Seedling emergence and longevity of *Senecio madagascariensis* Poir. (fireweed) in coastal south-eastern Australia

B.M. Sindel[A] and **P.W. Michael**[B], School of Crop Sciences, University of Sydney, New South Wales 2006, Australia.

Present addresses:
[A] Department of Agronomy and Soil Science, University of New England, Armidale, New South Wales, 2351, Australia.
[B] 5 George Street, Epping, New South Wales, 2121, Australia.

Summary

Monitoring of the population dynamics of *Senecio madagascariensis* Poir. (fireweed), an introduced African weed of pastures in south-eastern Australia, showed that population size varied greatly between sites and between years; peaks were reached in autumn and spring, coinciding with flushes of germination. Small numbers of seedlings emerged throughout most of the year. Survival curves typically showed rapid mortality following germination and again nearing senescence in late spring and summer. Mean life expectancy was 1.5 months at a site where the pasture was grazed and relatively vigorous, compared with 3.7 months at two less-productive, ungrazed sites. The biennial behaviour of plants depended more on site characteristics, e.g. soil condition, than climatic factors. Complementary data on the demise of *S. madagascariensis* were obtained from a high density population (>5000 plants m^{-2}) which was stimulated by cultivation. Fertilizing of pastures in autumn increased the rate of seedling emergence, growth and development, while slashing once during early vegetative growth reduced *S. madagascariensis* survival by up to 38.2%. Fast growing plants flowered within six weeks of emergence. Vigorous pasture growth reduced emergence of *S. madagascariensis* despite favourable climatic conditions for germination. Early autumn cohorts and large over-summering plants would appear to have the greatest potential to increase the soil seed population.

Introduction

Senecio madagascariensis Poir. (fireweed), native to southern Africa and Madagascar, is an opportunistic weed (Fernández and Verona 1984) which has invaded and colonized a variety of habitats in coastal areas of south-eastern Australia. It occurs predominantly on cultivated land and in poorly grassed, neglected and heavily grazed pastures (Green 1953, Martin and Colman 1977, Launders 1986). The weed is poisonous to livestock because of its pyrrolizidine alkaloid content (Culvenor unpublished data, cited by Bull *et al.* 1968, McBarron 1976) and is a vigorous competitor (Sindel 1987). Whilst its potential distribution appears to be restricted to eastern Australia (Sindel and Michael 1992a), it is one of the most troublesome weeds in that region (Sindel and Michael 1988).

The life cycle and population dynamics of *S. madagascariensis* are complex. Although the plant is most commonly a winter annual, under some conditions it acts as a biennial or a short-lived perennial (Sindel 1986). Individual plants can flower at most times of the year, and densities fluctuate dramatically, similar to species such as *Senecio jacobaea* L. (ragwort) (Harper and Wood 1957, Forbes 1974) and *Carduus nutans* L. (nodding thistle) (Popay *et al.* 1987). As with many other weeds (Roberts 1964), flushes of germination and patterns of seedling recruitment of *S. madagascariensis* are closely related to seasonal climatic conditions, particularly temperature and rainfall. Changes in pasture management practices and soil conditions are also likely to interact with environmental factors to affect population dynamics. Moreover, because *S. madagascariensis* seeds prolifically, its pattern of flowering may be an important determinant of potential infestations.

Weed management involves maximizing mortality as well as lowering reproduction (Mortimer 1983). An understanding of the factors that regulate the population dynamics of *S. madagascariensis* will assist in the proper evaluation and timing of control methods. For example, can pasture competition be used at particular times of the year to suppress germination and seedling emergence? Population studies also provide base line data against which to assess the effect of biological control. If sensitive stages in the life cycle of *S. madagascariensis* can be identified then these may be targeted to make control measures more effective. The aim of this study, in which three naturally-occurring field populations of *S. madagascariensis* were examined, was to find out when seedlings emerged, how long plants lived and when they flowered as a basis for developing a management strategy.

Materials and methods

Study sites

Three permanent quadrats, each 8 m^2 (2 × 4 m), were marked out in January and February 1986 at three pasture sites in the County of Cumberland, New South Wales. Quadrats 1 and 2 were located on the University of Sydney Agronomy Unit, Camden (34°01’S; 150°41’E), and a third on a farm 20 km north-east at Hoxton Park (33°56’S; 150°51’E). Quadrat 1 was located in a lightly wooded area on low fertility, unimproved pasture with moderate cover (approximately 50%) of *Paspalum dilatatum* Poir. (paspalum) and *Themeda triandra* Forssk. (kangaroo grass). Quadrat 2 was in a comparatively bare cultivation paddock (unworked for 18 months), had compacted soil and scattered plants of *Cynodon dactylon* (L.) Pers. (couch), *P. dilatatum* and *Plantago lanceolata* L. (lamb’s tongue) (approximately 20% cover). Both Camden quadrats were ungrazed. Quadrat 3 was a grazed *C. dactylon* dairy pasture, had comparatively dense vegetation cover (approximately 90%), and was continuously stocked at approximately 1.6 cows ha^{-1}. It also contained many *Soliva pterosperma* (Juss.) Less. (bindii) plants and was heavily infested with *Senecio madagascariensis* in 1985 after a summer fire promoted establishment. Quadrat 1 was the most sheltered of the three, being surrounded by tall grass and shaded by a nearby tree; Quadrats 2 and 3 were more exposed.

The major grass species present at each site were warm-season perennials, growing most vigorously from spring through to autumn. *P. dilatatum* and *T. triandra* both form tussocks while *C. dactylon* is a prostrate, stoloniferous and rhizomatous species. *P. lanceolata* is a perennial broadleaf weed which germinates in the autumn to winter period while *S. pterosperma* is a prostrate stoloniferous, annual weed which grows vigorously through spring and summer.

Experiment 1. Seedling emergence, flowering and survival

All over-summering *S. madagascariensis* plants were removed and counted and other weed and pasture growth cut to a height of 10 cm. Then each month for two years, newly-emerged *S. madagascariensis* seedlings were tagged at their bases with coloured plastic rings and their life cycles monitored through to flowering (defined here by the appearance of unopened capitula) and senescence. Owing to an extremely high germination of *S. madagascariensis* seeds at Quadrat 2 in May 1986, two subquadrats, each 0.5 m^2, were subsampled within the large quadrat for further assessment.

The effect of fertilizer application on survival and flowering of *S. madagascariensis* was measured over a period of 12 months in additional quadrats established on 6 February 1987. Four 0.5 m^2 quadrats (0.5 × 1 m) were located at the Agronomy Unit, Camden (pastures of variable botanical composition), and four quadrats, each 4 m^2 (2 × 2 m), at the Hoxton Park site (pasture type similar to Quadrat 3). The different quadrat sizes were chosen according to expected *S. madagascariensis* densities. On 5 March 1987 half the area (randomly allocated) of each of the four quadrats at the two sites received a surface dressing of 'Starter 18' fertilizer equivalent to 66 kg N and 30 kg P ha^{-1}; the other half remained unfertilized. Established *S. madagascariensis* plants were removed and new seedlings tagged and monitored on a monthly basis, as in the year-old quadrats. Emergence data were subjected to analysis of variance.

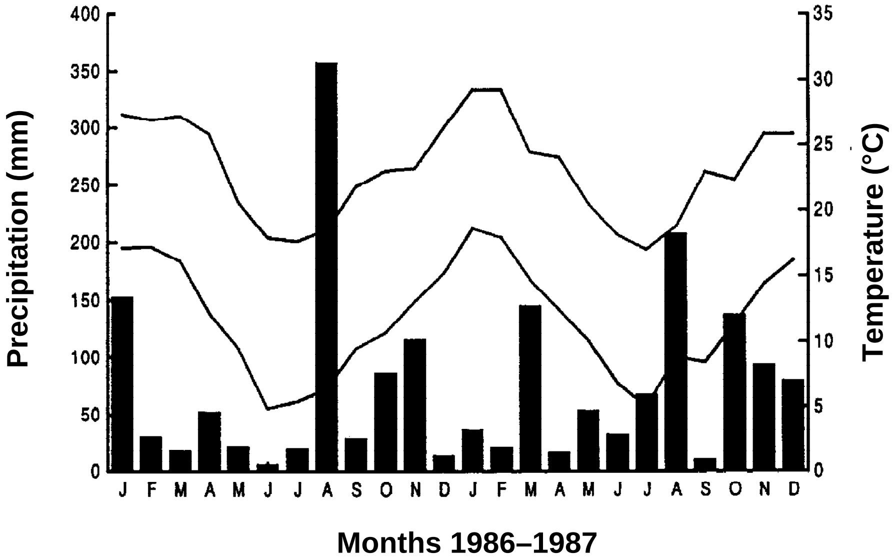

Figure 1. Monthly precipitation and mean daily maximum and minimum temperatures for Liverpool, New South Wales, from 1986 to 1987.

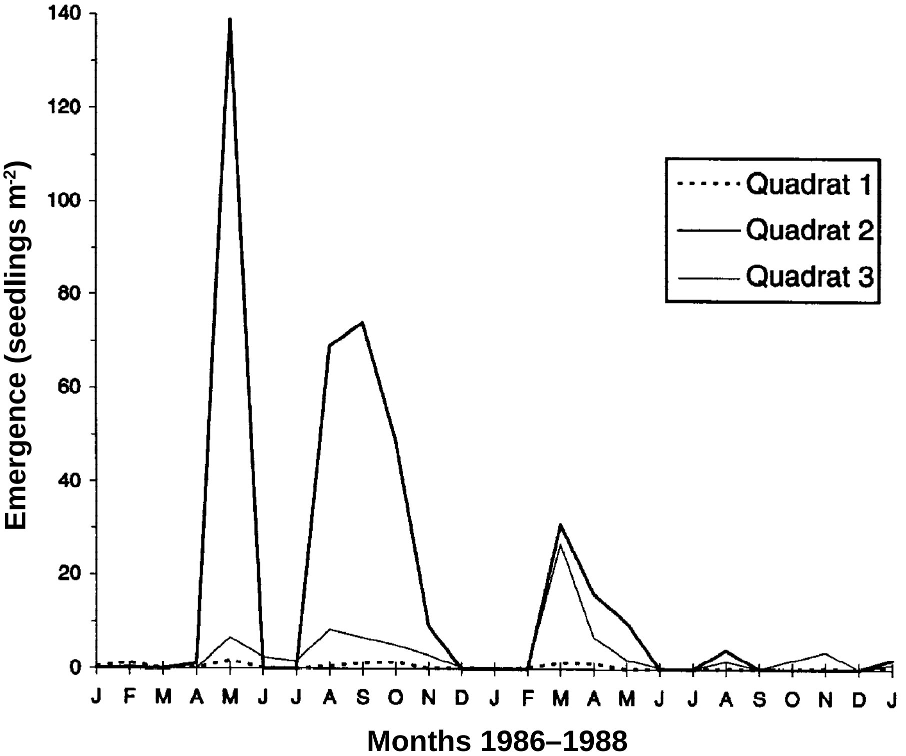

Figure 2. Emergence of *Senecio madagascariensis* at Camden (Quadrats 1 and 2) and Hoxton Park (Quadrat 3), New South Wales, from January 1986 to January 1988.

In late May 1987, two of the four additional quadrats at Hoxton Park which were used to compare fertilizer treatments were slashed at a height of 5–10 cm, thus providing the opportunity to determine the effect of cutting on survival and the pattern of flowering. Data were combined over the two fertilizer treatments and subjected to analysis of variance.

Experiment 2. Survival and seed production of uprooted plants

The ability of *S. madagascariensis* plants to set viable seed after being uprooted was assessed. On 22 April 1985, five plants with immature capitula (ray florets had not yet opened) were uprooted and dropped in an open paddock at Camden. On 10 May, an additional five plants at a similar stage of development were uprooted at Goulburn (34°45'S; 149°43'E) and placed in water in a lighted room. The fate of all plants was closely followed, and any seed they produced was collected and germinated on moist filter paper at room temperature.

Experiment 3. Dynamics at high densities

Extremely large numbers of *S. madagascariensis* seeds germinated concurrently with the emergence of a cultivated crop of forage sorghum during the summer of 1985/86 at Albion Park (34°34'S; 150°46'E). In March 1986, four quadrats, each 0.25 m^2 (0.5 × 0.5 m), were positioned in an area of the paddock with a high uniform density of seedlings. Four smaller 0.01 m^2 quadrats (10 × 10 cm) were placed within these quadrats for regular counting between March and September 1986 and on each visit destructive harvests (each 0.01 m^2) were taken within two of the larger quadrats. Height, dry weight, and number of leaves and capitula were determined for harvested plants.

Results

Experiment 1

Monthly rainfall and temperature data for Camden and Liverpool (6 km east of Hoxton Park), obtained from the Bureau of Meteorology, were similar over the experimental period, hence only data for Liverpool are presented (Figure 1). The number of over-summering *S. madagascariensis* removed from Quadrats 1 to 3 at the beginning of the experiment was equivalent to 5.6, 8.8 and 9.9 plants m^{-2} respectively.

Seedling emergence. The pattern of emergence of seedlings of *S. madagascariensis* was very similar at the three quadrats but the number of seedlings emerging varied considerably (Figure 2).

Small numbers of seedlings emerged during most months of the two year experiment at one or other of the three quadrats, but most emerged during flushes of germination in autumn and spring (Figure 2) and were closely related to the incidence of rainfall (Figure 1).

The first main germination period common to all quadrats in 1986 was in late autumn after 40–50 mm of rain fell in April. Seedling emergence at Quadrat 2 in May was 139 plants m^{-2}. Smaller germinations also occurred during June and July at Quadrat 3 (Figure 2). The second germination flush began in August with the onset of heavy rains (Figure 1) and continued through until late October/early November. The autumn break in 1987 occurred earlier than in 1986, leading to a major germination flush in March and April. The number of *S. madagascariensis* seedlings which emerged during autumn at Quadrat 3 in 1987 (35.5 plants m^{-2}) was much greater than in 1986 (6.6 plants m^{-2}) (Figure 2). At Quadrat 2, where there had been a very large autumn germination in 1986 (140 plants m^{-2}), the number was considerably smaller in 1987 (57 plants m^{-2}).

Senecio madagascariensis seedlings failed to emerge in substantial numbers in the spring of 1987 as they had done in 1986 despite over 200 mm of rain falling at Hoxton Park in August and 160 mm at Camden. Moreover, the precipitation falling in May, June and July at Camden (98.4 mm) and at Liverpool (152.4 mm) maintained high soil moisture throughout the whole of the winter period. Those *S. madagascariensis* seedlings which did emerge in the pasture at Quadrat 3 in August 1987 (Figure 2) were confined to two small bared patches in the pasture. A small number of seedlings emerged at Quadrat 3 in October and November. The quadrats established in 1987 to study the effects of fertilizer gave similar patterns of *S. madagascariensis* emergence to those already outlined (data not presented).

Mortality. Survival curves for *S. madagascariensis* cohorts characteristically decreased in a step-wise fashion; high mortality rates were interrupted by one or two 'survival plateaus'. The mortality rate was particularly high during late spring and summer when many plants were nearing the end of their natural life cycle (Figure 3). The mortality rate was also often high when seedlings were youngest, immediately following germination, but this varied depending on the season in which a cohort germinated. Population peaks were reached in autumn and spring.

Several factors in addition to moisture and temperature stress were observed to contribute to the premature death of *S. madagascariensis*. In June and July, 1986 and 1987, a number of small seedlings were killed by heavy frosts. Other seedlings were infected by the rust fungus *Puccinia lagenophorae* Cooke (fireweed rust). Others had their leaves chewed by pasture slugs. At Quadrat 3, some plants were trampled by cattle and others smothered by cattle faeces. Small seedlings were also sometimes grazed.

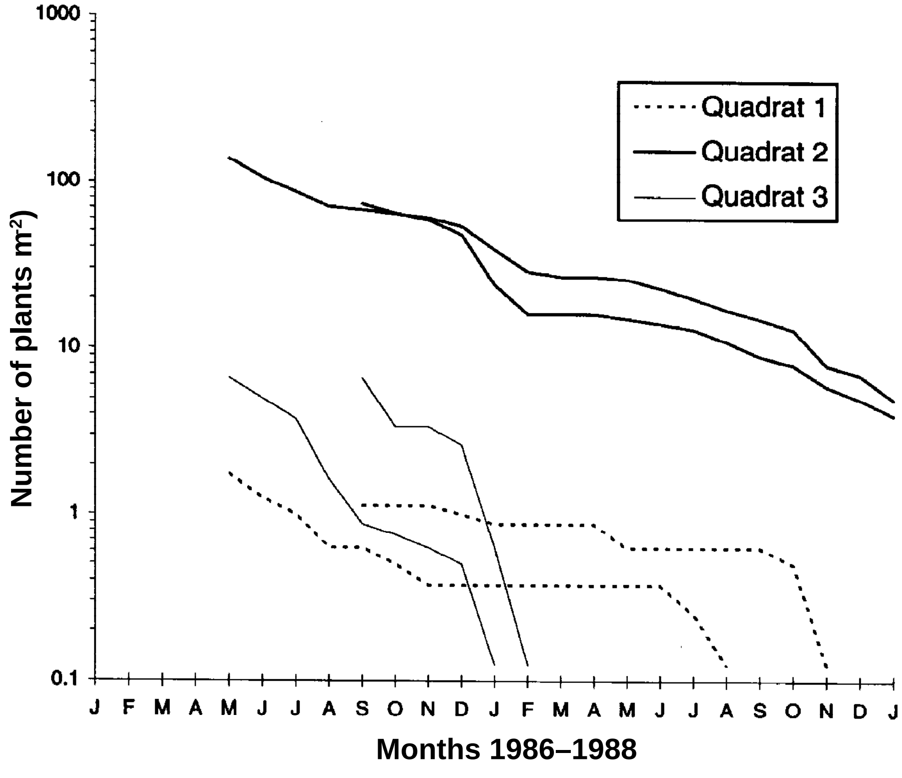

Figure 3. Survival curves for representative autumn and spring cohorts of *Senecio madagascariensis* at Camden (Quadrats 1 and 2) and Hoxton Park (Quadrat 3), New South Wales, from January 1986 to January 1988.

Longevity and flowering. At Quadrats 1 and 2, many *S. madagascariensis* plants from both autumn- and spring-germinating 1986 cohorts survived into a second year of growth. They constituted 40.0 and 12.9% of seedlings which emerged in 1986 at Quadrats 1 and 2 respectively. At Quadrat 3 all plants behaved strictly as annuals (e.g. Figure 3). The cohorts from Quadrat 3 which established in May, June and July, began flowering in September, whereas August and September cohorts first flowered in October (Figure 4). Few plants of late spring cohorts (October and November) produced flowers before they died. Plants which flowered throughout the spring (spring flush) (Figure 4) senesced in December and January.

In 1987, plants in Quadrat 3 and those established to study the effects of fertilizer, also acted primarily as annuals. *S. madagascariensis* seedlings which emerged with the flush of germination in 1987 (two months earlier than in 1986), grew rapidly and flowered some 6–8 weeks later in mid autumn (autumn flush) (Figure 4). Flowering then continued through winter till the middle of spring (November), after which there was rapid senescence, again 1–2 months earlier than in 1986. Annual plants generally had life cycles lasting for periods of up to eight months. Plants generally grew more slowly and took longer to flower at Quadrats 1 and 2 than at Quadrat 3 (Figure 4). In most cases, plants which flowered during spring in 1986 at Quadrats 1 and 2, and which also over-summered, flowered again in the following autumn and continued through winter to the spring of 1987. Flowering times were similar to those of the annuals at Quadrat 3 in 1987 (Figure 4).

Effect of fertilizing. Fertilizer did not affect the size of the autumn germination flush (means of 41.9 and 59.2 seedlings m^{-2} for fertilized and unfertilized plots respectively; $P>0.05$), but it increased the rate of seedling emergence. Hence, the proportion of autumn seedlings emerging in the March cohort in the fertilized plots (82.5%) was larger ($P<0.05$) than in the unfertilized plots (56.5%), where there were also sizable April cohorts. Fertilized plants grew more quickly and flowered earlier (Figure 5); however, survivorship was not altered in any consistent pattern. All plants behaved as annuals.

Effect of cutting. Of the autumn-germinating *S. madagascariensis* cohorts which were slashed in late May 1987, the March seedlings were most affected due to their larger size. Slashing reduced their survival by 18.8% one month after cutting and by up to 38.2% during the next six months ($P<0.05$). This early slashing, however, did not cause plants to over-summer, nor did it reduce the percentage of surviving plants flowering (Figure 6). The time at which plants began to flower varied considerably across the quadrats and this led to widely divergent graphs for percentage flowering before slashing occurred (Figure 6).

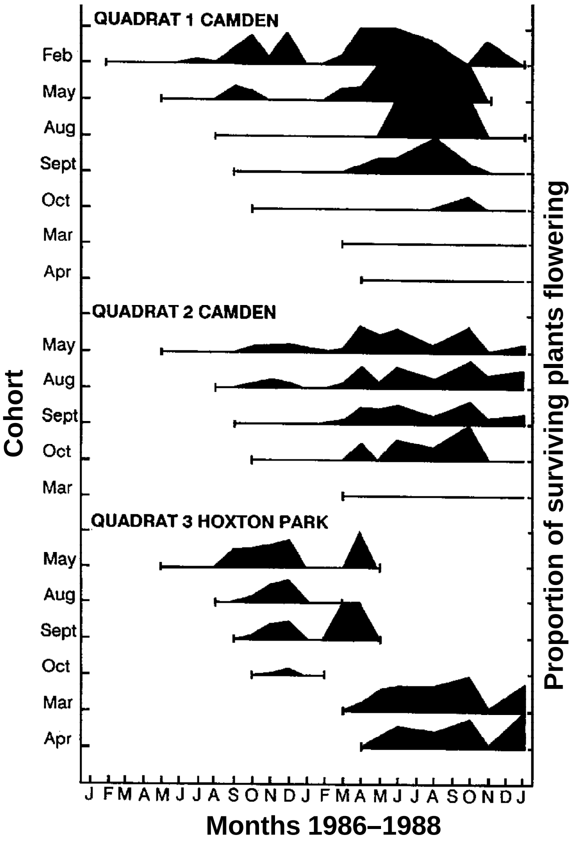

Figure 4. Flowering of the major *Senecio madagascariensis* cohorts (of Figure 2) from January 1986 to January 1988.

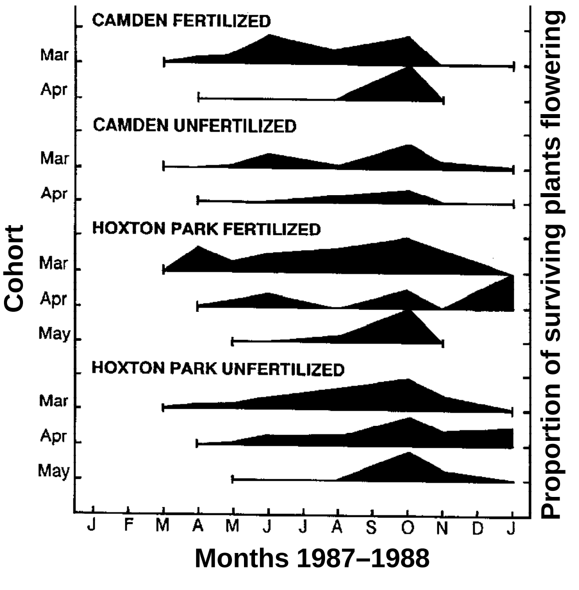

Figure 5. Flowering of the major *Senecio madagascariensis* cohorts in fertilized and unfertilized quadrats from February 1987 to January 1988.

Experiment 2

Of five flowering plants uprooted in April 1985, one re-anchored to the ground and continued to flower. Seed was released 33 days later. Plants which were uprooted and kept in water for 12 days also produced seed. Germination percentages for these seeds and those produced by the re-anchored plant were 100 and 84% respectively. Because April and May were wet months, the plants which were uprooted and did not re-anchor continued to maintain fully open capitula for some nine days after being uprooted, but none released seed.

Experiment 3

The density of *S. madagascariensis,* measured in mid March, was 5850 (± 740) plants m^{-2} and decreased to 2180 (± 430) plants m^{-2} by September (Table 1). Plant height increased over time, but the number of green leaves per plant and total shoot dry weight changed little. Less than 45% of surviving plants flowered by the end of the experiment in early spring; they were also tall and spindly and possessed very few branches. Plants which did flower produced, on average, less than three capitula per plant. On an area basis, this was equivalent to a maximum of 2850 capitula m^{-2}.

Discussion

Emergence

In this study, the inherent variability or plasticity of *S. madagascariensis* was expressed by low levels of germination outside the optimal environmental periods. Such a pattern of staggered germination and emergence is found in many other weeds (Popay and Roberts 1970, Reeves *et al.* 1981), is consistent with the wide temperature range for germination of *S. madagascariensis,* i.e. 10–30°C (Nelson 1980), makes the timing of control measures difficult, and ensures that some seedlings will survive even if many are killed during establishment.

The almost identical seasonal pattern of large emergence flushes across quadrats in autumn and spring suggests that climatic factors (both rainfall and temperature) and/or genetic programming of *S. madagascariensis* determined the pattern of germination. Temperature was likely to have influenced the periods in which peak germination occurred. Nelson and Michael (1982) found that germination was most rapid between 20 and 25°C and that the highest percentage germination after 14 days occurred between 15 and 27°C. In common with many annuals (Donald 1951), the size of *S. madagascariensis* flushes and resulting population densities varied greatly between years and sites (Figure 2).

Vigorous pasture growth may prevent substantial emergence of *S. madagascariensis* despite favourable climatic conditions for germination, as evidenced in this study during late winter and spring in 1987. Winter and spring pasture growth in 1987 was promoted by good rains and high minimum August temperatures (8.8°C). These temperatures were the highest on record (Bureau of Meteorology information) and, on average, 2.4°C above those for 1986 (Figure 1). Of the few seedlings which did emerge during that period, most did so in bared patches where there was no pasture cover. The inhibitory effect of vegetation on the germination of weed seeds and on seedling emergence is well-known (Sagar and Harper 1960, Popay and Roberts 1970, Phung and Popay 1981) and, in the case of *S. madagascariensis,* may be partly due to the responsiveness of its seeds to light (Alonso *et al.* 1982, Nelson and Michael 1982), which Guillén *et al.* (1984) concluded are photoblastic. It is not surprising then that *S. madagascariensis* appears to exploit open spaces in pastures. A dry summer can lead to a decline in pasture density and vigour, and indirectly result in a large germination of *S. madagascariensis* when autumn rains come, as occurred at Quadrat 3 in 1987. Such a sequence of events has long been observed by farmers (Sindel and Michael 1988). Likewise, soil disturbance often leads to an increase in the emergence of weed seedlings and, in this study, the highest density of *S. madagascariensis* was found in a cultivated sorghum crop (>5000 plants m^{-2} compared with <250 plants m^{-2} in pastures).

Mortality, longevity and flowering

Senecio madagascariensis has high natural seedling mortality and seedlings are most vulnerable immediately following emergence. At Quadrat 3, 44% of seedlings died within the first month of establishment. Moreover, this figure probably underestimates mortality because it does not account for seedlings which germinated and died before being counted. The mean life expectancy (calculated from the mean time from emergence to 50% survival of each accession) was only 1.5 months. This compares with 2.8 months for *Emex australis* (spiny emex) (Weiss 1981), and fits in with the expected low juvenile survival of most pioneer and colonizing species (Harper 1965). The mean life expectancy at Quadrats 1 and 2, where many plants were biennials, was 3.7 months.

The life cycle strategy (annual or biennial) adopted by individual *S. madagascariensis* plants is likely to be associated with the stability and/or productivity of the habitat in which they grow; at Quadrats 1 and 2 where there was no disturbance by livestock, little competition from pasture species, but soil conditions were less than favourable, plants grew slowly and behaved as biennials. At Quadrat 3, which was grazed and where the soil stimulated relatively vigorous pasture growth, *S. madagascariensis* had an annual life cycle. In contrast, Edmonds and Popay (1983) found that *Carduus nutans* grew quickly and behaved as an annual in pasture areas bared by herbicide whereas seedlings which survived through to flowering in untreated pasture behaved as biennials. While pasture competition had a major influence on the life cycle of *C. nutans*, soil conditions may have been the over-riding factor influencing the fate of *S. madagascariensis* in this study. Further work is needed to elucidate these effects.

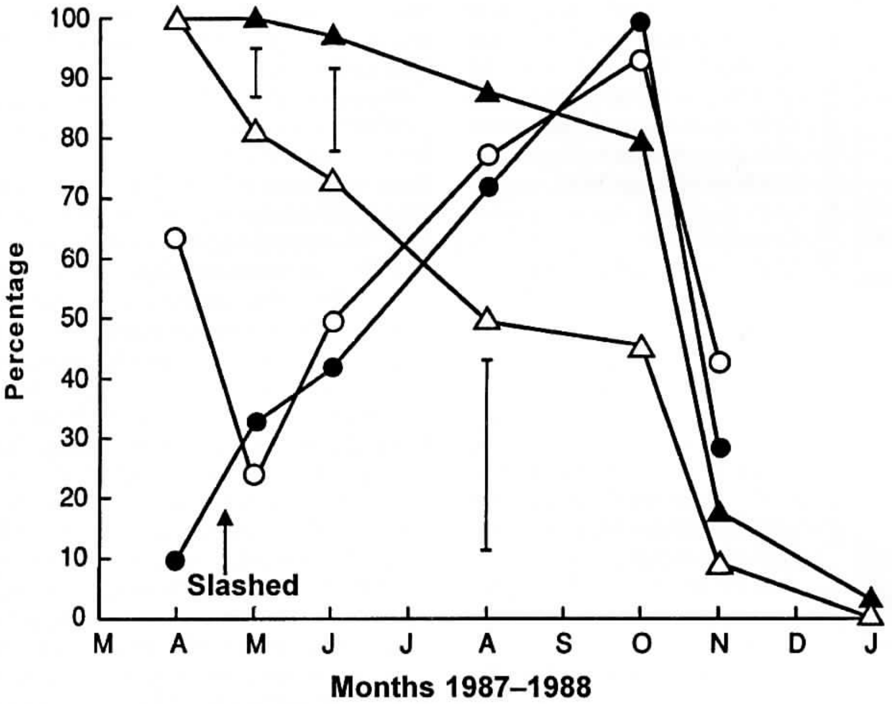

Figure 6. Percentage of March 1987 *Senecio madagascariensis* cohort at Hoxton Park which survived (△ ▲), and percentage of surviving plants which flowered (○ ●), in slashed (open symbols) and unslashed (filled symbols) quadrats. Vertical lines which represent l.s.d.s at the 5% level are presented where ANOVA comparisons of survival data were significant. Slashing had no significant effect on flowering.

Table 1. Growth data for *Senecio madagascariensis* at a high initial density (>5000 plants m^{-2}) at Albion Park, New South Wales.

	Date					
Parameter	19/3	2/4	23/5	14/7	18/8	18/9
Density 100 cm^{-2}	58.5 (7.4)	53.3 (6.7)	44.3 (5.2)	25.0 (6.9)	21.5 (3.1)	21.8 (4.3)
No. leaves^{A} plant^{-1}	6.19 (2.12)	6.58 (2.38)	7.77 (7.46)	6.54 (3.99)	7.10 (5.50)	9.66 (6.41)
Plant height (cm)	6.82 (2.12)	8.04 (2.64)	13.61 (4.38)	15.70 (6.62)	19.41 (7.86)	18.45 (6.73)
No. plants flowered 100 cm^{-2}	0 (0)	0 (0)	3.5 (2.1)	6.0 (2.8)	9.5 (3.5)	6.5 (0.7)
No. capitula 100 cm^{-2}	0 (0)	0 (0)	16.0 (1.4)	17.0 (11.3)	28.5 (9.2)	14.5 (0.7)
Shoot dry weight (g) 100 cm^{-2}	2.17 (0.38)	2.58 (0.19)	4.30 (1.38)	3.23 (0.23)	3.91 (0.77)	3.45 (0.39)

Values in brackets are standard deviations.
^{A} Green leaves >1 cm long.

Senecio madagascariensis seedlings which emerge in either early autumn or early spring under good conditions for growth and which survive initial competition from pastures, are able to grow rapidly, flower and set seed before growth is retarded either by low winter temperatures or hot, dry summer conditions respectively, as occurred at Quadrat 3 (Figure 4). Individual plants may die young and leave some progeny, but other individuals are able to exploit a long growing season. Early autumn accessions and large over-summering plants therefore have the greatest potential to increase the seed population of *S. madagascariensis*. Although the detached viable seeds present on and below the soil surface are an integral part of any *S. madagascariensis* population and are largely responsible for the perpetuation of the weed, their dynamics, including the length of seed persistence in the soil, have not yet been investigated. Management of seed banks for long-term control of *S. madagascariensis* will depend on the results of such studies. The role that over-summering biennials play in maintaining a seed bank of fresh viable propagules for reinfestation needs to be ascertained.

Implications for control

A vigorous and competitive perennial pasture forming a closed canopy in the autumn to spring period is likely to offer the best long term control of *S. madagascariensis*. However, because *S. madagascariensis* germinates in both autumn and spring, it cannot be readily avoided in the establishment of new competitive pasture species. This contrasts with other weeds, such as *Silybum marianum* (L.) Gaertn., which have strict seasonal emergence (Michael 1968). If seedling emergence could be limited in both new and established pastures to one brief period during the autumn then most *S. madagascariensis* could be controlled soon after by a single herbicide application. Any management practice which might help synchronize this emergence, such as fertilizer application or pasture harrowing, may enhance the effectiveness of the control procedure.

Fertilizer applications which promote pasture growth may reduce germination and survival of emerging seedlings, but in view of the stimulatory effect of nitrates on *S. madagascariensis* germination (Alonso *et al.* 1982) and on development and flowering of established plants

(Figure 5) (Sindel and Michael 1992b), correct timing would appear to be critical to their success. Field observations indicate that individual *S. madagascariensis* plants grow into strong robust plants on high fertility soils amongst improved pastures but the pest is much more prolific in areas of low fertility soils and natural pastures (Sindel and Michael 1988).

As a means of controlling *S. madagascariensis*, heavy grazing is not very effective because most seedlings utilize the improved light environment to quickly grow above the pasture canopy. Once plants are distinguishable from the pasture they are usually avoided by cattle. In contrast, regular light grazing or not grazing at peak emergence times may have a role in control. As an alternative management tool, cutting *S. madagascariensis* early in its life cycle reduces its survival, but many plants will regrow, flower and set viable seed. Similar to our own results, Fernández (unpublished data) found that with one cut, survival was reduced by 20%. The effect of cutting was improved dramatically if repeated one or two months later. Cutting late in the life cycle of *S. madagascariensis* is likely to cause some plants to reshoot and over-summer (Sindel personal communication).

Gill (1938) demonstrated that many temperate species, especially those among the Asteraceae and including *S. vulgaris* (common groundsel), produce viable seed even if the parent plant is cut down at the time of flowering. The ability of *S. madagascariensis* to set viable, non-dormant seed for a short while after being uprooted in this study suggests that seed ripening does not depend strongly on favourable environmental conditions. In terms of hand control, the results emphasize the importance of removing *S. madagascariensis* from the paddock in addition to uprooting it. Alternatively, plants which are cut during flowering should be burned.

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