Increased Above-Ground Biomass and Plant Species Decline Related to the Presence of *Eragrostis curvula* across Multiple Grazing Grasslands in the Snowy Monaro Region of Australia

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Key words: [Eragrostis curvula; Invasion Ecology; Species Richness; Aboveground Biomass]

Abstract
"It will be noticed that invasions most often come to cultivated land, or to land much modified by human practice." This quote was published in 1958 by Charles Elton, and holds true today, backed by empirical evidence suggesting mechanisms of disturbance, plant functional traits and propagule pressure can push a cultivated system towards an invaded state. 17 farms, with either a current or previous history of grazing and land modification, within the Snowy Monaro Region, NSW, Australia, were surveyed to explore the relationship between the non-native C_4 perennial tussock grass *Eragrostis curvula* [Schrad.] Nees. and species richness. As *E. curvula* increases above-ground biomass and proportion cover, we observed species richness declined within survey quadrats. *E. curvula* has the potential to outcompete desirable pasture species for vital resources, leading to a build-up of above-ground biomass and a decline in species richness. Impacts of *E. curvula* extent to the agricultural sector as graziers invest time, money and resources in management and supplementary feed. The data from this study was collected in 2019, a year impacted by drought leading to the onset of the "black summer" bushfires of early 2020. Therefore, this study's findings need to be interpreted in the context of drought and may not accurately represent "normal" Snowy Monaro Region conditions. Nevertheless, *E. curvula* can be an undesirable pasture species that negatively impact agricultural and ecological values. The development of practical solutions to manage *E. curvula* has been shown to prevent secondary invasion of undesirable species through appropriate fire use, fertilizer application, appropriate grazing, and herbicide application. However, widespread adoption of these solutions needs to be implemented at a community scale instead of at an individual scale for effective long-term management.

Introduction
From a human perspective, when the invasion of a plant species imposes some form of negative effect on a conceived value, human intervention may be necessary to prevent further economic, social or ecological degradation (Godfree et al., 2017). In an agroeconomic values context, an invasive plant species may occupy a space in an agriculture landscape while acting as an undesirable feed source for grazing livestock (Godfree et al., 2017, Currier et al., 2004, Badgery et al., 2005, Cousens, 1985). In the event the space-occupying plant species expands its local range to encompass more agricultural land, a stakeholder in that land may be required to purchase supplementary feed and implement control measures, resulting in increased operation costs (Baumont et al., 2000). At the same time, livestock will selectively graze the palatable vegetation, potentially decreasing plant biodiversity and ground cover (Currier et al., 2004). As a result of the expansion of an unpalatable low-quality invasive plant, excess biomass and litter are produced, and this can lead to 'smothering' of other pasture plant species and increase competition for light, water and nutrients leading to lower species biodiversity and decreasing desirable pasture species, in addition to acting as a fuel source for fire (Firn, 2009, Vojtech et al., 2007, Borer et al., 2014, Badgery et al., 2005).

An undesirable plant species across Australia's ecological and agricultural contexts and a potential symptom of an ecosystem state shift is the intentionally introduced southern African C_4 perennial tussock grass *Eragrostis curvula* (Schrad.) Nees (common name African Lovegrass (ALG) (Firn, 2009, Godfree et al., 2017, Firn et al., 2018, van Klinken and Friedel, 2017, Cook and Dias, 2006). ALG is often found in clusters with neighbouring ALG tussocks forming larger swards, transitioning from desirable pasture species to ALG monocultures producing excess above-ground biomass (Firn, 2009). For this paper, above-ground biomass is all plant material (leaf, stem, flower) attached to a plant above the soil, excluding litter detached from the plant. Above-ground biomass increase results from the accumulation of live and dead plant material that is yet to decompose or has not been subject to herbivory or displaced by other means (Morgan, 2015). In many Australian contexts, ALG is undesirable due to low crude protein content and high cellulose components, leading it to be a low-quality feed option while also possessing invasive growth traits potentially impacting plant biodiversity (Soto-Navarro et al., 2014, Firn et al., 2010b, Han et al., 2012). Holmes (2018) estimates that a "clean native country", that is, areas dominated by native perennial grasses, within the Snowy Monaro Region of Australia can sustain approximately four dry sheep equivalent (dse, a metric of the number of livestock able to be sustained in a grazing system) per hectare. While ALG invaded "native country" can sustain 2 or 3 dse per hectare and improved pasture sown with desirable non-native species can sustain up to 8 dse per hectare. Furthermore, Schlierenzauer et al. (2021) provide evidence for ALG to be considered undesirable in an ecological context as sites dominated by ALG had relatively lower species richness and species diversity when compared to sites with co-dominance of ALG and *Themeda triandra*, with ALG particularly impacting forb species richness and diversity. Firn (2009) and Roberts et al. (2021) provide comprehensive reviews of the impact ALG can have on Australia's ecological and agricultural values, highlighting the unpalatable biomass and invasive growth traits.

Methods and Study Site

The Snowy Monaro Region (SMR) within New South Wales, Australia, is defined by a political boundary known as a local government area, see Figure 1. Although a political boundary defines the study area, it serves as a useful ecological boundary defining the temperate grasslands of south-eastern New South Wales tablelands. The region is characterised by summer rains, with the highest rainfall months between November and January and mean annual rainfall of approximately 550 mm (Frost et al., 2018, Costin, 1954). Data collection in this study was undertaken in 2019, one of the SMR's driest years since 1911with an annual rainfall of approximately 300 mm; thus, subsequent results must be interpreted within a drought context (Frost et al., 2018). The topography of the SMR consists of tablelands in the centre and mountain regions to the west and east-north-east with altitudes of the region ranging from 213-2223 meters (mean = 1000 SD=259) (Costin, 1954, TERN, 2015, Gallant et al., 2011). Mean daily temperature minimum and maximum averaged across the SMR range from 9 to 28 degrees Celsius in summer and between -5 and 16 degrees Celsius during winter.

Within the SMR, 17 farms were surveyed. Farms ranged in size from approximately 10 ha to 3500 ha. Within each farm, between 1 and 4 transects, 100 meters long, ran perpendicular to vehicle corridors such as roads or farm tracks, with 39 transects surveyed in total. Every 5 meters along each transect, a 50 x 50-centimetre quadrat was placed. A vegetation survey was conducted within each quadrat with each species identity classified to the lowest taxonomic level possible and an estimate of each species' total cover as a per cent. Every 10 meters along the transect, all above-ground biomass within each 50 x 50-centimetre quadrat was cut to ground level and separated into ALG, litter and remaining above-ground standing biomass. Each category of above-ground biomass within each transect was weighed to the nearest 0.01 gram.

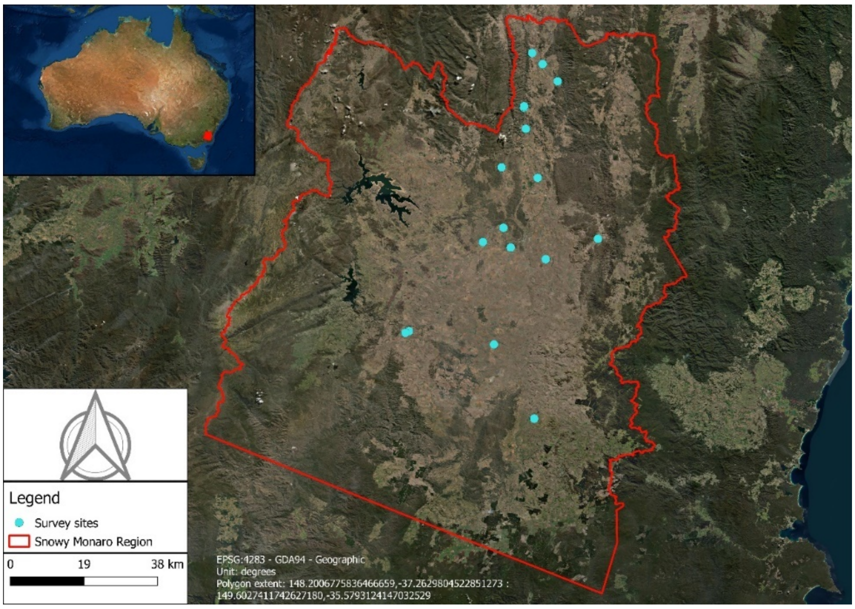

Figure 1 Map of the Snowy Monaro Region with survey farm locations. Blue points represent farms. Between 1 and 4 100 meter transects were run within each farm. The number of transects within each farm depended on the farm size, and farm size varied between 10 and 3000 hectares.

Data analysis

Linear model and Linear Mixed effect Model models, with the method of analysis set to restricted maximum likelihood (REML) using the nlme package in RStudio, are used to model the data (RStudio Team, 2019, Pinheiro J, 2020). The response variable of above-ground biomass weight was log-transformed to meet the assumption of normality. Values for ALG cover have been standardised so that ALG cover represents a proportion of quadrat occupied. Where necessary, the models have been adjusted for spatial autocorrelation within the models using an exponential correlation function.

Results

Results from the generalised linear mixed effect model, with family Poisson, log link function, with nested random effect of transect number within farm, fixed effects of response variable species number and predictor variable above ground biomass weight (grams) indicate that as biomass increases there is a significant decrease in species richness with an intercept of 1.35 (SE = 0.05) and a coefficient of -0.0027 (SE = 0.0008) for every 1 unit increase in above-ground biomass (grams) (z value = -3.54, P-value =<0.05). Results from linear mixed effect model with nested random effects of transect number within farm and fixed effects of log-transformed response variable biomass weight per quadrat (grams) and binary predictor variable ALG presence indicate that where ALG is present in a quadrat, mean above-ground biomass weight increases, with an intercept of 3.41 (SE = 0.15) and a coefficient of 0.60 (SE = 0.14) when ALG is present in a transect (t value = 4.36_{348}, P-value = <0.01). The Association/Correlation Between Paired Samples test using Pearson's product-moment correlation coefficient indicated a correlation of 0.94 (CI 0.93 - 0.95) between variables of ALG per cent cover and log ALG above-ground biomass (t value = 54.75_{373}, P-value < 0.01).

The output of generalised linear mixed effect model, including all transects, with response variable of species richness and fixed effect ALG cover proportion, with family Poisson, log link function and random effects of transect nested in farm indicate that as ALG cover increases, species richness decreases, with extracted coefficients of intercept 1.33 (SD = 0.06) and slope -0.46 (SD = 0.1) (z value = -4.27_{776}, P-value = <0.01). Further, when only transects with ALG present were included in the model ALG cover increases species richness decreases, with extracted coefficients of intercept 1.57 (SD = 0.09) and slope -0.79 (SD = 0.13) (z value = -5.93_{323}, P-value = <0.01), see Figure 2. The output of generalised linear mixed effect model, including all transects, with response variable of species richness and fixed effect ALG biomass proportion, with family Poisson, log link function and random effects of transect nested in farm indicate that as ALG biomass proportion increases species richness decreases, with extracted coefficients of intercept 1.30 (SD = 0.05) and slope -0.26 (SD = 0.14) (z value = -1.9_{385}, P-value = 0.058). Further, when only transects with ALG present were included in the model, as ALG biomass proportion increases species richness decreases, with extracted coefficients of intercept 1.42 (SD = 0.1) and slope -0.4.3 (SD = 0.19) (z value = -2.3_{158}, P-value = 0.02).

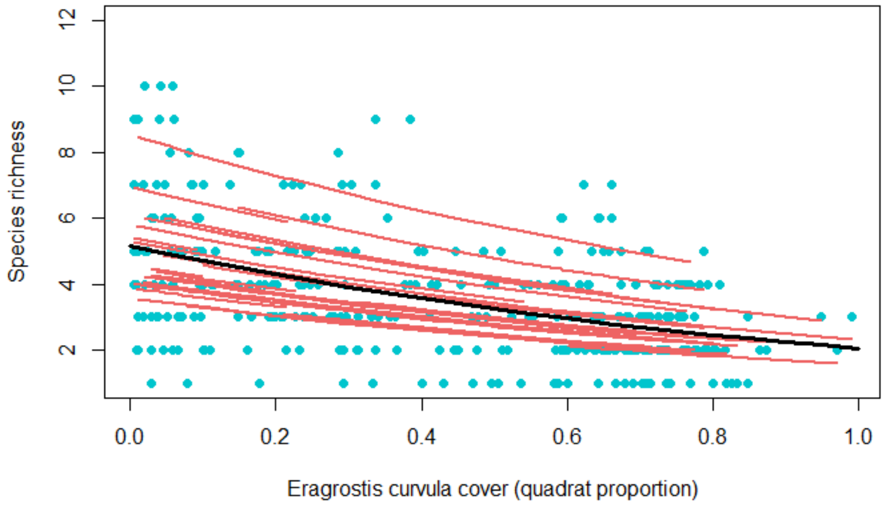

Figure 2 Relationship between the proportion of *Eragrostis curvula* and species richness across 21 transects, as derived from a generalised linear mixed effect model. Points represent values for species richness count within 50 x 50-centimetre quadrat with corresponding *E. curvula* cover. Red lines represent differing transects as derived from the generalised linear mixed effect model. The black line represents the mean response of species richness to *E. curvula* cover without incorporating random effects of farm and transect.

Discussion

The results indicate that as biomass increases in a quadrat, species richness is significantly decreased. Further, if ALG is present in a quadrat, the quadrat is likely to have greater above-ground biomass. A strong correlation exists between ALG cover per cent and ALG above-ground biomass. The results also indicate that as biomass and cover of ALG increase, there is a decrease in species richness, and this effect is most pronounced when only sites with ALG are included in the model.

As ALG matures, its feed quality lowers and is less likely to be grazed (Strickland, 1973, Johnston, 1989, Baumont et al., 2000). If the above-ground biomass remains intact, it can act as a physical barrier to light for species attempting to grow among the intertussock space, leading to species richness decline, simultaneously acting as an increased fuel source for fire (Borer et al., 2014, Mariotte et al., 2017). The main mechanisms responsible for declined species diversity in this study are related to levels of inter-tussock space and competitive exclusion of vital resources (Dybzinski and Tilman, 2007, Marshall et al., 2015).

This study's findings suggest that where ALG has become established, it excludes other species of the essential resource of light and potentially water as it is one of the few species to maintain substantial above-ground biomass during drought conditions (Mariotte et al., 2017, Mynhardt et al., 1994a, Mynhardt et al., 1994b, Johnston et al., 2002). The exclusion is exacerbated by the limited number of above-ground biomass removal mechanisms acting on ALG, such as fire, slashing and selective grazing. If ALG above-ground biomass is managed, other species recruitment may occur as competition for light and water is mediated (Hautier et al., 2018). However, recruitment relies on propagules being present and viable in the soil seed bank; otherwise, manual deposition of seeds and plants may be required. ALG will have an additional competitive advantage when drought conditions break due to the established biomass leading to the pre-emptive acquisition of resources and a "head-start" on the next generation's seed production, increasing its dominance. Complicating this is reports of ALG presence in the study region since at least 1948 (Leigh and Davidson, 1968). Therefore, ALG will have potentially been establishing and dominating for decades, limiting the viability of the natural soil seed banks as a viable option to restore invaded sites. However, further research is needed on the soil seed bank of invaded sites.

The implication of sustained high above-ground biomass is decreased species diversity and limited area to support desirable agricultural pasture species for grazing purposes (Cousens, 1985). For the farms surveyed in this study, if ALG is not managed, there is potential for species loss and negative impacts on biosphere integrity and agricultural profit, with evidence suggesting a decrease in 1 to 2 less dse per hectare (Holmes, 2018). If a 'business as usual approach is maintained, areas containing ALG may expand, thus further impacting biosphere integrity and agriculture productivity. ALG above-ground biomass can be managed, by varying degrees, through the use and combination of fire, herbicide, slashing, cropping, competition, and nutrient addition to improving forage quality (Firn et al., 2010a, Sanders et al., 2016, Firn, 2009, Han et al., 2012). However, removing an invasive species may not be a suitable long-term solution if underlying mechanisms facilitating initial invasion are not addressed, such as maintaining sufficient ground cover as competition, appropriate disturbance regimes and nutrient levels (MacDougall et al., 2014, Tilman et al., 1996, Buckley et al., 2007). Furthermore, if a suitable landscape-scale solution is achieved, desirable plants must either be already present in the seed bank or introduced into the system, if it is to recover. Combatting the adverse effects of excessive above-ground biomass from unmanaged ALG requires a community-based approach, aided by disseminating relevant information on the community benefits of managing ALG supplemented by financial and logical government support (Coutts et al., 2013).

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