Fig. 2. Survival of seeds and seedlings after fire. The treatments (left–right on *x*-axis) are (i) Control: background levels of seed germination and seedling survival adjusted to 100%; (ii) Dung: germination of seeds in dung after fire; (iii) Surface: germination of seeds on the soil surface after fire; (iv) 1cm: germination of seeds buried at 1 cm after fire; (v) Seedlings: survival of first-year seedlings after fire

Discussion

Our results highlight three major weaknesses in the life history of *Acacia nilotica* that could be exploited by land managers using low-cost practices. First, the majority of seeds are produced in a small fraction of the total area of the paddocks, leading to the conclusion that reducing the amount of bore drain habitat could drastically reduce seed production. Second, the majority of seeds rely on cattle for dispersal to new sites (and, to a lesser extent, sheep; Harvey 1981), suggesting that excluding cattle from seed producing trees could essentially eliminate movement of plants to new habitats. Third, seeds and seedlings in the open downs appear highly vulnerable to fire, pointing out the need for fire to prevent prickly acacia spread and establishment in open downs habitats. None of these practices is currently in use.

Land managers can use this knowledge to maximize the effects of a suite of existing management options. The concentration of most seed-producing trees within small areas allows land managers to implement control methods, including chemical (e.g. Diuron in bore drains) and mechanical techniques (e.g. chaining, capping bore drains) (QDNR 1996), over more realistic spatial scales than whole paddocks. The reliance of *Acacia nilotica* on cattle for seed dispersal allows managers to control dispersal with fences, and by quarantining stock until after seeds have passed through their digestive tracts (8 days; Harvey 1981). Understanding the importance of cattle in seed dispersal highlights the importance of controlling seed sources along bore drains. High seed and seedling mortality after fire gives managers a cheap tool for controlling invasion of extensive downs landscapes, despite the fire resistance of mature trees (Pratt & Knight 1971).

Although an integrated strategy based on ecological knowledge allows us to maximize our effect on *Acacia nilotica* populations while minimizing management efforts, we do not know whether such a strategy will reduce populations to below problem levels. Prickly acacia may produce enough seed in wet years to perpetuate existing populations through a number of succeeding years. Dung pat density (determined by cattle numbers and movements) may determine eventual tree density, rather than seed numbers only (D. Kriticos *et al.* unpubl.). Also, fire may prove ineffective if applied to older juvenile plants, which may be fire resistant (Pratt & Knight 1971). Projection of the results of this study into the future using generic woody weed models and detailed ecological data, plus further work into the efficacy of fire, are needed to fully elucidate the impact of integrated management strategies on prickly acacia populations.

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Bromus tectorum expansion and biodiversity loss on the Snake River Plain, southern Idaho, USA

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The Plain

The Snake River Plain forms a 6 million ha arc-shaped depression across southern Idaho. Basalt flows, fresh water sediments, loess and volcanic deposits cover its surface. Elevation increases eastward from 650 to 2,150 m altitude. Climate is semi-arid with annual precipitation ranging from 150 to 400 mm, arriving primarily in winter and spring. Native shrub steppe vegetation is dominated by *Artemisia tridentata* (big sagebrush) and bunchgrasses, e.g. *Pseudoregneria spicatum* (bluebunch wheatgrass), *Elymus* (wildrye) and *Poa* (bluegrass) spp., with interspersed *Purshia tridentata* (antelope bitterbrush) and *Pseudoregneria spicatum* communities. Salt desert shrub communities, e.g. *Atriplex* spp. (saltbush), *Ceratoides lanata* (winterfat), occupy drier areas.

Rangeland degradation and invasion of exotic annuals

Between 1840 and 1870 more than 300 000 emigrants and their livestock followed the Oregon Trail into southern Idaho. Mineral strikes in the late 1860s accelerated development of a thriving livestock industry (Yensen 1982). Native perennial grasses could not withstand the grazing levels imposed. By 1900 many native plant communities, particularly those in the drier western Plain, had degenerated to nearly monotypic stands of *Artemisia tridentata,* and severe soil erosion was widespread. Following growth and collapse of a dryland wheat industry between 1910 and the 1920s, exotic annuals invaded abandoned farmlands and depleted native communities (Yensen 1982). Most common were *Salsola kali* (Russian thistle), *Bromus tectorum* (cheatgrass), and several Brassicaceae species.

Excessive stocking levels were maintained as Idaho entered a 14 year drought following World War I (Yensen 1982). By 1930 *B. tectorum* had spread throughout its current range, and by 1949 it occupied 1.6 million ha in Idaho (Pellant & Hall, in Monsen & Kitchen 1994). Its competitiveness was attributed to its facultative winter annual habit, phenotypic plasticity, germination at temperatures from 0 to 40°C, root growth at 0°C, and increased seed production following fires (Monsen & Kitchen 1994). Low temperature germination and growth permitted *B. tectorum* to use soil water in late fall and early spring, precluding re-establishment of most natives.

Changes in wildfire regimes

Early summer senescence and continuous mats of fine fuel produced by *B. tectorum* lengthened fire seasons and increased fire frequencies (Monsen & Kitchen 1994). Impacts were most severe in the more arid western Plain. Fires spread from areas dominated by *B. tectorum*, into native vegetation, killing non-sprouting shrubs and permitting further expansion of annuals (the *B. tectorum*/wildfire cycle). Between 1978 and 1997 an average of 55 038 ha of US Dept of Interior, Bureau of Land Management (BLM) lands burned each year (BLM unpubl. data); blackened expanses replaced mosaics of vegetation at varying successional stages. In the Snake River Birds of Prey National Conservation Area, fire-return intervals declined from 81 years between 1950 and 1979 to 27 years between 1980 and 1995 (USDI 1996).

Shortened fire-return intervals further depleted native vegetation and seed banks, simplified community structure and species associations, and reduced landscape patchiness. Ecosystem resilience declined with disruption of critical functions (e.g. snow catchment, reduction of wind velocity, nutrient recycling) and loss of microbiotic crusts and mycorrhizae (Wicklow-Howard, Belnap & Rosentreter, in Monsen & Kitchen 1994).

Bromus tectorum has continued to spread into more arid and more mesic areas following wildfires. Between 1979 and 1994 wildfires reduced shrub cover in the Conservation Area from 51% to 30%. Greatest declines occurred in low-elevation *Atriplex confertifolia* (shadscale) communities in the 180 to 230 mm precipitation zone (Kochert & Pellant, in USDI 1996). In addition, fire ignitions in *B. tectorum* often burn upslope into mountain shrub and forested communities. The 1986 Squaw Butte (88 225 ha) and 1992 Foothills fires (104 000 ha) are two extreme examples (BLM unpubl. data). *Bromus tectorum* has spread into forested communities at altitudes of 2150 m that receive 500 to 600 mm of precipitation (Pellant & Hall, in Monsen & Kitchen 1994).

Recovery proceeds slowly where large areas are drastically altered and native seed sources depleted (Billings, in Monsen & Kitchen 1994). The *Bromus tectorum*/wildfire cycle frequently provides conditions for replacement by other weeds that are even more difficult to control. Seventeen noxious weed species were present on 465 500 ha of BLM lands in southern Idaho in 1997 (BLM unpubl. data); this area was estimated to increase by 20% in 1998.

The *B. tectorum*/wildfire cycle is a major factor in the decline of at least 10 sensitive vascular plants and one lichen on the Snake River Plain (BLM unpubl. data). Drastic declines in *Lepidium papilliferum* (slick spot peppergrass) led Moseley (unpubl. data) to recommend its listing as a Threatened species under the Endangered Species Act in 1994. Direct competition, habitat simplification, isolation of small populations, and reduced genetic variability increase the risk that additional localized species may become imperiled (Rosentreter, in Monsen & Kitchen 1994).

Losses of faunal diversity

Alterations of plant communities by *B. tectorum* have adversely affected shrub steppe animal species. Population declines and changes in community structure of raptors, their small mammal prey, gallinaceous birds, songbirds, ungulates, and insects have been related to wildfire losses of native shrubs and *B. tectorum* invasion.

Significant changes in vegetation characteristics and associated wildlife since the 1970s may not be reversible in the Conservation Area (USDI 1996). Wildfires throughout the area have significantly reduced occupancy and reproductive success at *Aquila chrysaetos* (golden eagle) nesting sites since 1971. Nesting *A. chrysaetos* rely on shrubland habitat to support their principal prey, *Lepus californicus* (black-tailed jackrabbit). *Lepus californicus* did not use areas where fires created annual grasslands with few shrubs. Continued wildfires that reduce shrub habitat could adversely affect the long-term persistence of *A. chrysaetos* in the Conservation Area.

Since 1976, *Falco mexicanus* (prairie falcon) populations in the Conservation Area have significantly declined where shrubs were lost before 1970 (USDI 1996). Reductions in numbers of nesting *F. mexicanus* have been influenced by wildfire-related prey declines. Populations of its primary prey, *Spermophilus townsendii* (Townsend ground squirrel), fluctuate more in burned habitats dominated by exotic annuals than in unburned native habitats. This, in turn, reduces prey availability for falcons foraging in annual grasslands.

Centrocercus urophasianus (sage grouse), an obligate shrub steppe species, has suffered alarming population declines in Idaho and throughout western North America (Connelly & Braun 1997). Breeding populations in Idaho declined 40% over the last 10 years (1986 to 1996) compared to the long-term 30 year average. Population declines have been attributed to wildfire losses of sagebrush followed by increases in annual exotic vegetation, especially *B. tectorum* (Idaho Dept of Fish and Game, unpubl. data). Wildfires and subsequent annual weed invasions are primary concerns listed by Idaho Dept of Fish and Game in their statewide management plan for *C. urophasianus*.

Shrub steppe songbirds experienced significant long-term population declines on local (Idaho) and regional (western North America) scales, where declines were related to the *Bromus tectorum*/wildfire cycle (cf. Saab & Rich 1997). Trends in populations of *Spizella breweri* (Brewer's sparrow) declined 1.3% per year and *Lanius ludovicianus* (loggerhead shrike) by 2.7% per year from 1968 to 1994 in sagebrush habitats of the interior Columbia River Basin, which includes Idaho. These birds and seven other shrub steppe species were the wildlife group of highest management concern in a large-scale conservation assessment for Neotropical migratory landbirds in the interior Basin. Shrub steppe habitat suffered the greatest loss in area among 11 habitat categories and further declines are predicted in all future Columbia River Basin management alternatives.

In south-central Idaho, songbird community composition and structure were dramatically altered in *B. tectorum* compared to native shrub cover types (*Artemisia tridentata* and *A. tripartita*) (Terrell D. Rich, unpubl. data). From 1981 to 1985, species richness ranged from 8.4 to 10.2 in shrub cover types, compared with 1.5 in *B. tectorum*. Of the most abundant species, *Eremophila alpestris* (horned lark) and *Sturnella neglecta* (western meadowlark) were habitat generalists common to all cover types. In contrast, abundant species unique to shrub types, i.e. Brewer's sparrow, *Pooecetes gramineus* (vesper sparrow), and *Oreoscoptes montanus* (sage thrasher), were considered habitat specialists (Saab & Rich 1997). Breeding bird densities were strikingly reduced in annual grasslands; densities averaged 0.6 ± 0.2 to 1.1 ± 0.3 birds/ha in *B. tectorum* compared with 3.9 ± 0.2 to 8.1 ± 3.1 birds/ha in native shrublands.

Frequent cheatgrass fires have destroyed critical shrub winter ranges for *Odocoileus hemionus* (mule deer) and *Antilocapra americana* (pronghorn antelope), especially in south-central and south-western Idaho (Yensen 1982; BLM unpubl. data).

Wintering areas most impacted by the *B. tectorum*/wildfire cycle are in lower altitude foothills where *Purshia tridentata* and other shrubs provide winter/spring browse and cover. In harsh winters, ungulates are forced to migrate from traditional winter ranges to lower altitude agricultural lands, frequently causing wildlife depredation problems.

Invasions of exotic weeds have influenced distributions and altered community structure of insect species in southern Idaho. The long-term persistence of *Cicindella arenicola* (Bruneau dunes tiger beetle) may be threatened by non-native weeds invading unvegetated soil that previously supported larval burrows (BLM unpubl. data). Insect assemblages, such as of Acrididae (grasshoppers), in native *Artemisia*/bunchgrass communities were characterized by lower densities but higher species diversity than insect assemblages in exotic annual grasslands (Fielding & Brusven 1993). Results suggested that rehabilitation of annual grasslands with native grasses and shrubs and protection of native plant communities would contribute to more diverse Acrididae communities.

Future of the Plain

Large areas of the western Snake River Plain are in transition to annual grasslands. National and regional efforts have identified restoration of shrub steppe habitats as a priority for conservation of terrestrial vertebrates (e.g. Saab & Rich 1997). Increased funding and changes in policy priorities are required to counteract the spread of annuals and enhance reestablishment of native vegetation. Current efforts focus on management to reduce fire size and frequency, thereby facilitating recovery processes and protecting remnant shrublands and revegetation projects. Advances in revegetation technology and improved availability of native seed sources are increasing the practicality of re-establishing shrub steppe species in key areas.

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Seedling emergence in mesquite infestations

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Introduction

Prosopis pallida (mesquite) is currently one of a number of exotic woody weeds spreading throughout Queensland's rangelands. Scattered infestations of *P. pallida* can be found over approximately 500 000 ha of northern Queensland, with smaller dense infestations (<5000 ha) occurring in the Hughenden, Karumba, Cloncurry and McKinlay regions (March 1995). In recent years, considerable effort and expenditure has been put in to try to eradicate these dense infestations, particularly those near Cloncurry and Karumba. Nevertheless, climatic modelling suggests that the area currently occupied by *P. pallida* is only a small percentage of its potential range, which includes as much as 60% of Queensland's grazing land (Csurhes 1996).

Seedling emergence, establishment, survival and growth rates are being investigated in a long-term field experiment at Hughenden to improve our understanding of the invasion dynamics of *P. pallida*. This preliminary paper focuses on one component of this study: the relationship between reproductive tree density and seedling emergence. This information will provide an indication of the numbers of seedlings that may be recruited into the population if optimum conditions for survival occur.

Materials and methods

The study site was located on a floodplain near Hughenden (20°51'S 144°12'E) in north-west Queensland. Long term annual mean rainfall for this region is 482 mm (Bureau of Meteorology 1988). Approximately 80% of this falls between October and March, which is defined here as the wet season. The experiment commenced in October 1995, after the removal of domestic stock from the site. Seven areas with varying densities of *P. pallida* were selected, and permanent transects 60 m long by 10 m wide were established within each area. Monthly recordings were made between October 1995 and August 1998

Fig. 1. Actual monthly totals and long-term monthly mean rainfall for Hughenden (■ actual rainfall; ● average rainfall)

Invasive plants