Summary  One potentially serious impact of environmental weed invasion is an alteration to the fuel characteristics and subsequent fire regimes of an area.

Considerable global evidence indicates that environmental weed invasion may produce ‘new’ fuel types, but there is little documented evidence of the impact of invasive exotic species on fuel characteristics and fire regimes in south-eastern Australia. This study on the impact of invasive exotic grasses in south-eastern Australia has revealed major changes to fuel characteristics, particularly fuel loads.

The invasive exotic pasture grass *Phalaris aquatica* L. has dramatically increased fuel loads in conservation reserves, urban parkland, roadside reserves, and remnant woodland on private land. Areas invaded by *P. aquatica* can have over three times the fuel load of native *Themeda triandra* Forssk. grasslands. The arrangement of the fuel, particularly the depth of the fuel bed, is also significantly altered.

Fuel characteristics have a major impact on fire behaviour. Therefore, alterations to fuels due to exotic grass invasion may have serious ecological, fire suppression and fire safety implications.

**Keywords**  Exotic grasses, invasive species, fuel characteristics, fire regime.

INTRODUCTION

One potentially serious impact of environmental weed invasion is an alteration to the fuel characteristics and subsequent fire regimes of an area (D’Antonio and Vitousek 1992). Considerable evidence now indicates that the impact of invasive exotic species on fuel and fire characteristics is an issue of global significance. Woody weeds have been responsible for major changes to fire regimes in South Africa (Van Wilgen and Richardson 1985), and invasive grasses have also been shown to have very significant impacts on fuel and fire characteristics in a number of ecosystems, both naturally fire prone and less fire prone, particularly in North America (e.g. Brooks 1999, Lippincott 2000), Hawaii (e.g. Hughes et al. 1991), and northern (Butler and Fairfax 2003) and south-western Australia (Baird 1977).

Although the invasion by potentially flammable exotic species has generated anecdotal evidence of altered fuel and fire characteristics, there is little quantitative evidence of the impact of invasive exotic species on fuel characteristics and fire regimes in south-eastern Australia (Stoner et al. 2004).

Of particular concern is the exotic pasture grass *Phalaris aquatica* L., which is highly invasive in non-pasture situations, and is reported to dramatically increase fuel loads in a number of settings, including conservation reserves, urban parkland, roadside reserves and remnant woodland. This study assessed the impact of the invasive exotic grass *P. aquatica* on fuel characteristics in south-eastern Australia, with particular emphasis on alterations to fuel loads.

METHODS

Five paired sites were selected. Each paired site consisted of an area of dense *Themeda triandra* Forsk. grassland which had not been subject to fuel modification for several years, and an adjacent exotic grassland dominated by unmanaged *P. aquatica*. Field sampling was undertaken during March and April 2003.

**Fine fuel loads**  Fine fuel loads were measured using randomly placed 0.5 × 0.5 m quadrats. All above ground fine fuel (<6 mm diameter) was clipped to ground level, collected and oven dried at 105°C for 24 hours. Samples were weighed and pooled to determine fine fuel load (t ha⁻¹).

**Depth of fuel bed**  Depth of fuel bed was measured at 10 points along a transect for each species at each site. Depth of fuel bed was measured using a disc drop method (McCarthy et al. 1999), and measurements pooled to determine mean depth of fuel bed.

**Vertical height**  Vertical height of the tallest inflorescence was measured at 10 points along a transect for each species at each site.

**Stalk biomass**  Stalk biomass (vegetation standing above the main fuel bed) was measured using randomly placed 0.5 × 0.5 m quadrats. All stalk biomass was clipped and oven dried at 105°C for 24 hours. Samples were weighed and pooled to determine stalk biomass (t ha⁻¹).
Statistical analysis Data were tested for normal distribution using a Kolmolgorov-Smirnov test, and paired t-tests were used to determine significance of differences between *T. triandra* and *P. aquatica*. Vertical height for *T. triandra* was not normally distributed, and data were tested using a Wilcoxon Signed Ranks test (SPSS v11.5).

RESULTS

Fine fuel loads Fine fuel biomass for *T. triandra* grassland ranged from 6.9 t ha$^{-1}$ to 8.7 t ha$^{-1}$, approximately one third of the *P. aquatica* dominated sites which ranged from 22.8 t ha$^{-1}$ to 31.1 t ha$^{-1}$. Mean fine fuel loads of *P. aquatica* (27.0 t ha$^{-1}$) and *T. triandra* (7.9 t ha$^{-1}$) were significantly different ($t_{14} = 10.575$, $P < 0.001$).

Depth of fuel bed Depth of fuel bed for *T. triandra* sites ranged from 127 mm to 199 mm, with a mean of 160 mm, while depth of fuel bed for *P. aquatica* sites ranged from 319 mm to 449 mm, with a mean of 395 mm. Mean depth of fuel bed was significantly different between the two species ($t_{89} = 16.954$, $P < 0.001$).

Vertical height Mean vertical height per site varied between 425 mm and 500 mm for *T. triandra*, and 1160 mm and 1395 mm for *P. aquatica*. Mean vertical heights of *P. aquatica* (1250 mm) and *T. triandra* (467 mm) stands were significantly different ($z = -6.166$, $P < 0.001$).

Stalk biomass Stalk biomass was significantly different ($t_{4} = 6.402$, $P < 0.005$) between *T. triandra* (0.1 t ha$^{-1}$) and *P. aquatica* (1.4 t ha$^{-1}$).

DISCUSSION
Fuel characteristics recorded for *T. triandra* in this study are consistent with those in unmodified *T. triandra* grasslands (Lunt and Morgan 2002), and with ‘traditional’ values assigned to grassland fuel loads in southern Australia (Luke and McArthur 1978). The extreme fuel load of *P. aquatica* will have a significant impact on fire intensity. However, modelling fire intensity for *P. aquatica* fuel loads is problematic as the current grassland fire behaviour models do not allow for the input of such high fuel loads.

Alterations to the depth of the main fuel bed and the overall height of *Phalaris* will significantly impact on fire behaviour. A deeper fuel bed, increased height, and increased biomass of *P. aquatica* will lead to greater flame depth, flame heights, fire intensity and scorch heights, which are more likely to cause irreversible damage to some native plant communities. Increased fire intensity, and flame residence and burnout times, may have implications for plant and seed mortality, and for successful regeneration of desirable species. In invaded communities, the greater fire intensity and increased flame and scorch heights may also have a negative impact on the native overstorey (Cheney and Sullivan 1997) and alter shrub density (Butler and Fairfax 2003). Exotic grass-fuelled fires in communities not adapted to fire can also result in decreased native species cover (D’Antonio et al. 2000). Altered fuel characteristics in grasslands now dominated by exotic grasses such as *P. aquatica* also have serious implications for fire management and firefighter safety. Increased fire intensity will make prescription burning potentially more hazardous, and fire suppression more difficult (Stoner et al. 2004), as it reduces the likelihood of successful direct fire attack, and increases ‘safe distance’ for firefighters (Butler 1997).

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