Supplementary Material

Simulating the population dynamics of barley grass (*Hordeum* spp.) and impacts of weed management strategies in a southern Australian lucerne (*Medicago sativa*) pasture

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Supplementary Materials

1. Barley grass population dynamics model equations

The six equations used to develop the barley grass model have been adapted from other population dynamics models (González-Andújar and Fernández-Quintanilla 1991, 2004).

As per other grass species, barley grass seedbanks are typically reduced over time by germination and dormant seed decomposition over summer, accruing with annual seed entry into the seedbank (R_t) (González-Andújar and Fernández-Quintanilla 2004). In the current model, seedbank size in the following year, SB_{t+1}, could thus be described by:

$$SB_{t+1} = SB_t (1 - DSM_t) (1 - e) + R_t \tag{1}$$

where SB_t is the barley grass seedbank in year t, e is the proportion of seedlings emerging from the seedbank, R_t is seed entry into the seedbank (number of seeds m^{-2}) and DSM is the dormant seed mortality over summer in year t (González-Andújar and Fernández-Quintanilla 2004).

The density of barley grass seedlings (Z seedlings m^{-2}) emerging at time t from the seedbank is described by the following relationship:

$$Z_t = eSB_t \tag{2}$$

where the seedling emergence parameter (e) represents emergence of seedlings from the top 5cm of soil at time t (González-Andújar and Fernández-Quintanilla 2004).

Seedling survivorship to maturity, (M mature plants m^{-2} at time t), is described by the following equation:

$$M_t = s\, Z_t \tag{3}$$

where s is a fixed rate for seedling survivorship (González-Andújar and Fernández-Quintanilla 2004). In annual plants, density dependence regulates population size through its influence on reproductive output as plant density increases (Sheppard 2000).

Studies by González-Andújar and Fernández-Quintanilla (2004) report a density-dependent relationship between mature plant density and fecundity (number of seeds per mature plant) for *L. rigidum* which could be expected in other annual weeds, such as barley grass. Consequently, the same hyperbolic model was implemented within the barley grass model to simulate the relationship between fecundity (F, number of viable seeds per plant) and plant density (M, number of mature plants per unit area) for barley grass at time t:

$$F = \frac{f}{(1 + a\, M_t)} \tag{4}$$

where f is the maximum number of seeds produced by an isolated plant and a remains a constant, representing the area required to produce f seeds (González-Andújar and Fernández-Quintanilla 2004).

Total seed production per metre (S seeds m^{-2}) was determined by multiplying seed production per plant, F, by mature plant density, M, at time t:

$$S_t = F_t \, M_t \tag{5}$$

Seed entry into the seedbank in year t (R_t, number of seeds m^{-2}) was described as the total seed produced (S_t) multiplied by the proportional loss (L) due to n abiotic factors (González-Andújar and Fernández-Quintanilla 2004) and is given by:

$$R_t = S_t \, (1 - L_t)n \tag{6}$$

In the current model, L_t represented the percentage of seeds lost by decay.

2.Barley grass model parameterisation

Data obtained from greenhouse studies conducted at Wagga Wagga (Kelly *et al*. 2020) were used in the development of parameters and relationships contained within the barley grass model.

Since plants were transplanted after complete emergence to facilitate required seedling quantities for density treatments during the study, an emergence parameter estimate was obtained for the model by counting surviving seedlings one week after transplantation. Although this may not reflect emergence in the field precisely, the values obtained were consistent with other studies investigating barley grass germination under controlled conditions (Shergill *et al*. 2015*)* and were, for this reason, used to parameterise the model.

Mean seed number per inflorescence was determined by dividing mean fecundity per plant by the mean number of inflorescences per plant.

Relationships between variables are presented in Fig. S1a to d. A linear model was found to closely fit the relationship between mean seed density (x) and seedling density (SD) (Fig. S1a, *SD = 0.9954x-0.2443*, $R^2 = 0.9997$, RMSE = 0.714, F (1, 18) = 63630, $p < 0.001$). The emergence value (e) was thus determined from the model coefficient to be 99.5%.

A linear model was also found to closely fit the mean seedling density (x) and mature plant density data (*MP*) (Fig. S1b, *MP = 0.9555x + 0.4725*, $R^2 = 0.997$, RMSE = 2.26, F (1, 18) = 5814.8, $p < 0.001$), producing a model coefficient value for seedling survivorship to maturity (s) of 95.55%. This relationship was not found to be density dependent, a result consistent with findings of González-Andújar and Fernández-Quintanilla (2004).
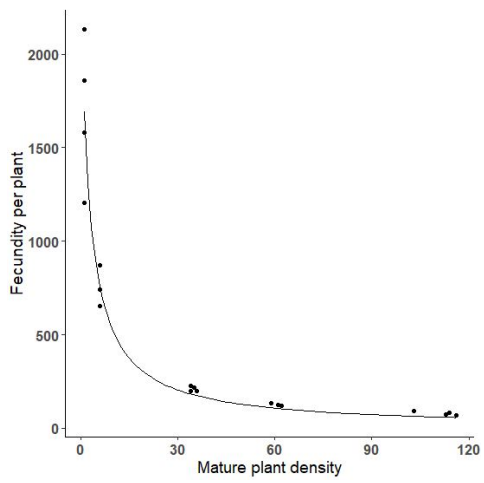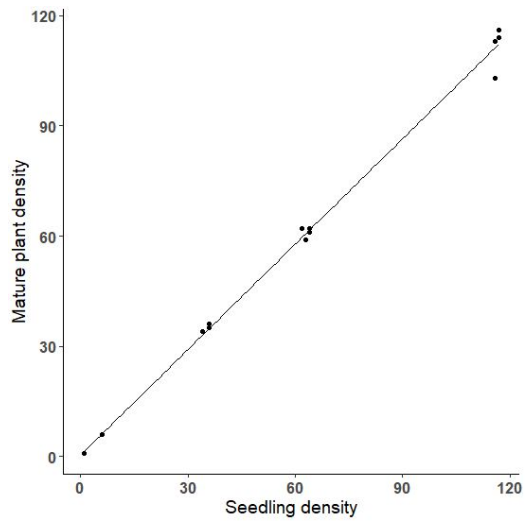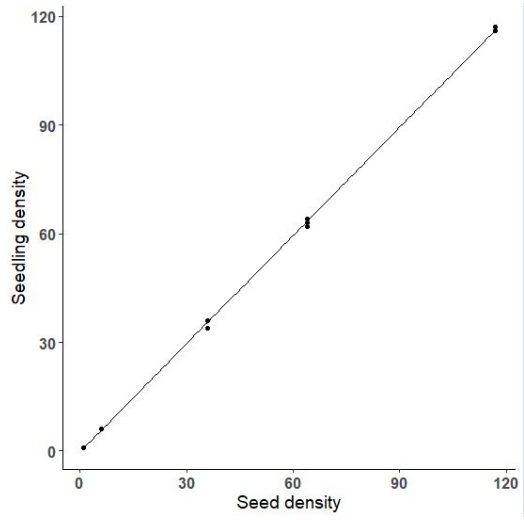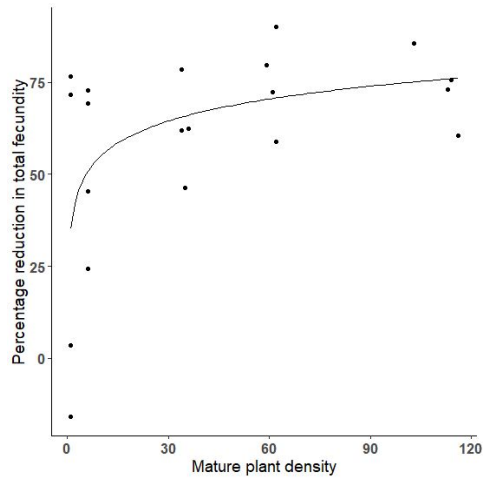
Fig. S1. Relationships between: **a.** mean seed density (x) and barley grass seedling density (y) at the 3 leaf stage (*seedling emergence*), **b.** mean seedling density (x) and mature barley grass plant density (y) at flowering (*seedling survivorship*), **c.** mature plant density (M) and seeds per plant (fecundity, F) at flowering (*individual plant fecundity*), **d.** mature plant density (M) and the percentage reduction in total fecundity (PRF) after a repeat defoliation at post inflorescence emergence (*% reduction in total fecundity*), all determined under greenhouse conditions during 2018 at Charles Sturt University, Wagga Wagga, NSW (see Kelly et al., 2020, n = 20 in each case).

2.1 Individual plant fecundity

A hyperbolic model fitted by non-linear regression to mature plant density (M) and individual plant fecundity (F) data was found to closely fit the data (Fig. S1c, *F = 2255 / (1+ 0.33 M)*, RMSE = 159.97, *df* = 18). The parameter values obtained were *f* = 2255 and *a* = 0.33.

2.2 Percentage reduction in total fecundity: the effect of mowing

The percentage difference in total fecundity between undefoliated and repeated defoliated plants was calculated from greenhouse plant data. The largest reductions in total

fecundity were observed between undefoliated plants and plants defoliated twice (repeat defoliation) as opposed to defoliations at seedling stage or after a single defoliation (Kelly *et al*. 2020).

To determine the relationship occurring between total fecundity decline due to defoliation and mature plant density, the percentage reduction in total fecundity (PRF) occurring after a repeated defoliation was calculated for each plant density using the following equation:

$$PRF = \frac{Total\ fecundity\ (repeat\ defoliated\ plants)}{Total\ fecundity\ (undefoliated\ plants)}\ \text{X}\ 100 \qquad (12)$$

A natural logarithmic function was subsequently fitted to this data (Fig. S1d) using nonlinear regression ($PRF_t = 8.602\ Log_e\ M_t + 35.208$, RMSE = 22.06, df = 18), where the dependent variable PRF_t is the percentage reduction in total barley grass fecundity after the repeated defoliation at time t, and M_t is final mature barley grass density at time t. This function was subsequently incorporated into the barley grass population model to simulate the percentage reduction in seed production likely as a result of repeated mowing, a variable which fluctuated with mature plant density (Kelly *et al*. 2020).

No fecundity data obtained from defoliating plants at any other plant growth stages were used to determine impacts of mowing in the barley grass model since differences in total fecundity between undefoliated plants and the defoliated plants at these stages were not significant (Kelly *et al*. 2020).