Summary  Mature seeds of the economically important broadleaf weed *Carduus nutans* L. were collected from plants at two different sites and were buried at depths of 2 cm and 10 cm in a plot at Canberra in 1994. Seeds were periodically exhumed to determine the percentage of viable seeds remaining. Of the seed buried at 10 cm, approximately 70% of seeds were found to be viable after the first year and over 50% remained viable until 2004. Of the seeds buried at 2 cm, 20% and 33% remained viable after the first year from site (a) and site (b) respectively. However, viability was reduced to 5% and 8% by the year 2002. Predictions of seed life indicate that some *C. nutans* seed buried at depths as little as 2 cm may live as long as 20 years, while the half life of seeds from both sites has been calculated to be 3.5 years at 2 cm and 21 years at 10 cm.

Keywords  *Carduus nutans*, seed bank, buried seed, half life.

INTRODUCTION
The longevity of weed seed banks is important when considering potential weed management systems such as biological control and IWM (Integrated Weed Management). The extent to which weed seeds persist in the soil when seed production has been prevented by chemical, cultural or biological means is important in determining how long such weed management strategies must be maintained.

One study done in North America involving 41 weed species (Burnside *et al.* 1996), showed that, at a depth of 20 cm, *Carduus nutans* L. (Asteraceae) seed could last up to 18 years. Seed banks of this species are predicted to be long lived in Australia (Woodburn and Briese 1996). This paper reports on a seed burial experiment to measure seed bank longevity in Australia.

MATERIALS AND METHODS
Seeds were obtained from seed heads, freshly collected just prior to this experiment, from two locations: Dry Plains near Adaminaby, New South Wales (NSW), 36°0′S, 148°55′E (site a) and near Armidale, NSW, 29°43′S, 151°38′E (site b). Full healthy seeds were carefully selected from the sample and assumed to be viable. No initial test of viability was undertaken. Thirty five groups of 1000 seeds were randomly allocated to each treatment. Each lot of 1000 seeds were placed in 60 mm × 60 mm closed packets made from weed mat material to prevent seeds being removed. These were then buried in 15 cm diameter pots filled with potting mix soil at depths of 10 cm and 2 cm at the CSIRO research site at Black Mountain, Canberra. The pots were then placed in the ground. Pots containing seeds from one location were placed 5 cm apart in a block of 5 × 7 pots. Pots containing seeds from the other location were placed in a similar pattern in an adjacent block. All seeds were buried within a 2 m radius.

Sampling consisted of randomly selecting five pots from each block every 1–2 years, removing both packets of seeds and counting the whole seeds remaining in each packet, except for year 5 when no sample was taken. Actual seed viability of the remaining whole seeds was determined by using tetrazolium chloride (Moore 1962).

The data were log transformed and a regression analysis of the number of surviving seeds against time was carried out to determine the rate of seed loss (Cousens and Mortimer 1995). As an additional measure, the slope (b) of this exponential decay curve was used to determine the half-life (i.e. the time taken for the seed population to decline by 50%) of *C. nutans* (Cousens and Mortimer 1995), according to the formula: $t_{1/2} = (\log e)/b$.

RESULTS
Results showed that seeds placed at 2 cm lost viability more rapidly than at 10 cm (Figure 1). After 10 years, 51% of seeds buried at 10 cm remained viable compared with only 5.3% (site a) and 7.7% (site b) of seeds buried at 2 cm. Projected seed viability using the combined data of site (a) and site (b) was used (Figure 2) and shows that after 20 years all of the viable seed buried at 2 cm would be expected to be gone. Regression analysis showed there was no difference between seeds collected from different sites, but a significant difference was found between seeds buried at 2 cm and 10 cm ($t_{12} = 2.92, P < 0.05$). The half life of *C. nutans* seeds buried at depths of 2 cm and 10 cm, was calculated to be 3.5 and 21.0 years respectively.
DISCUSSION

Other seed burial studies have used burial depths much greater than those used here (Tool and Brown 1946, Burnside et al. 1996). The depths of 2 cm and 10 cm used in this experiment were chosen because most *C. nutans* seed sampled from seed banks in Australia resided in the top 5 cm in undisturbed pasture and all the seed resides in the top 10 cm (T. Woodburn pers. comm.).

This experiment indicates the potential longevity of a *C. nutans* seed bank in an undisturbed environment with no input from new seed. However, it does not consider germination outputs from the seed bank, which play a significant role in grazed pastures in Australia (Woodburn and Sheppard 1996). Nonetheless, these data show that under Australian conditions, seed buried at a shallow depth (2 cm) could live for twenty years. When the last four data points of the seed buried

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**Figure 1.** Percentage seed viability for site (a) and site (b) at both 2 cm and 10 cm (note: seeds were not tested for viability in year 0).

**Figure 2.** Ln (number of viable seed) for site (a) and site (b) combined at both 2 cm and 10 cm depths. Dotted line = 10 cm depth and continuous line = 2 cm depth.
at 2 cm are replotted, the decay rate is increased \(y = -0.294x + 4.81, r^2 = 0.98\) and this result is statistically significant \((t = -9.39, P < 0.05)\). The seed life at 2 cm therefore may be four years less than the 20 years estimated by the regression from the full data set or that calculated from the half life. This experiment also confirms results from other studies, which show that the deeper seeds are buried the longer they survive (Tool and Brown 1946, Roberts and Feast 1972, James et al. 1998).

Only one soil type was used in this experiment and soil type could influence seed mortality. This may mean that predictions of \(C.\) nutans seed longevity in this experiment may vary depending on field conditions; however, James et al. (1998), showed seed viability was less affected by soil type than by burial depth.

These data add to the base line knowledge of \(C.\) nutans and aid on-farm decisions regarding management of nodding thistle infestations. Pastures known to contain quantities of this weed seed should preferably not be cultivated to limit access of seeds to deep burial and therefore greater longevity of seeds.

Demographic studies of \(C.\) nutans (Woodburn and Sheppard 1996) in Australia suggest that due to the high numbers of seed found in seed banks, this weed is rarely seed limited. However, due to the introduction of seed feeding and rosette feeding insects, which not only reduce seed production (Woodburn and Briese 1996, Woodburn and Cullen 1996), but can kill small plants in the rosette stage (Woodburn 1997), biological control of this species may occur sooner than previously anticipated (Swirepik and Smyth 2002). The long lived nature of some seeds in the soil seed bank however, will ensure the persistence of \(C.\) nutans for decades to come. Disturbances, such as drought and cultivation (including deep seed burial), promotes sporadic \(C.\) nutans germination allowing the weed to temporarily escape biological control agents which have been limited by a lack of resource prior to the disturbance events. The long term success of biological control will depend on how the insects respond to the temporal and spatial patterns of the weed population.

ACKNOWLEDGMENTS
I would like to thank Matt Smyth and David Briese for their advice with the statistics and earlier versions of the manuscript and Tim Woodburn for his experimental design.

REFERENCES


