descriptions of vegetative and sexual morphology. Taxonomy includes the Latin origin of the nomenclature. The distribution of hedgehog dogtail in North America is described as well established west of the Cascade Mountains from Oregon to southwest British Columbia.

Holmes, T. H. and K. L. Rice. 1996. Patterns of growth and soil-water utilization in some exotic annuals and native perennial bunchgrasses of California. Annals of Botany 78 (2) 233-243.

Authors' abstract: In western California, exotic cool-season annuals appear to have

widely replaced native perennial bunchgrasses as the herbaceous community dominants in grasslands, oak savannas, and oak woodlands. We argue that because these two herbaceous plant types possess very different life histories, this invasion may have correspondingly altered seasonal patterns of soil-water availability. To begin to assess this hypothesis, in this study we compared exotic cool-season annuals and native perennial bunchgrasses in terms of growth, biomass allocation, rooting distribution, root morphology, and soil-water utilization. Exotic cool-season annuals completed their life cycle early in the dry season through rapid growth apparently made possible by a high proportional allocation to shoots in combination with the efficient production of roots of high specific root length. Further, annuals tended to concentrate root growth and soil-water utilization in the upper soil profile. In contrast, native perennial bunchgrasses allocated a high proportion of their biomass to the production of a deep root system, which allowed them to continue soil-water utilization well into the dry season and contribute to the formation of a very dry soil profile. Taken together, these contrasting patterns suggest that the invasion of exotic cool-season annuals might have produced a corresponding increase in the amount of water present at depth in the soil profile during the dry season.

Hoopes, M. F. and L. M. Hall. 2002. Edaphic factors and competition affect pattern formation and invasion in a California grassland. Ecological Applications 12 (1): 24-39.

Authors' abstract: We used soil analyses, a greenhouse experiment, and a field experiment to examine the roles of competition and abiotic soil factors in plant community pattern formation in a California grassland. We collected soils from five microhabitats: one dominated by the native perennial grass *Sporobolus airoides* Torrey (alkali sacaton), two dominated by the nonnative annual grass species *Hordeum marinum* (Hudson) ssp. *gussoneanum* (Parl.) Thell (foxtail) and *Bromus diandrus* Roth (ripgut grass), and bare soil created either by gopher mounds or by high salt concentrations (sodic soils). We used principal components analysis (PCA) to determine whether soils from these five microhabitats differed in any discernible pattern. In the greenhouse we examined the emergence, growth, and survival of the native perennial in soil from the five habitat types. In the field we then examined a combined survival and reproduction measure to assess how competition with the two non-native annual grasses affected the fitness of *S. airoides.* PCA revealed that *B. diandrus* soils were distinct from soils occupied by *S. airoides*, although the perennial emerged, grew, and survived well on these soils in the greenhouse. Despite some differences in soil quality in the greenhouse experiment, sacaton emergence, growth, and survival were possible in all five soils. Those *S. airoides* plants that survived in sodic soils grew far larger than plants grown in other soils; survival, however, was very low in sodic soils. Sacaton actually performed worst in soils from areas dominated by *S. airoides*. In the field experiment, total available soil nitrogen affected reproduction and survival. In addition, soil ammonium levels interacted with competition from *B. diandrus* to produce lower survival than in control plots. There was no survival in the presence of high densities of *H. marinum gussoneanum*. The two nonnative species seem to represent threats from two distinct types of invaders: (1) "selective invaders," which only invade a narrow range of habitats but can restrict natives from those habitat types, and (2) "twin invaders," which have

similar niches to the native and can exist over almost the same range of habitats as the native. Twin invaders can potentially reduce fitness or threaten the persistence of the native over much of its range.

Kolb, A., P. Alpert, D. Enters and C. Holzapfel. 2002. Patterns of invasion within a grassland community. Journal of Ecology 90 (5): 871-881.

Authors' abstract: 1 Relatively few studies have looked for patterns of invasion by non-native species within communities. We tested the hypotheses that: (i) some types of microhabitats within a community are more invasible than others; (ii) microhabitat types that differ in invasion also differ in resource availability; and (iii) invasibility is mediated by effects of these resources on competition between native and non-native species. 2 To test the first two hypotheses, we measured plant cover and soils in a coastal grassland in northern California. Consistent with these hypotheses, cover of non-native plants was consistently high where nitrogen-fixing shrubs had recently grown, in the bottoms and sides of gullies and on deep soils, and these microhabitats tended to have relatively high nitrogen or water availability. 3 Cover and number of native species tended to be lower where cover of non-native species was higher, indicating that non-native species as a group negatively affected native species. However, the number of non- native species also tended to be lower where the total cover of non-natives was higher. This suggests that a few non-native species excluded natives and other non-natives alike. 4 To test the third hypothesis, we grew a common non-native, the annual grass *Lolium multiflorum*, and a common native, the perennial grass *Hordeum brachyantherum*, at different levels of water and nitrogen. The relative competitive ability of the native was higher at lower nitrogen availability but not at lower water availability. When 10-week-old native plants were grown with non-native seedlings and nitrogen was relatively low, the native out-competed the non-native. However, the non-native out-competed the native at all resource levels when species were both grown as seedlings. Competition between native and non-native grasses in this system may thus help prevent invasion by non-natives in microhabitats where nitrogen availability is low, but invasion may be relatively irreversible.

Kuske, C. R., L. O. Ticknor, M. E. Miller, J. M. Dunbar, J. A. Davis, S. M. Barns and J. Belnap. 2002. Comparison of soil bacterial communities in rhizospheres of three plant species and the interspaces in an arid grassland. Applied and Environmental Microbiology 68 (4): 1854-1863.

Authors' abstract: Soil bacteria are important contributors to primary productivity and nutrient cycling in arid land ecosystems, and their populations may be greatly affected by changes in environmental conditions. In parallel studies, the composition of the total bacterial community and of members of the Acidobacterium division were assessed in arid grassland soils using terminal restriction fragment length polymorphism (TRF, also known as T-RFLP) analysis of 16S rRNA genes amplified from soil DNA. Bacterial communities associated with the rhizospheres of the native bunchgrasses *Stipa hymenoides* and *Hilaria jamesii*, the invading annual grass *Bromus tectorum*, and the interspaces colonized by cyanobacterial soil crusts were compared at three depths. When

used in a replicated field-scale study, TRF analysis was useful for identifying broad-scale, consistent differences in the bacterial communities in different soil locations, over the natural microscale heterogeneity of the soil. The compositions of the total bacterial community and Acidobacterium division in the soil crust interspaces were significantly different from those of the plant rhizospheres. Major differences were also observed in the rhizospheres of the three plant species and were most apparent with analysis of the Acidobacterium division. The total bacterial community and the Acidobacterium division bacteria were affected by soil depth in both the interspaces and plant rhizospheres. This study provides a baseline for monitoring bacterial community structure and dynamics with changes in plant cover and environmental conditions in the arid grasslands.

Maron, J. L. and R. L. Jefferies. 2001. Restoring enriched grasslands: Effects of mowing on species richness, productivity, and nitrogen retention. Ecological Applications 11 (4): 1088-1100.

Authors' abstract: Species-rich grasslands that become enriched with nitrogen often suffer decreases in species richness, increases in plant biomass, and invasion by weedy exotic species. Suitable techniques to restore enriched grasslands and reestablish native communities are increasingly needed. Here we report results of a 5-yr experiment in enriched coastal prairie grasslands (Bodega Marine Reserve, Bodega Bay, California, USA), to determine the combined effects of mowing and biomass removal on total soil nitrogen, net rates of mineralization, nitrogen retention, and species richness and biomass. We mowed and removed plant biomass from plots in areas where the N-fixing shrub, bush lupine (*Lupinus arboreus*), had greatly enriched the soil, and where the community was composed of weedy introduced plants. Our goal was to facilitate the establishment of the native grassland assemblage such as was found at nearby low soil nitrogen sites. Mowing and biomass removal resulted in a dramatic change in the species assemblage, from exotic annual grasses to a mixed exotic/native forb community composed primarily of perennials. Species richness was significantly greater in treated plots than in control plots; weedy exotic grasses diminished in abundance, and both native and exotic forb species increased. In mowed vs. control plots, there was significantly less mean aboveground biomass, but significantly greater belowground biomass. This shift in species composition had significant impacts on nitrogen retention. In late fall and winter when plant-available N was highest, much nitrogen leached from the effectively fallow control plots where germination of annual grasses did not peak until midwinter. In contrast, mowed plots retained substantially greater amounts of nitrogen, due to the presence of perennial plants possessing large amounts of belowground biomass early in the season. Despite the cumulative removal of 22 g N/m2 in biomass over 5 yr, there was no difference between mowed and control plots in total soil N, pool sizes of inorganic N, or net rates of N mineralization. The results indicate that removal of plant biomass by mowing shifted this plant community from an annual grass to a perennial forb assemblage. However, in doing so, N retention by vegetation was increased, making it more difficult to reduce soil N.

Martini, F. and E. Polli. 1992. Contributions to the flora of the Karst of Trieste and Gorizia (North-eastern Italy). Gortania Atti del Museo Friulano di Storia Naturale 14 (0):

151-166.

Authors' abstract: The paper deals with new contributions to the flora of the Karst of Trieste and Gorizia (North-eastern Italy). The distribution of these taxa, considered rare or new in this region, is reported: *Ophioglossum vulgatum, Polystichum aculeatum, P. setiferum, Dryopteris affinis, Chenopodium botrys, C. hybridum, Stellaria pallida, Erysimum repandum, Sorbaria sorbifolia, Aethusa cynapium, Peucedanum verticillare, Tordylium apulum, Asclepias syrica, Gagea villosa, Bellevalia romana, Allium fuscum, Cynosurus echinatus, Parapholis incurva, Polypogon monspeliensis, Cenchrus longispinus, Carex divisa, Cyperus rotundus, Orchis sambucina.*

Maslovat, C. 2002. *Personal communication.* Botanist, Victoria, BC. October 9, 2002.

Maslovat has observed hedgehog dogtail in the field during her M.Sc. research on native grasses in Garry oak ecosystems. The seeds germinate in the fall and overwinter as small seedlings. The plants flower early the following spring and set seed early in the summer to take advantage of early spring moisture. Maslovat has observed the species in many thin-soiled Garry oak ecosystems.

Paschke, M. W., T. McLendon and E. F. Redente. 2000. Nitrogen availability and old-field succession in a shortgrass steppe. Ecosystems 3 (2): 144-158

Authors' abstract: The relationship between soil nitrogen (N) availability and plant community structure was investigated in old-fields in the shortgrass steppe of Colorado. Nitrogen availability was manipulated by N or sucrose additions for 4 years at three old-fields (early-seral, mid-seral, and late-seral) and at an uncultivated control site. The addition of N generally resulted in increased abundance of annual forbs and grasses relative to perennials at all of the previously cultivated sites. Conversely, experimental reduction of N availability generally increased the relative abundance of perennials. Despite a lack of detectable differences in N mineralization between sites and treatments, ion-exchange resin bags confirmed that sucrose additions reduced plant-available N and that N additions increased plant-available N. This was evidenced further by similar observations for plant tissue N content. The degree to which N additions increased N availability at the various sites supported the idea that late-seral plant communities are less effective at N capture relative to earlier-seral communities. The mid-seral old-field had the lowest rates of litter decomposition and a relatively large accumulation of litter on the soil surface. This mid-seral old-field was dominated by an exotic annual grass (*Bromus tectorum*), which appears to be a major hindrance to redevelopment of the plant-soil system. By experimentally reducing N availability at this stage, we were able, in 4 years, to change the plant community into one that more closely resembled the late-seral community. We also observed that the natural recruitment of weedy annual species on the uncultivated site during an unusually wet year was suppressed by reducing N availability. Our results suggest that available N is an important factor controlling the rate and course of plant and soil community redevelopment on abandoned croplands in the shortgrass steppe, and that manipulation of N availability might be useful in restoration of rangeland vegetation.

Pojar, J. and A. MacKinnon. 1994. Plants of coastal British Columbia including Washington, Oregon and Alaska. Ministry of Forests, Lone Pine Publishing, Vancouver, BC.

This field guide is designed for the lay botanist and provides basic identification characteristics. Key diagnostic features listed include prominent ligules, bristly round panicle, 3-10 mm long awns and paired sterile and fertile spikelets. The general habitat of the species is described as "clearings, roadsides, meadows and dry forest edges".

Ryan, M. and G. Douglas. 1995a. Status report on the golden paintbrush, *Castilleja levisecta,* in Canada. Committee on the Status of Endangered Wildlife in Canada, Ottawa, ON

Ryan and Douglas report that *Castilleja levisecta* should be considered an endangered species. The authors note that the species has been extirpated from much of its historical range. *C. levisecta* grows in grass-dominated meadows in Garry oak ecosystems. In the remaining sites where the species is found, it is associated with exotic grasses including hedgehog dogtail. Ryan and Douglas suggest that the largest threats facing the remaining populations of *C. levisecta* are competition from exotic species and fire suppression.

Ryan, M. and G. Douglas. 1995b. Status report on the prairie lupin, *Lupinus lepidus* var. *lepidus,* in Canada. Committee on the Status of Endangered Wildlife in Canada, Ottawa, ON.

Ryan and Douglas report that *Lupinus lepidus* var. *lepidus* should be considered an endangered species. *L. lepidus* has been extirpated from much of its historical range. The remaining habitat for *L. lepidus* is in grass-dominated meadows and steep rocky slopes. It is associated with a range of nonnative grass species and Scotch broom (*Cytisus scoparius*). Ryan and Douglas suggest that the largest threats facing this species are habitat destruction followed by competition from introduced species including hedgehog dogtail.

Schenk, H. J. and R. B. Jackson. 2002. Rooting depths, lateral root spreads and below-ground/above-ground allometries of plants in water-limited ecosystems. Journal of Ecology 90 (3): 480-494.

Authors' abstract: 1 In water-limited environments, the availability of water and nutrients to plants depends on environmental conditions, sizes and shapes of their root systems, and root competition. The goal of this study was to predict root system sizes and shapes for different plant growth forms using data on above-ground plant sizes, climate and soil texture. 2 A new data set of >1300 records of root system sizes for individual plants was collected from the literature for deserts, scrublands, grasslands and savannas with ltoreq1000 mm mean annual precipitation (MAP). Maximum rooting depths, maximum lateral root spreads and their ratios were measured. 3 Root system sizes differed among growth forms and increased with above-ground size: annuals<perennial

forbs=grasses<semi-shrubs<shrubs<trees. Stem succulents were as shallowly rooted as annuals but had lateral root spreads similar to shrubs. 4 Absolute rooting depths increased with MAP in all growth forms except shrubs and trees, but were not strongly related to potential evapotranspiration (PET). Except in trees, root systems tended to be shallower and wider in dry and hot climates and deeper and narrower in cold and wet climates. Shrubs were more shallowly rooted under climates with summer than winter precipitation regimes. 5 Relative to above-ground plant sizes, root system sizes decreased with increasing PET for all growth forms, but decreased with increasing MAP only for herbaceous plants. Thus relative rooting depths tended to increase with aridity, although absolute rooting depths decreased with aridity. 6 Using an independent data set of 20 test locations, rooting depths were predicted from MAP using regression models for three broad growth forms. The models succeeded in explaining 62% of the observed variance in median rooting depths. 7 Based on the data analysed here, Walter's two-layer model of soil depth partitioning between woody and herbaceous plants appears to be most appropriate in drier regimes (<500 mm MAP) and in systems with substantial winter precipitation.

Smith, W. P. 1986. Plant associations within the interior valleys of the Umpqua River Basin. Oregon, USA. Journal of Range Management 38 (6): 526-530.

Authors' abstract: Eleven plant associations were identified and characterized according to the frequency, percent cover, and relative dominance of the herbaceous and woody species among the vegetative strata, including stem density, diameter breast height (dbh), and basal area for tree species: *Cynosurus echinatus/Taeniatherum asperum; Bromus mollis/Cynosurus echinatus; Rhus diversiloba/Cynosurus echinatus; Quercus garryana/Rhus diversiloba/Taeniatherum asperum/Cynosurus echinatus; Quercus garryana/Rhus diversiloba/Dactylis glomerata; Pseudotsuga menziesii/Quercus garryana/Rhus diversiloba/Polystichum munitum; Quercus garryana/Arbutus menziesii/Rhus diversiloba/Cynosurus echinatus; Arbutus menziesii/Rhus diversiloba/Festuca arundinacea; Quercus garryana/Fraxinus latifolia/Rosa eglanteria/Juncus effusus; Pseudotsuga menziesii/Corylus cornuta/Cynosurus echinatus.* The intensity and duration of recent disturbance distinguished early seral stages which were characterized by a paucity of native shrub and herbaceous species and an abundance of annual invaders in the understory. The primary forces that influenced existing plant assemblages were fire and more recently agricultural practices, especially among grasslands and savannas. Grasslands without recent livestock use exhibited greater species diversity, supporting more species and a more homogeneous distribution of relative abundance among species.

Stark, J. M. and M. K. Firestone. 1996. Kinetic characteristics of ammonium-oxidizer communities in a California oak woodland-annual grassland. Soil Biology and Biochemistry 28 (10-11): 1307-1317.

Authors' abstract: We must have information on the kinetic characteristics of soil biological processes if we are accurately to predict how environmental change will affect soil nutrient cycles. Little information is available on the characteristics of NH-4+-

oxidizing bacteria in uncultivated soils. In addition, little is known about how much physiological diversity occurs in NH-4+-oxidizer communities within a single ecosystem. Therefore, we evaluated how NH-4+-oxidizer communities from an oak woodland-annual grass ecosystem in northeastern California respond to changes in temperature, osmotic potential and substrate concentrations. We used nitrification potential assays to determine the effects of temperature and osmotic potential on rates of NH-4+ oxidation in two soil depths, under two types of vegetative cover and during two seasons. We determined the kinetics of substrate utilization using soil slurries and enrichment cultures. In slurries, NH-4+ oxidation rates were measured using 15N-isotope dilution to avoid confounding the effects of NO-3- consumption with NO-3-production. Ammonium-oxidizer communities beneath the canopies of oaks had lower temperature optima, greater activities and greater seasonal fluctuations in activity than communities in open grassy interspaces. Temperature optima of communities beneath oak canopies (31.8 degree C) and in open grassy interspaces (35.9 degree C) were as different as those reported for communities from tropical and temperate climatic zones. Ammonium-oxidizer communities from beneath oak canopies and open interspaces showed no difference in tolerance of low osmotic potential. The effect of substrate concentration on NH-4+ oxidation rites in slurries were best described by the Michaelis-Menten equation. Rates in liquid cultures were best described by the Haldane equation because of substrate inhibition. The half-saturation constant (K-m) for NH-4+ oxidation in these soils averaged 15 mu-M NH-4+ (=0.012/mu-M NH-3), which is substantially lower than values reported in the literature for agricultural soils, sediments and sewage sludge, Enrichment cultures were inhibited by lower substrate concentrations (1600 mu-M NW or 1.3 mu-M NH-3) than reported for isolates from sewage systems. These results suggest that NH-4+-oxidizer communities in uncultivated soils are more oligotrophic in nature, and thus kinetic parameters reported in the literature for agricultural soils, sediments and sewage sludge are not appropriate for describing NH-4+ oxidation rates in these soils.

Svejcar, T. and R. Sheley. 2001. Nitrogen dynamics in perennial- and annual-dominated arid rangeland. Journal of Arid Environments 47 (1): 33-46.

Authors' abstract: It is often assumed that displacement of native perennial vegetation by exotic annuals will alter nutrient cycling. Nitrogen dynamics of native bunchgrass vegetation and adjacent stands of the exotic annual grass *Bromus tectorum* were compared on three sites in south-eastern Washington, U.S.A. The stands of *B. tectorum* had dominated the sites for at least 40 years. It should be emphasized that these sites were not prone to frequent wildfires as can be the case in some *B. tectorum*- dominated ecosystems. Over a 2-year period very few consistent differences were found between the two vegetation types in above-ground standing crop, root mass, in situ N mineralization, extractable soil N, or total soil C or N. *Bromus tectorum* above-ground plant mass and litter tended to have lower C/N ratios than did the native vegetation, but the results were not consistent over time or site. It appears that the exotic annual adapted to the resources on site and, at least at the fairly gross level measured, had little impact on soil nitrogen. These results suggest that caution must be taken when assuming that a change in vegetation type and growth form will necessarily alter soil N levels.

Watkinson, A. R., R. P. Freckleton and L. Forrester. 2000. Population dynamics of *Vulpia ciliata*: Regional, patch and local dynamics. Journal of Ecology 88 (6): 1012-1029.

Authors' abstract: 1 Data on the population dynamics of the annual grass *Vulpia ciliata* were collected at three levels, from the scale of the regional population down to small (10 X 10 cm) patches. We use these data to explore the degree to which fine scale processes influence large scale patterns of abundance. 2 Populations were characterized by their persistence, despite their small size. The mean half-life of populations was estimated to be around 45 years. Most populations are small (a few m2) in area, with only a few as large as a hectare in size. 3 Population regulation occurs as a consequence of density-dependent seedling recruitment. This reduces population growth by up to 87%. The nature of this density dependence appeared to be essentially the same across sites and years. 4 Interactions with perennial vegetation also significantly affected population dynamics, through reducing seedling recruitment and survival, and on average depressed population growth by a further 30% at one site and by up to 96% in another population. 5 Plants were aggregated and densities were positively spatially autocorrelated. This tends to buffer patches against extinction. Mean seed production per plant, was also significantly spatially autocorrelated; however, the strength of this was minor. 6 Data on small-scale extinction showed that disturbance is an important determinant of the distribution of numbers of plants within subplots. Comparison of the distribution of subplot densities with the results of a spatial simulation model suggested that disturbance at a relatively large scale (at least 20 X 20 cm) impacts on dynamics at the population scale. 7 An integro-difference equation model for patch expansion shows that populations are constrained to an area no larger than around 100 m2 on a time-scale relevant to the dynamics of this species (about 20 years). 8 We conclude that the most characteristic features of dynamics at the regional scale, namely the persistence and very small spatial size of individual populations, can be readily explained by processes operating at small spatial scales.

Watson, L., and Dallwitz, M. J. (1992 onwards). Grass genera of the world: descriptions, illustrations, identification, and information retrieval; including synonyms, morphology, anatomy, physiology, phytochemistry, cytology, classification, pathogens, world and local distribution, and references. Website: biodiversity.uno.edu/delta/grass/index.htm Version: 18th August 1999. Accessed: October, 23, 2002.

Watson and Dallwitz give highly detailed and technical descriptions of the vegetative and sexual morphology of hedgehog dogtail. The site highlights key diagnostic characteristics including the presence of a free sheath margin, an unfringed membrane, paired sexual and sterile spikelets and awned lemmas with 5 nerves. In addition, the site provides details about the cellular characteristics of the species including leaf sections, culm anatomy and cytology. Watson and Dallwitz provide range information for the genus and its economic importance. They also provide taxonomic classification including the Latin origin of the nomenclature.

Weed Science. 2002. Group A/1 resistant hedgehog dogtail (*Cynosurus echinatus*) Chile. Website: www.weedscience. org/Case/Case.asp?ResistID=5104. Accessed: October 23, 2002.

The website documents the resistance of hedgehog dogtail to a class of Group A/1 herbicides known as ACCase inhibitors. In Chile, there are currently 6-10 sites covering 501-1000 acres that have herbicide resistant hedgehog dogtail growing in canola and wheat fields.

White, T. A., B. D. Campbell and P. D. Kemp. 1997. Invasion of temperate grassland by a subtropical annual grass across an experimental matrix of water stress and disturbance. Journal of Vegetation Science 8 (6): 847-854.

Authors' abstract: An experimental matrix of water stress and disturbance was superimposed on a *Lolium perenne-Trifolium repens* grassland using a crossed-gradient design, and the annual subtropical grass *Digitaria sanguinalis* was introduced into the pasture as seeds and transplanted seedlings. *Digitaria* plants achieved maximum biomass at high water availability and high disturbance. *Digitaria* plants grown from transplanted seedlings attained greater biomass further from the conditions of high water availability and high disturbance, compared with those that had grown from seed. The biomass of the temperate species was maximized with high water availability and low to intermediate disturbance conditions. The reproductive effort of *Digitaria* was maximized under intermediate to high water availability and intermediate to low disturbance. Combinations of water stress and disturbance that gave rise to maximum growth of the temperate and subtropical species were consistent with those predicted by C-S-R theory. Results suggest that processes in the regenerative phase of the plant life cycle were constraining the success of *Digitaria* in New Zealand grassland. Addition of seed to the soil seed bank would probably be maximized in patches of grassland with high disturbance and water availability; these patches will subsequently act as foci for future invasions by *Digitaria*.

Yoshida, L. C. and E. B. Allen. 2001. Response to ammonium and nitrate by a mycorrhizal annual invasive grass and native shrub in southern California. American Journal of Botany 88 (8): 1430-1436.

Authors' abstract: The goal of this study was to determine the interaction of mycorrhizae and two N sources, ammonium (NH4+) and nitrate (NO3-), on the growth of a coastal sage scrub (CSS) species, *Artemisia californica*, and an exotic annual grass, *Bromus madritensis* ssp. *rubens*. Anthropogenic nitrogen deposition may be influencing the decline of CSS and replacement by exotic grasses, but the extent to which mycorrhizae are involved in shrubland decline is unknown. NO3- is the dominant form of deposition in southern California, although the native, uneutrophied soils have a greater concentration of NH4+. Seeds of each species were germinated in pots of sterile soil, inoculated with native soil containing mycorrhizal spores and infective root fragments, and fertilized with 50 mug/g of either NO3- or NH4+. NH4+ enhanced the growth of both mycorrhizal species, while NO3- did not. Control plants of *B. madritensis* under low N had a significant response to mycorrhizae, but *A. californica* did not. Nitrate increased

the growth of nonmycorrhizal *A. californica* as much as the mycorrhizal NH4+-treated plants. There is no evidence in this study to suggest that the decline of *A. california* or increase in *B. madritensis* is due to a mycorrhizal response to NO3-.Other life history traits of the two species must be used to explain the invasive behavior of the annual grass. Mycorrhizae may be more important in controlling plant growth in native uneutrophied soils dominated by NH4+ rather than NO3-.

Young, J. A., J. D. Trent, R. R. Blank and D. E. Palmquist. 1998. Nitrogen interactions with medusahead (*Taeniatherum caput-medusae* ssp. *asperum*) seedbanks. Weed Science 46 (2): 191-195.

Authors' abstract: Medusahead is an invasive annual grass that, once established, severely affects rangeland productivity and stability. Medusahead builds large seedbanks in the litter and on the soil surface. Effective weed control of medusahead involves either inhibiting germination from the seedbank, eliminating the seedbank, or enhancing germination so that plants are available for control. The purpose of this study was to determine the influence of nitrogen enrichment, immobilization, and nitrification inhibition treatments in the field on the size and germination status of medusahead seedbanks. The germination status of medusahead seeds in seedbanks was determined by periodically collecting field samples of surface soil and litter and bioassaying them in greenhouse emergence tests. Control seedbanks had increased seedling emergence with KNO3 or GA3 enrichment of the bioassay substrate. The combination of these two materials increased emergence. Nitrogen enrichment increased seedling establishment in the field. Carbon enrichment in the field decreased seedling establishment and increased medusahead seeds in seedbanks. Nitrapyrin treatment decreased medusahead in the field similar to carbon enrichment. In comparison to the control or other treatments, GA3 enrichment was not as effective in increasing emergence from nitrapyrin-treated bioassay samples. The combination of carbon and nitrapyrin treatments was very effective in eliminating medusahead emergence in the field, but in wetter years, it never completely eliminated medusahead seedling recruitment and subsequent reproduction. These treatments have promise for influencing succession in medusahead infestations if an adapted perennial species, capable of competing under low nitrogen levels, becomes available.