The ecology and control of fireweed (*Senecio madagascariensis* Poir.)

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Summary

This review includes a full description of the southern African plant *Senecio madagascariensis*, now widespread in coastal New South Wales, a key differentiating it from closely related forms of the Australian native species *S. lautus*, an account of its life cycle and distribution, and a general treatment of factors related to its toxicity and methods of control involving herbicides, pasture management and cultivation. The potential of biological control is discussed.

Introduction

Fireweed (*Senecio madagascariensis* Poir.) belongs to the family *Asteraceae* (Compositae) and to the tribe *Senecioneae*. For many years in Australia this yellow-flowering weed (sometimes referred to as 'variable groundsel') was thought to be a form of the very variable native species, *Senecio lautus* Forst.f. ex Willd. (Ali 1969; Walker and Kirkland 1981). However, specimens sent to Dr O. M. Hilliard, University of Natal, South Africa, in 1980 confirmed suspicion that the species originates in south-eastern Africa and Madagascar (Michael 1981) and has been introduced to Australia. *S. madagascariensis* was first described by Poiret in 1817, the type specimen having been collected by Commerson in Madagascar. It has also been classified in some instances under the names *S. ruderalis*, *S. junodianus*, *S. incognitus*, *S. burchellii* (Hilliard 1977) and *S. lautus* aff. ssp. *lanceolatus* (Ali 1969).

Possible explanations for its common name include its ability to 'spread like wild fire', its bright yellow colour, its apparent potential to cause spontaneous combustion in lucerne hay, and its appearance soon after bushfires. It should not be confused, however, with other plants sometimes also referred to as fireweed, e.g. cotton fireweed (*S. quadridentatus*), fireweed groundsel (*S. linearifolius*) and hill fireweed (*S. hispidulus*). In Argentina, where *S. madagascariensis* also occurs, two of the common names given to it are 'golden button' (botón de oro) and 'the yellow flower of Mar del Plata' (flor amarilla de Mar del Plata) (Laguinge 1959, cited by Verona *et al.* 1982).

The great abundance of fireweed in many parts of coastal New South Wales after the breaking of the drought in 1983, its continued spread into new areas, particularly along the south coast, and recent reports on its toxicity to cattle have stimulated a study of the existing literature which is reviewed here. A typical severe infestation of fireweed is shown in Figure 1.

Description and identification

Because fireweed (*S. madagascariensis*) fits, in general terms, the descriptions of the similar native *S. lautus* complex given in Australian floras, it is important to differentiate between the two species. This is especially relevant since members of the *S. lautus* complex are essentially non-weedy (Michael, personal communication) and the content of alkaloids, which cause poisoning in livestock, varies widely between *Senecio* species (Walker and Kirkland 1981). However, because of the variability that occurs within the *S. lautus* complex and the possibility of hybridization and gene exchange between its different forms (Ali 1966; Ornduff 1964), differentiation from *S. madagascariensis* can be difficult.

Ali (1964*a,b*) was able to show that in Australia five main ecological groups, called genoecodemes, may be recognized in the *S. lautus* complex, namely: coastal, moist gully, mallee, montane and desert. After consideration of the genetic system within the complex (Ali 1966), he later gave these taxa subspecies status, with the exception of the desert group (Ali 1969). They are respectively sspp. *maritimus*, *lanceolatus*, *dissectifolius* and *alpinus*. Because the desert group is morphologically similar to members of the mallee and coastal genoecodemes, Ali described such a population as 'aff. ssp. *dissectifolius* and ssp. *maritimus*'. Leaf shape was used predominantly for distinguishing these subspecies, but

Figure 1 Cattle grazing typical fireweed-infested pasture in late winter near Gloucester, New South Wales.

characters such as height, leaf length, number of involucral bracts, number of disc florets, and the length of the corolla of both the ray and disc florets, were also measured.

While Ali did not recognize *S. madagascariensis* as such, it is known from a study of herbarium specimens (Nelson 1980) that he included it among his group of plants known as *S. lautus* aff. ssp. *lanceolatus* (Ali 1969).

Despite Ali's differentiation of the various members of the *S. lautus* complex, it was not possible prior to the taxonomic work of both Nelson (1980) and Daniel (1984), to differentiate between *S. lautus* and *S. madagascariensis*.

Nelson (1980) concluded that the number of involucral bracts or phyllaries (20–21) is of major importance as a distinguishing characteristic of *S. madagascariensis*. Only the desert genoecodeme of *S. lautus* has a similar number of involucral bracts (19) per capitulum (Ali 1964*b*), but owing to its geographic isolation, confusion between them in the field is unlikely. One known difference is that of achene or 'seed' size. The achenes of the desert genoecodeme (Ali 1968) are much larger than those of *S. madagascariensis*. In Argentina, the number of involucral bracts was also found to be critical in the correct identification of *S. madagascariensis* (Verona *et al.* 1982). The shape of the phyllaries, achene morphology, calycular bract morphology and leaf shape are also important for identification.

Because the number of ray florets (commonly called 'petals') varies, and is similar (usually 13) in some members of *S. lautus*, it is of little use in distinguishing *S. madagascariensis* from the *S. lautus* complex.

A detailed description of fireweed (*S. madagascariensis*) and a key, which allows for the differentiation between these two species, can now be given.

Figure 2 Fireweed seedlings at the one-leaf stage (above), and the seven-leaf stage (below).

(a) Habit

A glabrous or very sparsely hairy bush or herb up to *c.* 60 cm tall (Daniel 1984). Rarely decumbent (Nelson 1980), most commonly found as an erect plant, stem often simple (Hilliard 1977) and weakly lignified at the base, often much branched above. Seedlings at two different growth stages are shown in Figure 2.

(b) Leaves

Bright green, alternate, very variable, up to 12 × 2.5 cm (Hilliard 1977) but often much smaller. Cauline leaves mostly linear-lanceolate to elliptic-lanceolate, apex acute, margins denticulate to coarsely and irregularly toothed, tapering to a narrow petiole-like half clasping base, sometimes minutely eared. Upper occasionally pinnately lobed, reduced petiolate, subsessile or sessile. Possesses predominantly α2-type leaves (Daniel 1984) according to the classification of leaf forms of the *S. lautus* complex given by Ali (1964*b*) (see Figure 3).

(c) Flowers

Heads heterogamous, radiate, few to many on bracteate peduncles in open, corymbose panicles, terminal or axillary, the small decurrent bracts similar to the calycular bracts of the capitulum (see Figure 4*a*). Involucre campanulate, 3–5 mm diam., principal bracts or phyllaries *c.* 20–21 (Nelson 1980), herbaceous with membranous edges, 4–5(–6) mm long about equalling or a little shorter than the disc (Hilliard 1977), width 0.8–1.3 mm, keeled, nerves 1–3, resinous, attenuated to an acute apex. Calycular bracts *c** 8–12, ¼ to ⅓ length of upper bracts, often purple-tipped (Nelson 1980). Disc florets many, rays *c.* 13, ray corolla length 8–14 mm (Nelson 1980), often revolute with 4 resinous lines, particularly obvious on upper surface. Ray and disc florets canary yellow.

(d) Fruits

Achenes (see Figure 4*b*) 1.5–2.5 mm long, 0.30–0.45 mm wide, cylindrical, shallowly ribbed, with short hairs or bristles *c.* 0.025 mm long in *c.* 9–10 longitudinal lines or bands, each band 0.03–0.05 mm wide (Daniel 1984). Achenes dark brown, light brown or green with light brown being most abundant (Verona *et al.* 1982). Pappus 3.5–6.5 mm long.

(e) Roots

Shallow, branched, annual or perennating taproot with numerous fibrous roots, growing from 10 to 20 cm deep (Watson *et al.* 1984).

The following key allows for simple differentiation between *S. madagascariensis* and the more common representatives of the *S. lautus* complex.

Agricultural significance

Fireweed is significant principally because of its invasiveness and toxicity.

Invasiveness

Fireweed (*S. madagascariensis*) is an opportunistic weed with the ability to invade and colonize a great variety of habitats in a short period of time (Fernández and Verona 1984). It is, however, found predominantly in poorly grassed, neglected or heavily grazed pastures and on cultivated land during the autumn to spring period (Green 1953; Whittet 1958; Martin and Colman 1977; Walker and Kirkland 1981). In most areas colonized, it has the competitive advantage of active winter growth when pasture production is low. The extent to which pasture growth is suppressed depends on the level of infestation.

Fireweed is important because of its ability to invade pastures growing on highly fertile soil (Verona *et al.* 1982). Watson *et al.* (1984) also observed that fireweed will quickly invade pastures after drought. They suggested that fireweed competes strongly with existing pasture plants for light, moisture and soil nutrients (notably phosphorus and nitrogen), and that this competition can lead to the deterioration of pastures.

Previously, Martin and Colman (1977) considered that fireweed probably had scant influence on pasture production, at least in warm climate

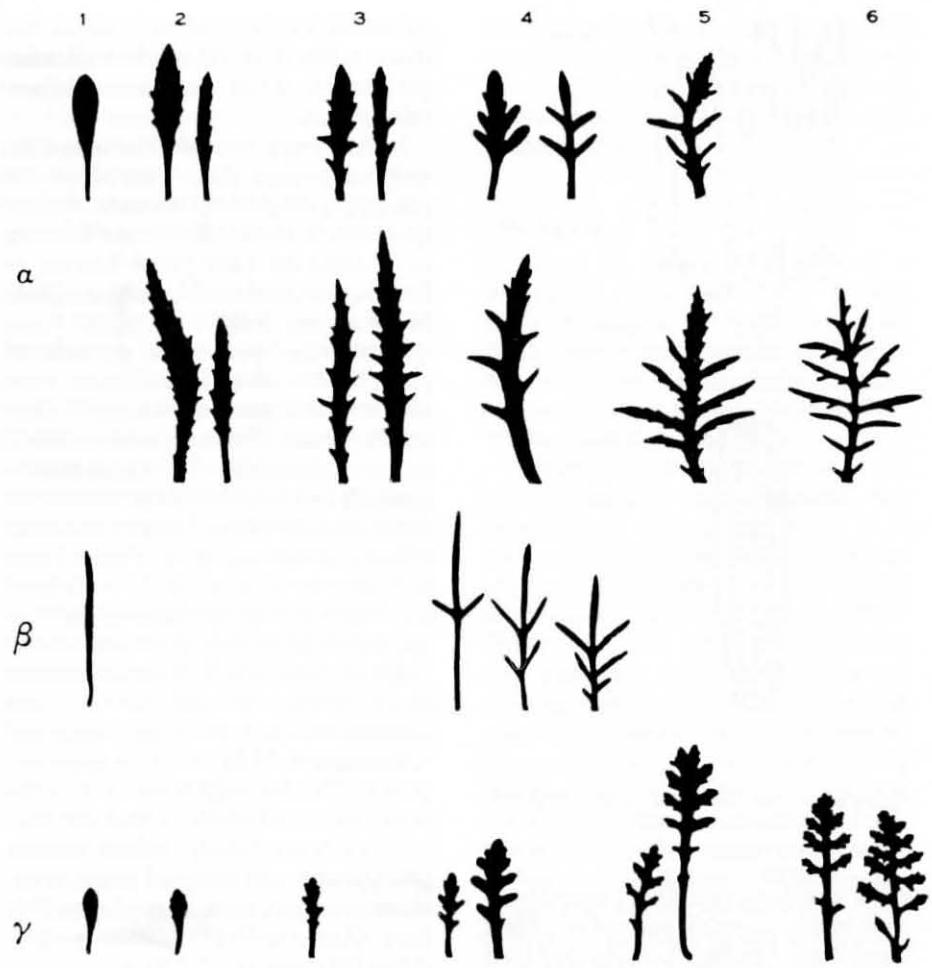

Figure 3 Leaf forms of the *Senecio lautus* complex. Forms α, β and γ are the three main types recognized, while numbers 1–6 refer to subtypes (Ali 1964*b*).

Key to the species

A. Prostrate herb with γ-type leaf pattern (see Figure 3).
S. lautus ssp. *alpinus* (Montane). Alpine and subalpine regions in New South Wales, Victoria and Tasmania.

A.* Erect or decumbent herbs or small shrubs with α- or β-type leaf pattern (see Figure 3).

B. Leaf pattern β-type; involucral bracts 13–20 (mean 15), 3.5–6.0 mm long; achenes 1.9–2.7 mm long, mostly hairy.
S. lautus ssp. *dissectifolius* (Mallee). Widely distributed in all States.

B.* Leaf pattern α-type.

C. Involucral bracts *c.* 13.

D. Leaves noticeably succulent; biggest cauline leaf not lobed, less than 5.5 cm long × 1.2 cm wide. Involucral bracts 4–12 mm long; achenes prominently ribbed, 1.9–4.5 mm long.
S. lautus ssp. *maritimus* (syn. *S. spathulatus* A. Rich.) (Coastal.) Usually on sand dunes or exposed to the sea in southern Queensland and all other States.

D.* Leaves not succulent; biggest cauline leaf not lobed, greater than 5.5 cm long × 1.2 cm wide. Involucral bracts 4.5–6.5 mm long; achenes 1.8–2.0 mm long.
S. lautus ssp. *lanceolatus* (Moist gully). Queensland, New South Wales, Victoria and Western Australia.

C.* Involucral bracts 20–21, 4–6 mm long; achenes 1.5–2.5 mm long with short hairs in longitudinal lines, ribs very shallow.
S. madagascariensis (Fireweed). South-eastern Queensland and coastal New South Wales.

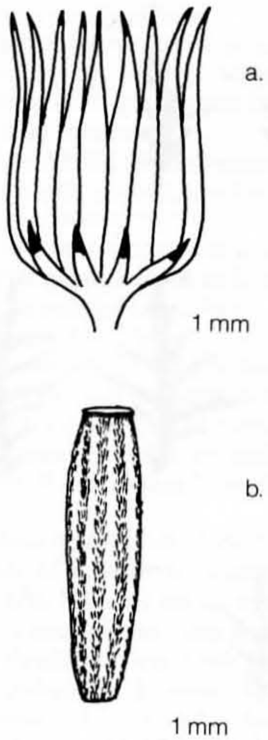

Figure 4 (*a*) Involucre of the capitulum, and (*b*) achene of fireweed.

grass pastures, and that competition with pasture species was small. Their conclusion was based on the fact that at the highest density in their study (4.79 plants m^{-2}) total fireweed yield (106 kg ha^{-1}) was not a significant part of the total herbage on offer. However, as Green (1953) and Whittet (1958) noted, fireweed is much branched and generally avoided by stock, along with the pasture growing beneath it. Consequently, the effective grazing area is reduced considerably. Densities much higher than five plants m^{-2} are also likely to occur.

While fireweed can grow in all types of pasture (Green 1953; Whittet 1958), the amount appears to be influenced by the quantity of ground cover and competition provided by the pasture at particular stages of growth of the weed. It is not generally a problem in irrigated pastures or crops, possibly due to the better overall growth and the more intensive management of these situations (Watson *et al.* 1984).

The potential of fireweed for further colonization once established, due to high seed production, is another of its important invasive characteristics (Nelson 1980).

Toxicity

Senecio was one of the first plant genera to excite attention as being harmful to domestic livestock (Bull *et al.* 1968). In many countries, ingestion of the widespread species *Senecio jacobaea* (ragwort) is responsible for more deaths of livestock than all other poisonous plants together (Robins 1977).

In Australia, several *Senecio* species have also been incriminated in the poisoning of grazing animals (Bull *et al.* 1968), *S. lautus* (Bennetts 1935) and *S. madagascariensis* (then known as *S. lautus*) (Green 1953; Whittet 1958) being among them.

Mortalities and poor growth of cattle in the Hunter Valley of New South Wales were shown by Walker and Kirkland (1981) to be also caused by fireweed toxicity. Fireweed, experimentally fed to three calves, caused the death of two within 77 days and depressed growth rate in the third. These findings were augmented by a study of a substantial field mortality of cattle in the Bulahdelah district on the central coast of New South Wales (Kirkland *et al.* 1982). On the basis of the autopsy findings, histopathology and consumption of fireweed, it was concluded that fireweed toxicity was the principal cause of these mortalities.

It is known that as well as causing poor growth and death of stock, other *Senecio* species have been responsible for a drop in milk production in dairy cattle (Watson *et al.* 1984).

Fireweed is poisonous owing to the presence of a pyrrolizidine alkaloid believed to be senecionine (Culvenor unpubl. data, cited by Bull *et al.* 1968; McBarron 1976). The structures of senecionine and the general form of pyrrolizidine alkaloids are given in Figure 5.

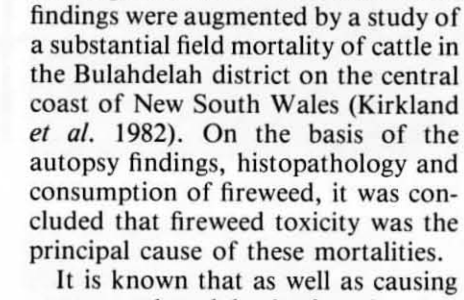

Figure 5 Structures of (*a*) the general form of pyrrolizidine alkaloids (R = H, OH or O-acyl; R_1 = alkyl), and (*b*) senecionine, the pyrrolizidine alkaloid present in fireweed.

The alkaloid content of *Senecio* species is very variable (White 1969) and especially among members of the *S. lautus* complex (Walker and Kirkland 1981). Mature fireweed (*S. madagascariensis*) has been reported as having a total alkaloid content of 0.03%. Although this is only a relatively moderate level, Walker and Kirkland (1981) conclude that, at least in the Hunter Valley, significant mortality and poor growth of stock can occur from its ingestion.

Symptoms and treatment

The disease pyrrolizidine alkaloidosis or seneciosis, produced by the consumption of *Senecio* plants, is characteristically chronic in nature with most pyrrolizidine alkaloids being cumulative poisons (Swan 1967). These induce a form of liver (hepatic) damage characterized by megalocytosis and inhibition of cell division (Bull *et al.* 1968). The disease is progressive, symptoms and deaths of animals commonly occurring weeks or months after consumption of the plant has ceased (Swan 1967; Anon. 1930; Bull 1955). The pathological symptoms characteristic of the disease (Bull *et al.* 1968; Hooper 1978) have all been reported in animals which have grazed or been fed fireweed (Walker and Kirkland 1981; Kirkland *et al.* 1982).

The clinical signs that have been observed in cattle suffering from fireweed poisoning are diverse, but weakness, marked loss of condition, and emaciation with recumbency and death were most prominent (Walker and Kirkland 1981). Nervous signs such as aimless wandering, slight or incomplete paralysis, loss of muscular coordination, insensibility and apparent blindness have been seen infrequently. In older stock, photosensitization, jaundice and abdominal straining were observed in sporadic cases. Other signs may include dullness, chronic scouring and loss of appetite and condition (Watson *et al.* 1984).

The most common effect attributed to fireweed in cattle is ill-thrift and poor growth in young stock. A condition in cattle on the Central Coast of New South Wales known as coastal ill-thrift, is believed to be partly due to fireweed toxicity. Varying degrees of chronic but not fatal damage are seen in these animals (Watson *et al.* 1984).

There is no effective treatment for this disease (Reynolds 1936; Craig *et al.* 1930; Watson *et al.* 1984). Movement of stock to areas free of fireweed may prevent further development of the disease but because this form of liver damage is irreversible (Bull *et al.* 1968), the syndrome of ill-thrift and poor growth will continue. In order to prevent the access of livestock to fireweed and the possibility of poisoning, control of the weed is most desirable.

Factors affecting poisoning

Poisoning may be affected by several factors. These include the palatability of fireweed, age of the plant, availability of alternative feed, variation in animal tolerance and weather conditions.

The risk to livestock grazing infested pastures is contested because fireweed is generally unpalatable to cattle and horses (Watson *et al.* 1984). Many other *Senecio* species are also regarded as unpalatable to livestock. Feed rejection problems have been encountered with both *S. lautus* (Bennetts 1935) and fireweed (*S. madagascariensis*) (Walker and Kirkland 1981) in experiments with sheep and cattle respectively.

Some evidence suggests that when the *Senecio* pyrrolizidine alkaloids are in their N-oxide form they may be more palatable and therefore more likely to cause poisoning (Schoental 1955). This was observed in young growing plants (Schoental 1957). Preference for young *Senecio* plants, however, has not been confirmed (Cockburn *et al.* 1955).

The palatability of some toxic *Senecio* species, including fireweed, may be improved by spraying (Matthews 1971) or slashing, possibly because wilted or dried material is more readily consumed (Murnane 1933). Because fireweed remains poisonous when dry (Walker and Kirkland 1981), there is a danger that poisoning may occur following such operations.

Since the evidence concerning the effect of age on the toxicity of *Senecio* plants is contradictory, and the relative toxicity of immature fireweed has not been reported, potential toxicity throughout the life (and death) of the plant should be assumed (Nelson 1980).

Providing sufficient alternative feed is available, cattle and horses will consume only small quantities of fireweed. Where its ingestion cannot be avoided, poisoning is more likely to occur. Such circumstances may include pastures heavily infested with young fireweed plants and poor quality pastures where there is a shortage of alternative feed (Watson *et al.* 1984). It is in the latter situation, where a pasture has a low grazing capacity, that fireweed is often most prevalent (Green 1953; Whittet 1958; Martin and Colman 1977). In the Hunter Valley, like other areas along the New South Wales coast, there is often a seasonal shortage of pasture from late winter to mid or late summer (Walker and Kirkland 1981). It is at these times that fireweed is most abundant and a scarcity of alternative feed forces cattle to consume the plant despite its unpalatability. Cotton fireweed (*S. quadridentatus*) has also been incriminated in stock losses under these conditions (Kater 1965). Poor seasonal conditions or droughts and heavy stocking rates present potentially dangerous situations.

In prepared feeds containing fireweed, selection is difficult for the animals and poisoning is more likely to occur. Hay containing other *Senecio* species has caused livestock poisoning (Craig *et al.* 1930; Leyshon 1926), while silage is also reported as dangerous (Donald and Shanks 1956; Ferguson 1940). This suggests that the pyrrolizidine alkaloids are not destroyed in either the hay-making or the ensiling processes. Therefore the control of fireweed (*S. madagascariensis*) in areas to be used for hay or silage is critical.

While seneciosis has been reported in all the major classes of livestock, susceptibility varies. Though sheep and goats readily eat fireweed, they are much less susceptible to poisoning than cattle and horses (Bull 1955; Smith 1983; Watson *et al.* 1984). They may even show preference to it over other pasture plants. Sheep have often been used to graze down pasture land badly infested by ragwort (*S. jacobaea*) (Hexter 1950; Parsons 1973) with apparently no ill effects (Reynolds 1936). However, other evidence suggests that sheep are affected by pyrrolizidine alkaloids but progression of the disease is much slower (Bull *et al.* 1956; Bull *et al.* 1968). Detoxification of the alkaloids by specific bacterial enzymes in the rumen of sheep (Bull *et al.* 1968), or the high activity of a hepatic microsomal enzyme (Swick *et al.* 1983), could account for their relative resistance.

It is likely that the age of livestock also affects tolerance. Thus Walker and Kirkland (1981) found group mortalities most often in calves. In contrast, mortalities in older animals occurred sporadically and the syndrome of poor growth was more prominent. This may reflect a greater tolerance due to larger body size and prior exposure to the plant.

Evidence suggests that changes in weather conditions may also influence fireweed poisoning. During January and February 1980, 75 cattle died from a herd of 800 in the Bulahdelah district on the Central Coast of New South Wales. Kirkland *et al.* (1982) concluded that fireweed toxicity was the principal cause. They also observed that the peak of these mortalities occurred after major changes in the weather, e.g. after rain and an improvement in nutrition. At the time of the mortalities, drought conditions had prevailed for 6 months. In cases of poisoning with other *Senecio* species, increased mortality has also occurred following environmental changes (Donald and Shanks 1956).

Life cycle

Fireweed (*S. madagascariensis*) is a short-lived perennial plant (Green 1953; Whittet 1958; Cabrera and Ré 1965; Martin and Colman 1977; Verona *et al.* 1982) which behaves most commonly as an annual (Hilliard 1977; Walker and Kirkland 1981).

The majority of plants die off at the end of their first year of growth, but especially in agricultural soils, it is common to find plants which continue to grow and reproduce actively during their second year (Verona *et al.* 1982). This is true even without some external stimulus, such as mechanical damage which could promote the regeneration of its stem. For example, plants which are slashed are not killed but may regrow and become two-year plants. This persistence through summer is confirmed by observations made by Nelson and Michael (1982). In some plants, regrowth from roots can occur following the death of the top growth over summer (Watson *et al.* 1984). Since rooting along the woody stems of decumbent fireweed plants has also been observed (Nelson 1980), it is possible that shoots associated with these adventitious roots remain alive, while those of the parent roots die off. Verona *et al.* (1982) had reservations in considering it a strict perennial, however, because with rare exceptions, the few plants that survive the second year are decrepit and ready to senesce. It is likely for this reason that Humbert (1963) reports *S. madagascariensis* as a biennial.

It is not uncommon therefore to find variations in the life cycle of this plant. Similar variations are known to occur in *S. jacobaea* (Forbes 1977, cited by Verona *et al.* 1982), a biennial plant which may also behave as a perennial under certain conditions. In this context, *S. madagascariensis* represents a species with high plasticity or capacity to vary its life cycle. This undoubtedly is associated with the duration and stability of the habitat which supports it (Southwood 1977, cited by Verona *et al.* 1982).

Fireweed is capable of growing and reproducing during a large part of the year, although most seed germinates from March to July with the plants dying off from September to November. At the moment of dispersion a high proportion of seed is viable and ready to germinate (Alonso *et al.* 1982; Nelson and Michael 1982). Nelson and Michael showed this to be 90% three days after collection at 20°C. It is suggested that because of this more than one generation may occur throughout the winter period (Nelson 1980). While extreme temperatures induce dormancy of the seeds (Alonso *et al.* 1982), innate dormancy is negligible under normal conditions. High spring and summer temperatures may help to explain the lack of new seedlings appearing in that period.

Nelson and Michael (1982) showed that most rapid germination occurred between 20°C and 25°C. Highest germination after 14 days occurred between 15°C and 27°C with greatly reduced germination at lower and higher temperatures. This helps to explain why fireweed can germinate over much of the year. Nelson and Michael also found, and this has been confirmed by the author, that there is no germination at 35°C but seed exposed to this temperature was viable when germinated at 20°C. The optimum temperatures observed for germination and the ability of the seeds to withstand high summer temperatures are those expected of a winter-growing species in parts of coastal New South Wales (Nelson 1980).

Although light (Nelson and Michael 1982; Alonso *et al.* 1982) and nitrates (Alonso *et al.* 1982) are not essential, they generally stimulate germination. Responsiveness to light has also been reported in *S. vulgaris* (Popay and Roberts 1970) and may be of direct consequence to the establishment and survival of seed, by determining the maximum depth of soil from which germination may take place (Koller 1964). The depth of *S. madagascariensis* seed in the soil does affect germination with seedling emergence not occurring below 2 cm (Alonso *et al.* 1982).

Osmotic potentials ranging between 0 and −3 bars did not differ in their effects on germination (Alonso *et al.* 1982). Although the percentage decreased at potentials below this level, some seeds were still able to germinate at −10 bars. The three types of achenes (dark brown, light brown and green) (Verona *et al.* 1982) had different germination behaviour and morphological characteristics.

It has been estimated that, under laboratory storage, all seeds lose their viability after 4 to 5 years (Alonso *et al.* 1982). Nothing is known concerning the longevity of seed in the field.

Fireweed seedlings develop rapidly with the plants producing flowers 6 to 10 weeks after emergence. Time to flowering decreases with increasing temperature (Nelson 1980). Growth rates (dry matter and leaf area) are positively correlated with mean air temperature (Nelson 1980; Fernández and Verona 1983). Dry matter allocation to leaves prevails during the early developmental stages with an increasing proportion of assimilates going into the stems over the life of the plant. Allocation to roots decreases rapidly with plant age (Fernández and Verona 1983).

S. madagascariensis is a precocious species with flower intensity greatest at the beginning of spring. A flush in flowering also occurs in the middle of autumn (Verona *et al.* 1982). An individual plant has the ability to produce large quantities of seed during its life cycle. In a seed production study (Nelson, personal communication) the average plant produced approximately 230 flowers with 80 seeds per flower (total of 18 000 seeds). At a nominal germination rate of 50%, it was estimated that the average plant produced 9000 viable seeds. Because the seeds are small and light (135 μg) and each is attached to a relatively persistent pappus of white hairs (Daniel 1984), they are easily spread by wind. It is the dispersal of large amounts of seed in this way that is considered to be the major factor responsible for the rapid spread of the weed over large areas and long distances (Watson *et al.* 1984). The seeds can also be spread in hay and grain products, on clothing and vehicles, and by livestock, birds and other animals. There have also been suggestions that seed has blown into piles of superphosphate and then been spread to new areas when the fertilizer was applied aerially.

Distribution

The earliest record of fireweed in New South Wales — and probably in Australia — is a specimen collected at Raymond Terrace in 1918 (Nelson 1980). It first became prominent in pastures in the Hunter Valley and from there spread throughout many parts of coastal New South Wales, being introduced to the North Coast in about 1940 in crop seed (Martin and Colman 1977). It is now especially abundant in the Richmond, Manning and Hunter Valleys, in the County of Cumberland and between Wollongong and Berry on the South Coast. The weed is also known to occur as far south as Bega and in south-eastern Queensland.

While the weed primarily infests the coastal river valleys of New South Wales, distribution does extend into the northern and southern Tablelands (Nelson and Michael 1982) and an isolated occurrence exists further inland at Dubbo (Watson *et al.* 1984). The potential distribution of fireweed in Australia is not known, but in view of its rapid spread in recent years it can be expected to occupy areas much larger than at present.

In southern Africa it is known to occur up to 1500 m above sea level and is widely distributed from Madagascar and the Mascarene islands through coastal Mozambique to Natal, the Transkei and eastern and southern Cape as far west as the Uniondale district. Though not common, it is also found in the Transvaal (Hilliard 1977).

In Argentina, though originally classified as *S. incognitus* (Cabrera 1941) and subsequently as *S. burchellii* (Cabrera 1963; Cabrera and Ré 1965), *S. madagascariensis* was first known in the early 1940s surrounding the port of Bahia Blanca. Since then it has spread greatly and is now a significant weed of agricultural grasslands in the south-eastern part of Buenos Aires province (Verona *et al.* 1982).

The present distribution of *S. madagascariensis* in southern Africa, Australia and Argentina is shown in Figure 6.

On a local scale the pattern of distribution may vary considerably on account of differences in soil and previous cultural systems. Fireweed is drought tolerant and able to grow on a wide range of soils of varying fertility (Verona *et al.* 1982). Although it prefers soils which are well drained, not compacted, and of high fertility, it can also grow in sand and heavily limed soil. Low fertility soils are less likely to support vigorous pastures and, lacking competition, fireweed grows freely (Watson *et al.* 1984). Although these authors also state that it will not persist in poorly drained or waterlogged situations, Verona *et al.* (1982) concluded the opposite to be true. The results of a trial conducted by Daniel (1984) also suggest that fireweed may show adaption to different drainage regimes and indicate that it has a large potential for physiological variation.

Control

Although fireweed was declared a noxious weed in certain shires of New South Wales from 1946 to 1971 (Martin and Colman 1977), it is now generally considered that eradication and prevention of spread are not feasible.

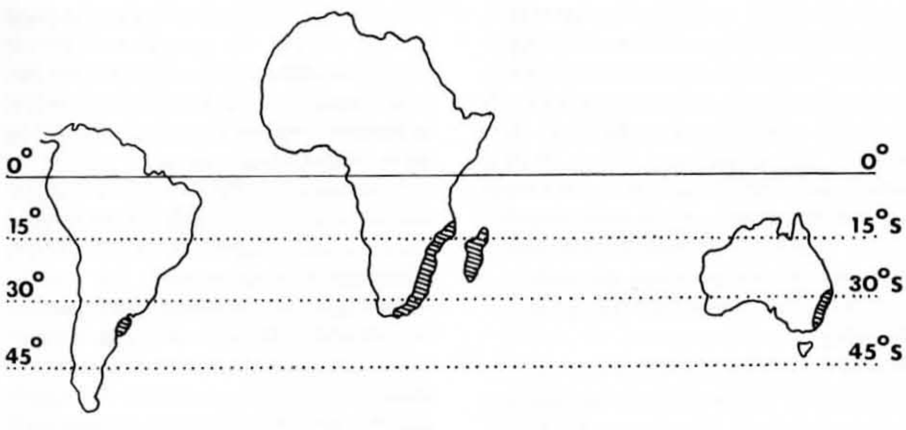

Figure 6 World distribution of *Senecio madagascariensis*.

The characteristics of fireweed which often make its control difficult include:

1. resistance to drought;
2. prolific seed production;
3. ease of seed distribution;
4. annual/perennial habit;
5. adaptability and variability in the field;
6. establishment when summer pasture growth is declining but before most winter pasture growth has begun;
7. germination, growth and flowering during much of the year; and
8. a long flowering period.

Despite the importance of the weed, very little work has been done on its control, and that has been mostly confined to work with herbicides. An integrated approach is surely desirable. To this end, a range of possible control methods is discussed here.

Herbicides

The most desirable time for herbicide application is during the small seedling to early flowering stages (normally autumn to winter) (Watson *et al.* 1984). While a number of herbicides have been compared for efficiency in killing fireweed, glyphosate (as Roundup) and bromoxynil (as Brominil) have proved to be the most effective (Launders 1979).

An excellent kill of young fireweed was achieved with an application of bromoxynil at 280 g a.i. ha^{-1}. However, when applied to advanced plants, the percentage kill dropped to less than 55% (Launders, personal communication). It was concluded that after bud formation, between 500 and 560 g a.i. ha^{-1} were needed. Bromoxynil is a selective herbicide. While grasses are unaffected it will cause some scorching of the upper leaves of clover. This effect, however, is temporary and the clover generally recovers quickly.

Further trials assessed the use of ropewick applicators on fireweed (Launders 1984*a,b*). These enable non-selective herbicides such as glyphosate to be selectively applied to species. Both bromoxynil at 200 g a.i. per litre, and glyphosate at 100 g a.i. per litre proved effective against young plants, but glyphosate was needed to ensure a good kill after flowering (Launders 1984*a*). In the second trial, two passes of the applicator using glyphosate gave a 94% kill of flowering plants compared to 69% with only one pass (Launders 1984*b*). When glyphosate is applied via a ropewick applicator the target weeds should be at least 15 cm taller than the pasture. To help achieve this situation the area should be grazed prior to treatment.

Tests to determine whether these two herbicides have any effect on the germination of fireweed seeds when the plants have been sprayed in the late flowering stage, indicate that both reduce germination, with glyphosate being the more effective of the two.

As previously mentioned, fireweed plants treated with herbicides may, however, become more attractive and palatable to stock. This could increase the risk of fireweed poisoning even though stock may be withheld from the treated areas until the plants are completely dead.

Because pastures that initially proved suitable for invasion by fireweed are likely to suffer the same fate again, herbicide control must be considered a temporary measure and be carried out in conjunction with pasture improvement.

Pasture management

The essential principle in any fireweed control program according to Smith (1983) must be provision of a vigorous, competitive pasture. This had previously been recognized by Green (1953) and Whittet (1958). Any factors which open up pastures such as overgrazing, drought, uncompetitive pasture species and areas bared by trampling, e.g. around watering or feeding places, appear to favour the development of fireweed.

A dense, vigorous and competitive pasture during early autumn to winter is likely to provide the best form of control. It is possible that this could be achieved by the growing of early winter pasture species, by allowing standover of summer pasture feed, or by combinations of winter–summer pastures (Watson *et al.* 1984). This is particularly relevant since fireweed is of greatest abundance in naturalized summer-growing pastures such as paspalum (*Paspalum dilatatum*)/carpet grass (*Axonopus affinis*) dominant pastures of the Central to North Coast regions of New South Wales (Martin and Colman 1977; Launders 1979). The low productivity and high relative stocking rates in the winter months predisposes them to invasion.

Due to the need for continuity of feed, particularly on dairy farms, new pasture species may need to be drilled directly into the existing pasture rather than using conventional cultivation before sowing. Possible winter species include phalaris, ryegrass, fescue, white clover, subterranean clover and oats, while summer species such as kikuyu, paspalum, setaria and Rhodes grass have potential. Kikuyu dominance, even under heavy grazing, is said to markedly reduce fireweed density (Martin and Colman 1977), possibly because kikuyu has a longer period of active growth in autumn than either carpet grass or paspalum (Colman 1970). It therefore competes more strongly with regenerating seedlings of fireweed.

Careful fertilizer management is also likely to be a critical tool in fireweed control (Nelson 1980). The application of fertilizer during the active growth period of the grasses could increase their yield and therefore decrease the density of fireweed. However, the opposite may be true if application occurs when conditions are unfavourable for response by the pasture, for example, in autumn when the summer-growing species have ceased active growth.

Pasture management through controlled grazing, appropriate fertilizer applications and the sowing of new species, as a method of fireweed control, has potential and warrants further investigation.

Mowing

Very little has been reported concerning the effectiveness of mowing or slashing as a means of controlling fireweed. The results of mowing throughout the autumn to spring period have been variable (Watson *et al.* 1984). In trials near Taree close mowing did not kill the plants but only slowed their growth and delayed flowering. Because mowing may promote regrowth (Verona *et al.* 1982), it will cause some fireweed plants to survive through summer and continue to grow and flower in the second year.

Nevertheless, regular mowing can assist in control over small areas. It is likely to be more successful if carried out at late flowering rather than earlier in the life cycle of the plant. Mowing when conditions are unfavourable for pasture growth, or in young and unthrifty pastures, should be avoided since the weed may recover more quickly than the pasture and therefore become dominant.

Because wilted or dried fireweed plants retain their toxicity and may become more palatable to stock, the risk of poisoning may also be increased.

Cultivation

Following the finding of Nelson (1980), that germination of fireweed in the dark was only 8%, it appears that burial of the seed could aid in reducing plant populations. An experiment, designed among other things, to test this as a method of control (Daniel 1984) showed, however, that even where the soil was inverted by mouldboard ploughing, fireweed increased rather than decreased in density. Cultivation of natural carpet grass pastures, in order to establish improved species, has also been observed to increase the density of fireweed (Launders 1979).

More often than not, soil cultivation stimulates massive germination of fireweed seed and provides a suitable bed for seeds blown in from other areas. Therefore to be effective and kill emerging seedlings, cultivation must be thorough, repeated and followed up with the establishment of either a suitable perennial pasture or, alternatively, a winter crop followed by a perennial pasture (Watson *et al.* 1984). Where continuity of feed is important, complete cultivations of this nature are likely to be uneconomical.

Any consideration of the long-term implications of weed control must take into account the population of dormant, viable weed seeds present in the soil (Daniel 1984). At present, however, nothing is known of the survival of fireweed seed in a soil system. Because cultivation will mix weed seeds between conditions enforcing dormancy and conditions which favour germination (Roberts 1964), the longevity of the seeds of fireweed in cultivated ground is expected to be much less than in undisturbed ground.

Grazing

While low stocking rates are recommended to allow pasture to compete more vigorously with fireweed, it is believed that grazing with sheep or goats may be of some use in fireweed control (Watson *et al.* 1984). They have been used in Australia and overseas for the control of other weedy *Senecio* species in pastures. For example, in the Gippsland area of Victoria, many dairy farmers carry some sheep, usually crossbred wethers, for the sole purpose of controlling ragwort (*S. jacobaea*) (Parsons 1973). Although the effect of defoliation on fireweed has not been documented, experience shows that sheep and goats do provide a level of control worthy of serious consideration.

This method, however, is not without difficulties. Running sheep under coastal conditions would lead to an increased incidence of parasites and diseases. Improved or additional fences and yards may be required and flock composition would need to be altered regularly in order to avoid eventual poisoning of the animals. Stocking rates would also have to be managed carefully so that the fireweed was suppressed but the pasture was not overgrazed. Lastly, many farmers would feel it impractical to introduce sheep into predominantly dairying areas.

Biological

Although a number of insects both in Australia and Argentina are known to feed on *S. madagascariensis* and a rust infest it, their impact is still relatively unknown.

In Argentina, during its vegetative stages of growth, *S. madagascariensis* is a frequent host of ants, principally *Acromirmex lundii* (Verona *et al.* 1982). These eat the leaves and vegetative shoots and in the more advanced plants feed on the beginnings of the inflorescences. Another insect, still not identified, feeds on the ovaries, reducing their growth and the reproductive capacity of the weed. In young branches, fly larvae (*Lamproxynella* sp.) cause the formation of galls. A pseudococcid has also been observed in the roots. In greenhouse-grown plants an aphid (*Myzus persicae*) has been found to feed on the leaves, while in gardens the young plants are eaten by a snail (*Helix aspera*).

In Australia, insects such as the larvae of a pyralid moth (*Homoesoma* sp.), the cineraria leaf miner (*Phytomyza syngenesiae*), the senecio moth (*Nyctemera amica*), the metallic flea beetle (*Haltica* sp.) and various pasture slugs are known to feed on the plant (Watson *et al.* 1984). A Lygaeidae bug (*Nysius* sp.) is also commonly found on the inflorescence.

A relatively widespread autoecious rust, *Puccinia lagenophorae*, infests fireweed in the field and can cause considerable growth retardation on heavily infected plants. Like other plant diseases, the severity and spread of this rust on fireweed is dependent on prevailing, favourable weather conditions. In Britain, *S. vulgaris* and *S. squalidus* are readily attacked by it. The rust, thought to be native to Australia and New Zealand, was discovered here as early as 1884 (Wilson *et al.* 1965). It has both telia and aecia but no pycnia. The telia and aecia, when found on the leaves and stems of plants are dark brown to black and pale yellow to orange respectively. The rust attacks a range of plants in the family *Asteraceae* and it is because of its relatively wide host range that its use in inundative biological control is unlikely. It is capable of infecting many garden plants including calendula, or English marigold (*Calendula officinalis*), English daisy (*Bellis perennis*) and garden cineraria (*Senecio cruentus*) (Wilson *et al.* 1965). Watson *et al.* (1984) report that a grey mould fungus (*Botrytis cinerea*) also infects fireweed.

As *S. madagascariensis* is not a native of Australia, it is possible that some pathogen or natural enemy of the plant may be found in southern Africa or Madagascar which would enable control. However, due to strict legislation and the need for extensive experimentation such control is, of necessity, a long-term goal.

Acknowledgments

I gratefully acknowledge the support of the W. C. Turland, University of Sydney postgraduate scholarship, for research into the ecology and control of fireweed. Thanks are also given to Dr P. W. Michael for his assistance and comments on the manuscript.

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gence obtained in the 0.0032% a.c. prochloraz treatment at 86 days is not known. In the field trial at Bundaberg in 1984 (Table 2), prochloraz at 0.0126% was as effective in sett treatment as the recommended organomercurial fungicide treatment in either the billet- or trash-planting systems.

From the studies reported in this paper, prochloraz at 0.0126% a.c. is recommended as a commercial canesett treatment as this concentration provides a satisfactory safety margin. The unexpected result from very low rates of prochloraz indicates that similar studies are required with other recommended sett treatments.

Acknowledgments

We wish to thank Mr R. Magarey, J. Lopez, B. Pearce and N. McGill of BSES and Mr D. Biffin of Schering Pty Ltd for their assistance.

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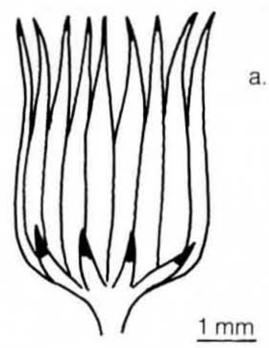
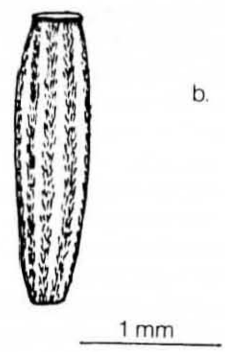
Erratum

On page 166 of *Plant Protection Quarterly* Volume 1(4), scale lines were accidentally omitted from Figure 4 of the paper 'The ecology and control of fireweed (*Senecio madagascariensis* Poir.)' by B. M. Sindel. The correct diagram is shown here.



(*a*) Involucre of the capitulum



(*b*) achene of fireweed.