The biology and non-chemical control of Common Ragwort (*Senecio jacobaea* L.)

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Common ragwort
(Ben weed, cankerweed, staggerwort, stinking willie, St James's wort, tansy ragwort)
***Senecio jacobaea* L.**

Occurrence
Common ragwort is a weed of wasteland, waysides, dunes, open woodland and grassland, particularly neglected pasture (Clapham *et al*., 1987). The natural habitat is sand dunes but it is now more common in low-grade grassland, roadsides and railway banks (Harper, 1958). Cleared or burnt areas form an ideal seedbed for ragwort. This non-stoloniferous biennial to monocarpic perennial occurs in every county in the UK but is most abundant in the south and west (Grime *et al.,* 1988). It is prevalent on light neutral or calcareous land of poor fertility, particularly if overgrazed, and frequently infests horse pastures (Gibson, 1997). It is not found on acid peaty soils but grows on light sands, loams, gravels and clays from pH 3.95 to 8.20 (Harper, 1958). The potential distribution of common ragwort has been mapped using botanical survey and soil survey data (Firbank *et al.,* 1998). The probable distribution was seen to be an even pattern across all soil types. In a survey of 502 grassland farms in England and Wales, 4% of the farmers considered it a problem but only 1% of fields were seriously affected (Peel & Hopkins, 1980). Ragwort does not survive frequent soil cultivation and is therefore not a significant problem in arable crops. It is absent from well-managed pasture on good soil (Cameron, 1935).

Marked fluctuations can occur in ragwort populations but the cause of this is unknown. Numbers may suddenly increase or decrease for no apparent reason (Fryer & Chancellor, 1956; MAFF, 1957). Sometimes a population of uniform age may all mature, flower and die. It has been suggested that a decrease in ragwort may be associated with very dry summers (Harper & Wood, 1954). However, rainfall is not a major limiting factor and common ragwort grows in low rainfall areas (Harper, 1958). In Australia, final plant density was strongly influenced by the level of seedling emergence in autumn and spring (Amor *et al*., 1983).

Common ragwort is poisonous and regularly causes loss of livestock. It is specified in the Weeds Act, 1959 and the Ragwort Control Act, 2003. Other closely related species not included in the act can be equally dangerous to stock e.g. hoary ragwort, *S. erucifolia* and marsh ragwort, *S. aquaticus* (MAFF, 1973; Watt, 1993). Marsh ragwort is more prevalent in waterlogged soils and hybrids may be formed where it occurs with together with common ragwort (Harper, 1958).

There are several pyrrolizidine alkaloids present throughout the plant (Cooper & Johnson, 19--). Ingesting the plant results in liver damage (Barker, 2001). Cattle and horses usually avoid ragwort when there is adequate grazing but newly turned out stock may eat the weed if hungry. Sheep are partial to it in the young state and appear to be more resistant to the poison than cattle but they are not immune (MAFF, 1949). The presence of ragwort in hay, silage or dried grass is the main source of poisoning.

The poisonous properties are not affected by drying or other processes. Wilted plant material is more palatable to stock than the growing plant but is equally toxic (MAFF, 1957). The alkaloid can cause liver damage in domestic fowl (Harper, 1958). Ragwort in the diet of animals can cause a potentially dangerous accumulation of copper in the liver (Watt, 1993).

The toxic alkaloids are present in all parts of the plant including the flowers. In the USA honey sometimes contains such large amounts that it is unsaleable (Watt, 1987a; 1993). In New Zealand, honey from ragwort infested areas is dark coloured and tainted (Harper & Wood, 1954). There has never been a problem in Britain although traces of alkaloid are found occasionally.

As a native plant, a large range of different organisms feed directly on ragwort (Harper, 1965; Bacon *et al.,* 2003). Over 200 species of insect and other invertebrates have been found on ragwort (Harper & Wood, 1957; Watt, 1993). Studies have shown that the flowers are among the most frequently visited by butterflies in Britain. *Longitarus dorsalis* is a nationally scarce flea beetle associated with ragwort (Crofts & Jefferson, 1999). Common ragwort has been observed as a host to the common broomrape (*Orobanche minor*) (Bacon *et al.,* 2003).

The biology, toxicity and control of ragwort was reviewed previously by Harper & Wood (1954) and by Watt (1987a).

Biology

The flowering period is long, starting in mid-June and continuing until November, being especially prolonged if plants have been damaged in the first flush of flowering (Harper & Wood, 1957). As a biennial, ragwort will only flower after exposure to winter cold. Rosette size is also important as plants must attain a threshold size to be able to flower and this may take more than 3 years (Watt, 1987a). The probability that a plant will flower increases with the diameter of the rosette at the start of the flowering season (Meijden & Waals-Kooi, 1979). The threshold size for vernalisation varies among populations (Wesselingh & Klinkhamer, 1996). Plants vernalised during the winter may or may not flower depending on conditions in spring. The flowers are insect pollinated (Grime *et al.*, 1988). The early ripening of the anthers favours cross-pollination (Cameron, 1935).

The seeds begin to ripen in July/August but are shed chiefly from September onwards. Ragwort produces two types of seeds with different characteristics, ray seeds from florets around the edge and disc seeds from florets in the middle of the flower head (Watt, 1993; McEvoy, 1984). The average seed number per flower head is 70, but the number of heads per plant varies from less than 100 to over 2,000. The number of flower heads and hence the number of seeds increases exponentially with rosette diameter (Meijden & Waals-Kooi, 1979). Total seed numbers per plant range from under 5,000 to well over 100,000 (Harper & Wood, 1954), 4,760 to 174,230 (Harper, 1958; Cameron, 1935). Salisbury (1961) talks of 50,000-60,000 seeds per plant, while Fryer & Chancellor (1956) give a figure of 150,000 per plant. In sand dune populations, seed number per plant ranged from 1,000 to 30,000 (Meijden & Waals-Kooi, 1979).

Seeds collected from flower heads at different stages of maturity and tested immediately, showed a gradual increase in percentage germination until a maximum value was reached (Meijden & Waals-Kooi, 1979). Ray seeds reach physiological maturity 21 days after flowering but reach maximum germination after 18 days (Baker-Kratz & Maguire, 1984). The disc seeds reach maturity at 24 to 27 days after flowering depending on their position in the seed head. Maximum germination is attained after 21 days. Viable seeds are produced on cut down flower stems provided the flowers are open and the stigmas visible at the time of cutting (Gill, 1938). Seeds are not viable if the flowers are in bud. The germination of seed collected from plants cut down in flower may be 70-80%.

Mature seeds from flower heads borne on the lower branches of the inflorescence have greater average weights and a higher percentage germination than seeds from flowers nearer the apex (Baker-Kratz & Maguire, 1984). The disc seeds are lighter and equipped with a pappus of hairs that assists wind dispersal (McEvoy, 1984). The ray seeds are heavier, smoother, stay on the plant longer and possess only a vestigial pappus so do not disperse far from the parent plant. After the disc florets have dispersed, the ray florets loosen and fall into the involucral cup where they remain until shaken out. The seed from flowers on a ragwort that has regrown after cutting or grazing is lighter than from primary shoots and may have lower viability (Watt, 1987a). The seed ripens around 2 months later than normal in flowers on regrown stems (Islam & Crawley, 1983).

The seeds of ragwort do not possess innate dormancy (Meijden & Waals-Kooi, 1979). Seeds shed in the summer germinate that autumn or in the following spring (Harper, 1958). Some seeds germinate almost immediately after dispersal (Meijden & Waals-Kooi, 1979). The disc and ray seeds differed in their germination behaviour when put at 20^{o}C with alternating 12 hr periods of light and dark (McEvoy, 1984). With the disc seeds, germination time decreased with seed weight while the reverse was found for ray seeds. The slower germination rate and reduced germination level exhibited by the ray seeds was due to the physical effects of the thicker seed coat. Seed dimorphism in common ragwort extends seed germination both in time and space thereby increasing the number of sites that can be exploited. Germination is greater at fluctuating temperatures (Meijden & Waals-Kooi, 1979). It is highest when the maximum temperature is between 10 and 15^{o}C. There is a clear check in germination when temperatures are above 30^{o}C or below 5^{o}C. Freezing may induce dormancy. Both ray and disc seeds germinate most rapidly at alternating temperatures of 20/30^{o}C (Baker-Kratz & Maguire, 1984). Seeds germinate readily in the light but secondary dormancy is induced by burial (Watt, 1987a). Seeds may remain dormant for many years when buried but if left on the surface of bare soil they germinate mainly in the autumn, just a few germinate in spring (MAFF, 1973; Cameron, 1935). The quantity of summer rainfall determines the extent of seedling emergence (Islam & Crawley, 1983). Emergence is greatest from seed lightly covered with soil (Cameron, 1935). Maximum germination was found when seeds were covered with 1 mm of sandy soil (Meijden & Waals-Kooi, 1979). Germination was lower when seeds were not covered perhaps due to reduced moisture retention. When buried at a depth of 1 cm or more, no germination takes place probably due to lack of light.

A few seeds sown in a 75 mm layer of soil in open cylinders in the field and stirred periodically emerged soon after sowing in autumn (Roberts, 1986). In the following year the seedlings emerged from February to September with the main peak of emergence in April and a smaller peak from August to September. A reducing number of seedlings emerged in subsequent years but none emerged after year 4.

Germination and seedling establishment is better in conditions of high humidity (Sheldon, 1974). The seed's hairy pappus remains erect when conditions are dry holding the seed with the scar of attachment in contact with the soil. Water uptake by the seed is mainly via the cells in this region. In moist or humid conditions the pappus collapses and the seed lays on the soil surface.

Seeds need an open site in which to germinate and grow. Common ragwort has been shown to establish better from seed in fields grazed by sheep than by cattle (Watt, 1987c). Seedlings often become established where a parent rosette has died and left a bare patch in the sward. In this situation, it is often difficult to determine whether a young plant has grown from a seed or from the root bud of a plant that has died or been removed (Harper & Wood, 1954). Any damage to an established sward may open the way to invasion by ragwort e.g. poaching, overgrazing, rabbit activity etc (Harper, 1958). The maximum seedling emergence is likely to occur in the largest gaps (Watt, 1987b). Seeds brought up with the soil on molehills will germinate but the seedlings are at risk of burial by further mole activity (Watt, 1987c). The seedlings survive better where the sward has died under a dung patch. In leys, ragwort seedlings can become established during the early stages before the sward closes up, or later when short-lived species disappear (MAFF, 1973). Seedlings will only establish if there is a lack of vigour in the pasture. Common ragwort has been associated with rabbits since their close grazing allows the seedlings to become established but they then avoid the weed (Fryer & Chancellor, 1956). Ragwort seedlings die if deprived of light by taller vegetation (Cameron, 1935). Although ragwort does not establish readily in a closed sward pasture, once established it is an effective competitor and the developing rosette will suppress neighbouring plants (Bain, 1991). There may be an allelopathic effect but this has not been determined.

When left undisturbed to grow and set seed, common ragwort is a biennial. However, on farmland where it is often defoliated it acts as a perennial (MAFF, 1973). A well-established plant in pasture has a spreading rootstock that may be branched and often consists of a group of offsets derived from the original plant. When flowering finally occurs it may be quite extensive. The original taproot rarely persists and is replaced by an extensive system of adventitious roots in the first 2 months of seedling growth (Harper, 1958). It is the secondary system of coarse whitish roots springing from the rootstock and lower stem nodes that acts as a source of new growth. The roots, or even 1 cm fragments of them, may produce adventitious shoots that quickly colonize adjacent spaces. Damage to the parent plant stimulates this process (Fryer & Chancellor, 1956; Salisbury, 1961). Roots on a first year crown are able to regenerate from September in year 1 then as the following September approaches the ability is gradually lost and these roots eventually die (Hudson, 1955). The cycle is then repeated with the new crowns. Severed but undisturbed roots are more likely to regenerate than disturbed ones. The rather fleshy roots extend to a depth of 30 cm (Mitich, 1995).

Studies of ragwort regeneration following caterpillar attack suggest that only the main shoot dies after flowering and that new shoots arise from the surviving root stock

(Islam & Crawley, 1983). Plants do not commit all their reserves to flower production and some are allocated to maintaining the rootstock. In these studies 75% of plants that flowered produced shoots the following year. In other studies it was considered that plants lost the ability to regenerate once the flowers had been pollinated and turned from yellow to brown (Meijden & Waals-Kooi, 1979). Ragwort is not tolerant of flooding and cannot survive long periods underwater (Watt, 1987a). Severe frost may kill the above ground plant parts but regeneration usually occurs from the crown.

Persistence and Spread

Seed densities of 5 million per acre in the upper layer of soil have been reported (Harper, 1958). Common ragwort seeds may accumulate under scrub vegetation germinating only when the cover is removed (Schmidl, 1972). Seeds that are buried deeper than 40 mm in soil persist 10-16 years or longer. Seeds in the 0-20 mm surface layer of soil die within 4-6 years (Thompson & Makepiece, 1983; Watt, 1987a). In cultivated soil seeds did not persist beyond 4 years (Roberts, 1986). Seed stored at room temperature or at field temperature for a year did not show any significant change in percentage germination (Meijden & Waals-Kooi, 1979).

Some populations of common ragwort plants disappear within 4 years others survive for more than 10 years (Meijden & Waals-Kooi, 1979). The data from a 12-month study repeatedly mapping the dynamics of a natural ragwort population was used to construct a model of population flux (Forbes, 1977). In the hypothetical population, of the plants that did not survive longer than a year, 57% died as seedlings, 35% as vegetative rosettes and 8% died after flowering. Within the plants that survived into a second year, 8% were winter annuals, 39% were biennials and 53% could be described as perennials.

The invasion of clean pasture is primarily by seed carried for short distances by the wind. Under damp conditions, however, the seed heads do not open and the seeds are not shed (Watt, 1993; McEvoy, 1984). Laboratory tests suggest maximum seed dispersal distances for the lighter disc seeds of 3.7 and 5.5 metres at wind speeds of 10.9 and 16.4 km/hour respectively but this would be affected by plant height (Sheldon & Burrows, 1973). Longer dispersal would only occur if convection currents carried the seeds up high. The ray seeds being heavier and lacking a fully developed pappus do not disperse far from the parent plant McEvoy, (1984). They remain after the other fruits have blown away and are eventually shaken out (Green, 1937). In set-aside fields in north-east Scotland, common ragwort made up a significant proportion of the seed rain (Jones & Naylor, 1992). Seed was shed from mid-August to late-October. Cutting time could influence the amount of seed returned to the soil. Seeds were wind dispersed up to 72.5 m from the set-aside area but most travelled less than 12.5 m from source. In New Zealand, less than 0.5% of seeds were dispersed and the maximum distance travelled was 40 m (Fryer & Chancellor, 1956; Schmidl, 1972). An isolated common ragwort plant in a hedgerow may be responsible for a local infestation (Harper, 1958).

Common ragwort seeds may be dispersed by water. Initially the seeds float, then sink but float again as they begin to germinate (Harper & Wood, 1954). Seeds can be carried in hay or in manure. Birds may eat the seeds but viable seeds are rarely found in bird droppings. Seeds that are eaten by sheep, however, pass through the digestive system undamaged. Ragwort seed can occur as a contaminant of agricultural seeds such as clovers and grasses (Harper, 1958).

Management

In the UK, The Ragwort Control Act passed in 2003 has led to the provision of a Code of Practice that gives guidance on preventing the spread of ragwort in situations where it is likely to be a danger to horses and other livestock (Defra, 2004). The Code does not seek to eradicate ragwort but only to control it where there is a threat to the health and welfare of animals. Guidance on the disposal options for common ragwort has been prepared to supplement the advice given in the Code of Practice and should be read in conjunction with it (Defra, 2005).

In pasture, control is by improved grassland management. Soil fertility should be optimised for the grass and under or over grazing avoided. A vigorous sward will smother new seedlings. Cutting and removal of stems at flowering prevents seeding but does not kill the plant. In fact it can encourage the development of side shoots. The cutting of all flower stems in a marked area in August of one year made little difference to the number of flowering stems that had developed by the following August (Forbes, 1974). The later the cutting and the higher the cut, the more likely the plant is to die out (Harper, 1958). Cut stems in full flower should be burnt to prevent seed setting and to avoid any risk to stock (MAFF, 1973). Repeated cutting in June, August and September is said to give effective control if continued for 2 years. On small areas the weed can be hand-pulled after rain (MAFF, 1949; Morse & Palmer, 1925). Hand tools such as the Rag-Fork have been developed to help in removing the plants and attached roots completely. Improving fertility after removal of the adult plants helps the sward to outcompete seedlings and regenerating root buds (Cameron, 1935). Common ragwort is rare in dense grassland and is found almost exclusively in areas of local disturbance (Meijden & Waals-Kooi, 1979).

In a study in Switzerland, the most important factors influencing the occurrence of common ragwort were related to grassland management (Suter *et al.*, 2007). There was a greater risk of ragwort occurring in an open sward, at low levels of N under continuous grazing pressure. The risk increased with high seed inputs from plants in and around the pasture. Long term control of common ragwort was achieved by avoiding sward damage and preventing seed formation in the local area.

Control can be achieved by close grazing in spring with sheep that eat the plant when young (Morse & Palmer, 1925). However, if the sheep are removed the ragwort may recover even after 5 years of intensive grazing (Schmidl, 1972). Plants seem to be weakened by winter/spring grazing by sheep but there is some risk to animals on heavily infested fields (MAFF, 1957). Seed set in particular is reduced because sheep graze young rosettes and prevent flowering (Watt, 1987a). Sheep grazing should be only at the rosette stage of ragwort, with just a low infestation rate and with other herbage available (Soil Association, 2002). Old ewes will eat the crown of the plant while younger sheep eat only the leaves (Harper, 1958). It is said that sheep will eat the young flower heads. Sheep will not eat ragwort if there is an alternative and if they do eat it for prolonged periods they are just as liable as other animals to suffer ill effects (Forsyth, 1968). In Australia, ragwort density was generally lower on sites grazed by sheep than on ungrazed areas or those browsed by cattle (Amor *et al.*, 1983). Grazing with cattle may increase the ragwort problem (Harper, 1958).

Grazing a few old ewes with the cattle all year will help to keep the weed down (Cameron, 1935).

Heavily grazed swards are characterised by the presence of certain weeds including common ragwort (Gibson, 1997). In surveys in Wales in 1949, severe infestations of ragwort were less frequent or absent from grassland fields grazed by sheep or mown at regular intervals (Davies, 1953). Ragwort populations were greater in fields grazed solely by cattle. In a subsequent unreplicated plot trial the number of ragwort rosettes increased in the treatment not grazed by sheep and more than half of the plants flowered. Where sheep grazed for all or part of the winter no plants flowered later in the year and there was a reduction in rosette number following the full winter grazing treatment. Winter grazing with sheep from mid November to the end of March gave the greatest reduction in rosettes (Harper, 1958). Poultry have been seen to scratch out and eat ragwort rosettes down to the roots but the plants quickly regenerate.

Mowing is at best a short-term measure to prevent seed production and it causes plants to perennate and persist (Fryer & Chancellor, 1956). Ragwort may remain for long periods as small rosettes in closely mown lawns (Harper & Wood, 1954). Hand pulling of plants is only feasible for small infestations and regrowth may occur from the detached roots left in the soil (Watt, 1993). Nevertheless, pulling is probably more effective than cutting. The time taken to extract ragwort with hand tools depends on the growth stage of the plant, the terrain, the density of the ragwort population, the density of other vegetation and the level of soil moisture. Removal is easier on flat sites in well-grazed vegetation. The leaf rosettes are more obvious in the second year. In grass, the leafy rosettes become highly visible in May and this is the time to start clearance before the plants flower in July. The rosettes can also be removed in autumn. Plants are pulled out more readily from moist soil. Common ragwort at a low density may take around 3 to 11 man hours per ha to clear while plants at a high density could take over 44 man hours per ha to clear (Trevelyan, 2001). Mechanical pulling with an 'Eco-puller' is possible when the flower stem has elongated and there is sufficient height difference with the crop (Soil Association, 2002). The machine has a working width of 1.5 m and a ground speed of 5 kph at 540 rpm. Weeds should be at least 30 cm tall. The weeds are drawn between rollers that pull vertically to lift out the weeds with their roots and deposit them into a collecting hopper for disposal. Pulled material should be removed from the site and disposed of safely. In a study on grassland grazed by cattle, mechanical pulling in July failed to reduce mature plant numbers later in the year or in the following year compared with an untreated area (Pywell *et al.*, 2003). Pulling in July and again in August resulted in an 80% reduction and ragwort density remained lower in the following year.

Where grassland is severely infested, ploughing and cropping for a limited period before putting the land back down to grass sown under a cover crop can achieve eradication (MAFF, 1957). Immediate reseeding with grass will often result in rapid re-infestation by the weed. Regular soil disturbance prevents common ragwort becoming re-established. The introduction of an arable rotation is an effective method of control. Oats or a smother crop will out compete common ragwort seedlings. In Australia, on steep hill land where cultivation is not possible, a change of land use from agriculture to forestry has successfully controlled ragwort (Schmidl, 1972). The presence of clover and maintaining adequate phosphate levels are said to discourage common ragwort establishment (Harper, 1958). Control of grazing is also important. Ragwort was common in unsown set-aside land in Scotland but numbers were lower where a sown cover had been established (Fisher *et al.*, 1992).

Some authors suggest that common ragwort is not eaten by rabbits (Tansley, 1949; Clapham *et al*., 1987). However, common ragwort is attacked by rabbits according to other authors including Meijden & Waals-Kooi (1979). A plant may regrow and flower later in the year after defoliation or it may form a rosette and flower the following year (Meijden & Waals-Kooi, 1979). Clonal growth may follow regeneration from the root crown leading to the formation of a compact cluster of rosettes. Where the root crown has been consumed by rabbits leaf rosettes may form on individual roots up to 30-60 cm away from the original plant. However, the exclusion of rabbits from grassland does not appear to result in an increase in ragwort (Watt, 1981). The action of rabbits is generally favourable to the increase of ragwort. When the rabbit population was drastically reduced by myxomatosis in the 1950's, infestations of common ragwort declined because the grasses formed a denser vegetation cover in the absence of rabbit scraping (Thomas, 1960). Initially there was an increase in flower production because the flowering stems of existing plants were not gnawed down. In subsequent years few rosettes were recorded.

Various insect larvae feed on the flower heads and may destroy some seed but this cannot be relied upon (MAFF, 1973; Cameron, 1935). The moth, *Homoeosoma nimbella*, a stem borer, has been found infesting 70% of ragwort on sand dunes and appeared to be killing the plants (Harper, 1958). Caterpillars of the cinnabar moth (*Tyria jacobaeae*) may strip plants of all the leaves and flowerheads (Islam & Crawley, 1983). The extent of recovery and subsequent seed production depends on the size of the plant when the moth eggs are laid. The cinnabar moth occurs as an adult from May to July. Rosette size at oviposition in May-June is critical. The number of emerged caterpillars is less important. The yellow eggs are laid on the underside of leaves in batches of up to 150 (Bacon *et al.*, 2003). The larval stage lasts about 4 weeks and caterpillars are common throughout June and much of July. Recovery and flower formation occurs through the regrowth of shoots from the root crown and surviving remains of the main shoot. Seed number is roughly halved by caterpillar grazing. Plants attacked earlier tend to regenerate and produce seeds sooner than plants attacked later in the year. Seeds on regenerated shoots are generally ripe 2 months later than normal at a time when conditions are less conducive to dispersal. The seeds are much lighter than normal and have a slightly lower rate of germination (Crawley & Nachapong, 1985). Seedlings that develop from these seeds grow successfully in an open, disturbed habitat but are less able to compete even in short vegetation compared with seedlings from normal seed.

Ragwort may benefit from caterpillar grazing in terms of increased stem density following regrowth. But this depends on initial plant density, timing and duration of attack and caterpillar density. A continuous attack on a limited number of plants will mean regrowth is also consumed. Moth density may be influenced by ragwort abundance in the previous year. Egg predation is minimal but the cinnabar moth caterpillars are attacked by several different predator insects that can have a drastic effect on their numbers (Cameron, 1935; Bacon *et al.*, 2003). Larval mortality from predation can be 60% and is much greater if predatory ants are present. Moles are thought to be the main predator of cinnabar moth pupae. Rainfall pattern has an important effect on both ragwort and cinnabar moth populations (Lakhani &

Dempster, 1981). The caterpillars are likely to have the greatest effect when summer rainfall is low and the regenerative ability of defoliated ragwort plants is reduced by moisture stress (Cox & McEvoy, 1983). The cinnabar moth was introduced into Canada as a biocontrol agent for common ragwort and after an initial lag period the moth population has built up gradually (Zwölfer, 1970). Unfortunately some of the cinnabar moths that were released in Australia were infected with disease that reduced their survival and prevented establishment (Syrett, 1983). The larvae also suffered massive predation by the scorpion fly (*Harpobittacus nigriceps*) (Delfosse & Cullen, 1982). In addition, the regenerative ability of common ragwort limited the usefulness of the cinnabar moth (Schmidl, 1972).

A model of the interaction between a cinnabar moth population and its food plant has been developed (Dempster & Lakhani, 1979; Lakhani & Dempster, 1981). The model takes into account the effects of rainfall and defoliation by the moth on ragwort biomass, the effect of food supply and adult moth density on moth reproduction and the effect of larval density on mortality. The results suggest that increasing the moth population by 20% has no lasting impact on the ragwort population indicating that the cinnabar moth alone is unlikely to provide complete control of common ragwort.

The ragwort seed fly (*Pegohylemia seneciella* Meade) is another important predator of ragwort (Cameron, 1935). It makes its appearance in late-June and eggs are laid in the flowerheads. The larvae eat the immature seeds. The ragwort seed fly and the root-feeding flea beetle (*Longitarus jacobaeae* Waterhouse) as well as the cinnabar moth have been introduced into several countries as biological control agents for ragwort (Syrett, 1983; Watt, 1987a, Bain, 1991; McLaren, 1993). The ragwort seed fly was successfully introduced into New Zealand where it was reported to have destroyed 70% of seeds in some flower heads (Harper, 1958). In Tasmania, both French and Italian strains of the flea beetle that were introduced appear to have become established (Ireson & Terauds, 1982). In the UK, this beetle has caused severe damage to ragwort. The adults feed on the foliage while the larvae attack the root crown and feed externally on lateral roots. This may result in defoliation of the weed but does not necessarily reduce the population except where plants suffer moisture stress (Syrett, 1983). In areas of the UK where the flea beetle and cinnabar moth occur together, large populations of common ragwort still flourish. The flea beetle has one generation per year in the UK but in mainland Europe the life cycle varies with the area in which it is found (Delfosse & Cullen, 1982). In Victoria, Australia, the flea beetles *L. jacobaeae* and *L. flavicornis* and the ragwort leaf and crown boring moth, *Cochylis atricapitana* have been established on ragwort (McLaren, 1993). One of the flea beetles, *L. flavicornis*, has established only in high altitude, high rainfall locations.

Some rust fungi and other pathogens infect ragwort but do not cause serious injury. Most of the fungi that are associated with common ragwort are unlikely to provide an effective means of control. The suitability of *Puccinia expansa* as a biological control agent has been investigated in glasshouse conditions with favourable results (Bain, 1991). Common ragwort is more susceptible to infection than several other *Senecio* species (Alber *et al.*, 1986).

Flaming can be used to deal with isolated infestations of ragwort (Harper, 1958). It will destroy flowering and seeding shoots but some plants may regenerate.

Barrier H, a herbicide based on citronella oil, has been developed specifically for the control of ragwort (Jenkins, 2002). It is being trialled by local authorities as an alternative to hand-pulling along roadside verges. Barrier H is sprayed directly onto the plants and destroys ragwort at all stages of growth. Small rosette plants are killed by a single treatment but for control of larger plants a second application may be needed (Dixon & Clay, 2001). The product was licensed in 2000 as a Ministry Approved Pesticide. While spot treatment was effective in a grassland study but the dead shoots remained in situ and may be a potential hazard to stock (Pywell *et al.*, 2003). Barrier H is not selective and spot treatment of a large number of seedlings would be time consuming and expensive.

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