Biological control of tansy ragwort (*Senecio jacobaeae*, L.) by the cinnabar moth, *Tyria jacobaeae* (CL) (*Lepidoptera*: *Arctiidae*), in the northern Rocky Mountains

G.P. Markin[1] and J.L. Littlefield[2]

Summary

The control of tansy ragwort on the coast of western North America is a major success story for weed biological control. However, tansy ragwort is still expanding into the colder interior regions of the Pacific Northwest of the United States where previous efforts to establish the same complex of agents have failed. We have successfully established one of the agents, the cinnabar moth, *Tyria jacobaeae* L., on a major new tansy ragwort infestation in the mountains of northwestern Montana. The cinnabar moth is still expanding its range, but in the areas where first released, it has given excellent control, having eliminated tansy ragwort as a visible component in the forest ecosystem while not impacting native *Senecio* species. Although establishment in other areas has been slower, we predict that we will eventually control tansy ragwort over most of its range in the northern Rocky Mountains of the United States.

Keywords: tansy ragwort, *Senecio jacobaea*, cinnabar moth, *Tyria jacobaeae*.

Introduction

In the Pacific Northwest corner of the United States, tansy ragwort, *Senecio jacobaea* L., (*Asteraceae*), an introduced European forb, is an invasive weed in pastures, native meadows and open forests (Coombs *et al.*, 1991, 1999). It is a particularly serious problem for grazing livestock because it contains toxic alkaloids. Along the Pacific Northwest coast in the 1960s and 1970s, a USDA-ARS program successfully established three biological control agents and resulted in one of the most successful biological control weed programs in North America (Turner and McEvoy, 1995; Coombs *et al.*, 1996, 2004; Julien and Griffith, 1998). Tansy ragwort, however, is still spreading east of the Cascade Mountains into eastern Oregon, Washington and northern Idaho.

In 1994, a wild fire burned 6100 ha of fir and pine forests in a mountainous area straddling the boundary between Lincoln and Flathead Counties in northwestern Montana. Tansy ragwort was probably already present, but after the fire, an explosive flush of new plants occurred, which was first noticed in 1996. Management plans were immediately initiated with the goal of herbicide spraying to begin in 1997. In attempting to obtain funding for the program, it was necessary to develop an integrated management strategy, and biological control was added as an afterthought.

Initially, we felt the three biological control agents used on the west coast would fail in Montana, but the funding provided the chance to investigate why these agents had not established previously when released east of the Cascade Mountains. Our preliminary studies showed that all three agents would establish, but in Montana, the cinnabar moth, *Tyria jacobaeae* (L.) (Lepidoptera: Arctiidae) was particularly suitable. This paper describes the success we observed in subsequent years to the release of this moth.

[1] US Forest Service, RMRS, Forestry Sciences Laboratory, Bozeman, MT 59717, USA.
[2] Montana State University, Department of LRES, Bozeman, MT 59717, USA.
Corresponding author: G.P. Markin <gmarkin@fs.fed.us>.

Materials and methods

Source of cinnabar moths

The first colonies of cinnabar moths, obtained from Oregon in 1996 from the Willamette Valley and along the coast near Florence, were used for preliminary non-target host studies. Additional shipments from the Willamette Valley in 1997 were used for three field-cage releases within the area burned by the forest fire in Flathead County in Montana. In 1998, a new moth population was located near Mount Hood at 1300-m elevation in the Cascade Mountains of Oregon in a forested site with a heavy winter snow cover, similar to northwestern Montana. From 1998 to 2000, egg masses from the Mount Hood population were shipped to Bozeman, sterilized by soaking in a 0.1% sodium hypochloride for 5 min and rinsed in running water to eliminate bacterial or viral contaminants. After hatching, first-instar larvae were held, ten individuals to a Petri dish, for 10 to 14 days, fed tansy ragwort leaves treated with 100 ppm of the fungicide Benomyl (Benlate sp. fungicide, DuPont Agricultural Products, Willmington, DE, USA) to eliminate microsporidium that were reported to be present in the west coast cinnabar moth populations (Bucher and Harris, 1961; Hawkes, 1973). If any larvae died, the entire batch was discarded. Larvae that reached third instars without mortality were used for subsequent studies in the laboratory and for field release in 1998 to 2000.

Non-target plant testing

Initially, there were questions concerning using the cinnabar moth because, in early laboratory testing, it fed on several North American *Senecio* sp. (Bucher and Harris, 1961) and had been reported attacking a field population of *Senecio triangularis* Hook in Oregon (Diehl and McEvoy, 1989). It was therefore necessary to determine whether Montana varieties of *S. triangularis* might also be at risk. In 1996, no-choice feeding tests using third-instar larvae in Petri dishes offering either Montana *S. triangularis* or tansy ragwort leaves were set up, and the rate of development, survival and weight of any pupae produced was determined. In 1997 and 1998, the tests were repeated but expanded to look at other species of *Senecio* found in the Montana tansy ragwort area. Those species were *Senecio* (sym: *Packera) pseudaureus* Rydb., *Senecio hydrophilus* Nutt., *Senecio integerrimus* Nutt. and *Senecio* (sym: *Packera*) *canus* Hook (Hanson, 2000). When these tests indicated that *S. pseudaureus* could be fed on, the first field releases in 1997 and 1998 (of 300 larvae each) were made in 2 × 4 m field cages (three each year) containing intermixed *S. pseudaureus* and tansy ragwort plants.

Open field release

By 1999, studies indicated that the cinnabar moth was not a threat to native *Senecio*, and the rapid population increases in cages indicated it might be a useful biological control agent for Montana. The original six cages were removed that year so the moths could disperse naturally, and we began a program of additional releases to spread them as rapidly as possible through the remaining tansy ragwort area.

The tansy ragwort infestation in Montana occurs in two counties, Flathead County and Lincoln County, each differing environmentally and in land ownership. In Flathead County, the infestation was restricted to National Forest lands in the eastern half of a 4000 ha area of remote rugged fir and pine forest (elevation, 1350–1560 m) that was burned in a wildfire in 1994 and subsequently salvage logged. Initially, the tansy ragwort infestation was thought to cover only 100 ha, and the program was aimed at controlling and, if possible, eradicating the infestation using herbicides. By 1997, additional surveys indicated that there were at least 500 ha to be sprayed. There were also numerous small environmentally sensitive sites located close to water where herbicide was not allowed to be used, and these were used for the initial biological control studies. Besides the six caged releases in 1997 and 1998, uncaged releases of 300 larvae each at eight new field sites in the burned area and three in the surrounding unburned forest were made in 1999.

In 2000, the program was expanded westward into the Little Wolf Creek drainage in Lincoln County where the remaining third of the area burned by the wildfire also contained dense stands of unsprayed tansy ragwort. This area was primarily the property of a timber company, which thought chemical control was not economically justifiable. In 2000 and 2001, 12 releases of 300 early instar larvae, collected from the now well-established populations in Flathead County, were made. From 2002 to 2004, emphasis shifted to a third area approximately 12 km to the southwest of Little Wolf Creek in the vicinity of Island Lake, a small mountain lake. The land ownership here was a mixture of National Forest, private timber company and private ranches. The area differed from the first two targeted areas, as it was unburned and consisted of an 8000-ha mosaic of different aged fir, pine and larch forests and open meadows. The area was extensively disturbed by heavy grazing and logging. Tansy ragwort was concentrated in the more open and disturbed sites and was as abundant and dense as in the burned area. Seven releases of 300 early instar larvae from the Flathead County population were made in 2002.

Monitoring impact

During the three caged releases made in 1997, and repeated in 1998, all tansy ragwort plants in the cages were recorded as either seedlings, rosettes (would not bolt that year) or mature plants that had bolted. These gave estimations of populations within the six caged areas and were compared to populations at six similar

but uncaged areas between 50 and 100 m away, at which no releases were made. In 1999, when the cages were removed, a permanent marker was placed at the centre of each of these 12 study sites. At 1 m radius out, all tansy plants found within four 25-cm^2 quadrats were counted to determine site density. Monitoring through the remainder of this program continued at the six initial caged release sites and the six uncaged areas. Within a few years, all uncaged areas had been inundated by the cinnabar moth so all data has been combined for an average of the 12 study sites.

When the program changed from research in 1999 to an operational program in which we were trying to redistribute the cinnabar moth as rapidly as possible, no further detailed monitoring was conducted, although all new releases were marked. These sites were visited annually, and visual estimates were made of the abundance of tansy ragwort and cinnabar moth larvae in mid- to late July when the plants were in flower and the larvae were most active and visible. Larvae population estimates were made by walking a 50-m transect in 5 min while counting or estimating the number of larvae seen feeding on the flower heads and, later in the study, on any surviving rosettes.

Results

Non-target feeding

Laboratory feeding tests showed that *S. triangularis* from Montana was an unsuitable host (Table 1). Feeding occurred in starvation tests, but development was much slower and produced only a few small pupae. Even poorer development was seen on *S. hydrophilus, S. integerrimus* and *S. canus*. Subsequent observations in the field on natural populations of *S. triangularis* and *S. hydrophilus* intermixed with tansy ragwort at five locations in Flathead County showed that, even during the peak population of the cinnabar moth and its collapse after the elimination of the tansy ragwort, both species were totally ignored. Why *S. triangularis* should be fed on in the field in Oregon but not in Montana has not been resolved.

By contrast, *S. pseudaureus* in laboratory no-choice feeding tests supported almost normal development of larvae, although the larvae would not feed on it in choice tests when tansy ragwort was also available. Subsequent field observations showed that, during the first 2 or 3 years of the cinnabar moth build up, *S. pseudaureus* was ignored. However, when the supply of tansy ragwort was exhausted, females would occasionally lay egg masses on *S. pseudaureus*. The resulting larvae skeletonized the leaves that contained the egg mass and then disappeared. Furthermore, if late-instar larvae totally consumed adjacent tansy ragwort plants and dispersed in search of food, they occasionally fed on *S. pseudaureus*. This minor feeding was observed for a year or two until the tansy ragwort had disappeared, and when the cinnabar moth population collapsed, feeding on *S. pseudaureus* ceased. At no time after the disappearance of tansy ragwort in 2003 have any cinnabar moths been found utilizing *S. pseudaureus* as a permanent host. *S. pseudaureus* in Montana therefore will not support a permanent population of cinnabar moths and suffers only temporary attack when adjacent tansy plants are stripped of foliage. The potential for it to attack other *Senecio*'s exists, however, so this moth should not be released in new areas without preliminary host testing of local *Senecio*.

Establishment of the cinnabar moth

Of the six original cage releases, five built up populations that, by the second year, were causing 50%

Table 1. Comparison of survival rate and development times for larvae and pupal weight of the cinnabar moth raised on tansy ragwort, *Senecio jacobaeae*, and other species of *Senecio* native to Montana.

Species	Larvae no.	Pupae no.	Pupate %	Days to pupate	Pupae weight (g)
1997					
Senecio jacobaea	26	24	92.3(a)[a]	22.6(a)[a]	0.122(a)[a]
Senecio pseudaureus	24	16	66.7(b)	25.0(a)	0.110(a)
Senecio hydrophilus	28	16	57.1(b)	32.6(a,b)	0.070(b)
Senecio triangularis	21	2	9.5(c)	46.0(b)	0.070(b)
Senecio integerrimus	22	0	0.0	0.0	0.000
Senecio canus	25	0	0.0	0.0	0.000
1998					
Senecio jacobaea	43	34	90.5(a)	20.4(a)	0.130(a)
Senecio pseudaureus	42	38	79.1(a)	21.9(a)	0.110(a)
Senecio hydrophilus	29	22	75.9(a)	28.2(b)	0.080(b)
Senecio triangularis	21	2	9.5(b)	39.5(b,c)	0.080(b)
Senecio integerrimus	30	1	3.3(b)	29.0(c)	0.090(a,b)
Senecio canus	33	1	4.4(b)	40.0(c)	0.090(b,b)

[a] Each year, grouping is compared based on Tukey HSD at 0.05 level.

defoliation. Of the eight additional open releases, all established and spread and, by 2004, had reached 95% of the infested area. In Flathead County, the cinnabar moth population collapsed after the disappearance of the tansy ragwort around 2003. While plants continue to sprout from the soil seed bank and may escape detection while small rosettes, within a year of flowering, they are usually found by the moth and destroyed. This pattern of low numbers of cinnabar moth and low plant number equilibrium has been observed in Oregon for the last 20 years and we expect is now the situation in Flathead County. The exception is a small (less than a quarter hectare) site in which a dense stand of tansy ragwort has, so far, escaped attack in the moist bottom of a narrow valley.

In the Little Wolf area, Lincoln County, six of seven releases, which were made on a hillside, established but population build up was slower than in the Flathead County sites. A large amount of tansy ragwort, resulting from the lack of a spray program, is present. Consequently, it will take longer for the cinnabar moth population to reach a level capable of overwhelming this huge biomass, a problem not encountered in Flathead County where the majority of the tansy ragwort biomass had been eliminated by herbicide spraying. By contrast, the five releases made within 30 m of Little Wolf Creek failed. It is presumed that these and the failure in Flathead County are due to micro-climatic effects restricted to these narrow mountain valley bottoms.

In Flathead County, establishment occurred at three sites in unburned forest, but our initial six releases, of 300 larvae each, in the unburned area around Island Lake failed. In 2004, releases of between 1000 and 2000 late instar larvae were made at ten sites around the lake. By 2005, most of these releases established. By 2006, five had expanded, and they were totally defoliating the tansy in areas ranging from 0.5 to 5 ha; three had low populations that were not causing significant defoliation, and two appeared to have failed. We have no explanation why small releases of early instar larvae failed, but large releases of late instar larvae gave rise to rapidly expanding populations.

Impact

Tansy ragwort density at the 12 original sites in Flathead County remained constant for the first 3 or 4 years, while the populations of the cinnabar moth built up. They then declined to a low in 2003 when tansy ragwort was almost undetectable (Fig. 1). The cinnabar moth population then collapsed due to the lack of food. The tansy ragwort re-sprouted from the seed bank, and the peak in 2004 represents only new seedlings or very small rosettes. However, the cinnabar moth soon reappeared at all sites and suppressed the plant. Today, the tansy ragwort and the cinnabar moth appear to be in equilibrium, maintaining the plant population at a much suppressed level. The major visible impact of our program has been the almost total disappearance of flowering tansy ragwort plants since 2002. The Little Wolf and Island Lake areas in Lincoln County now have well-developed moth populations, and in many areas, they have caused the demise of mature plants. We predict that these populations will continue to increase and spread and that they will reduce tansy ragwort to levels comparable to those in Flathead County.

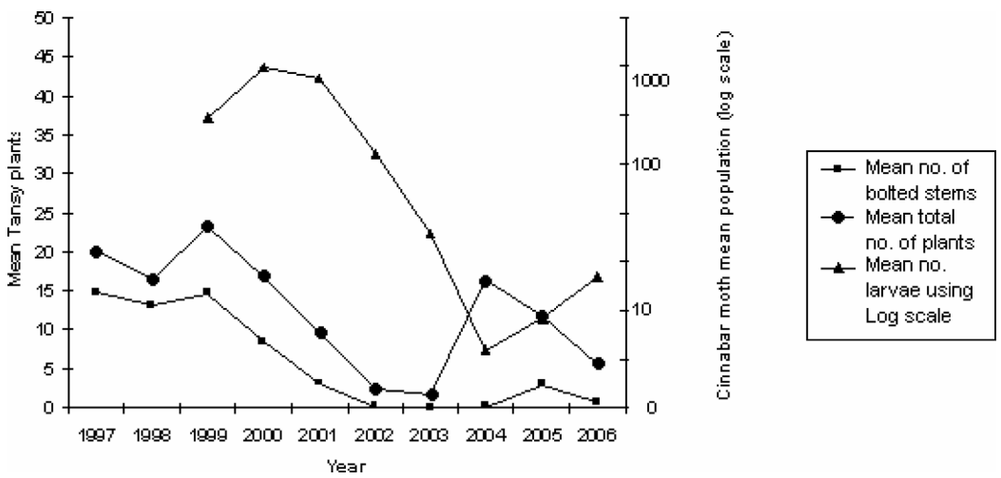

Figure 1. Density of tansy ragwort, *Senecio jacobaeae*, showing the total numbers of plants and the numbers that were mature and bolted. Data are the mean of 12 permanent plots at Flathead County, MT. The estimated numbers of late-instar larvae of the cinnabar moth, *Tyria jacobaeae*, counted in 5 min along a 50-m transect at the same 12 sites. No estimate for 1997 or 1999 since the cinnabar moth was confined in field cages.

Discussion

Comparison of effectiveness between Montana and Oregon

The success of the cinnabar moth in Montana raises the question why this insect fails to control tansy ragwort along the west coast (van der Meijden, 1979; Myers, 1980; Crawley and Gillman, 1989). This may be due to climate differences affecting the phenology of the plant. In Oregon, the cinnabar moth was often observed defoliating large mature plants. However, the plant compensated with re-growth during the following mild, wet fall and winter (Hawkes, 1981; Cox and McEvoy, 1983; Turner and McEvoy, 1995). In Montana, plants that survive defoliation do not recover noticeably before the onset of cold weather in October and permanent snow cover in November (Fig. 2). Surviving plants emerge the following spring as small rosettes that seldom flower. Several consecutive years of cinnabar moth feeding on even the strongest plants in Montana continue to reduce them in size until they are eventually killed. It is interesting that the only other location where the cinnabar moth is credited with controlling tansy ragwort is the eastern Maritime Provinces of Canada (Harris *et al.*, 1973, 1978), an area similar to Montana with a long cold winter and snow cover that probably protect the over wintering pupae in the soil from freezing (Fig. 2).

Future of the cinnabar moth in Montana

On the west coast, the cinnabar moth populations are affected by severe diseases (Bucher and Harris, 1961; Hawkes, 1973). We took great efforts to eliminate diseases from the populations that we introduced to Montana, and our monitoring there has detected no sign of disease that could limit the cinnabar moth's effectiveness.

To counter this possibility, we are continuing our effort to establish the tansy ragwort flea beetle, *Longitarsus jacobaeae* (Waterhouse*)*, in those areas where the cinnabar moth has not established. Hopefully, flea beetle colonies will be numerous enough that, if the cinnabar moth population eventually collapses, they will be ready to replace it (see Littlefield *et al.*, this volume).

An integrated control program

The rapid success obtained in eliminating tansy ragwort in Flathead County was due to a combination of herbicide application and biological control. There was an intensive herbicide spray program between 1997 and 1999 that probably killed 99% of mature, flowering plants. The only unsprayed tansy ragwort was in the buffers around springs, moist seeps or riparian zones, where spraying was prohibited and which was used for the biological control study. However, after spraying, a flush of seedlings was observed, and by 2001 and 2002, flowering plants began to reappear as the replacement generation matured. At this time, the cinnabar moth population was well established at our research sites, spreading rapidly through the surrounding tansy ragwort area and, within a few years, eliminated the need for additional chemical treatments. Chemical treatment of tansy in Flathead County is now limited to roadside spraying of any isolated plants found to prevent their

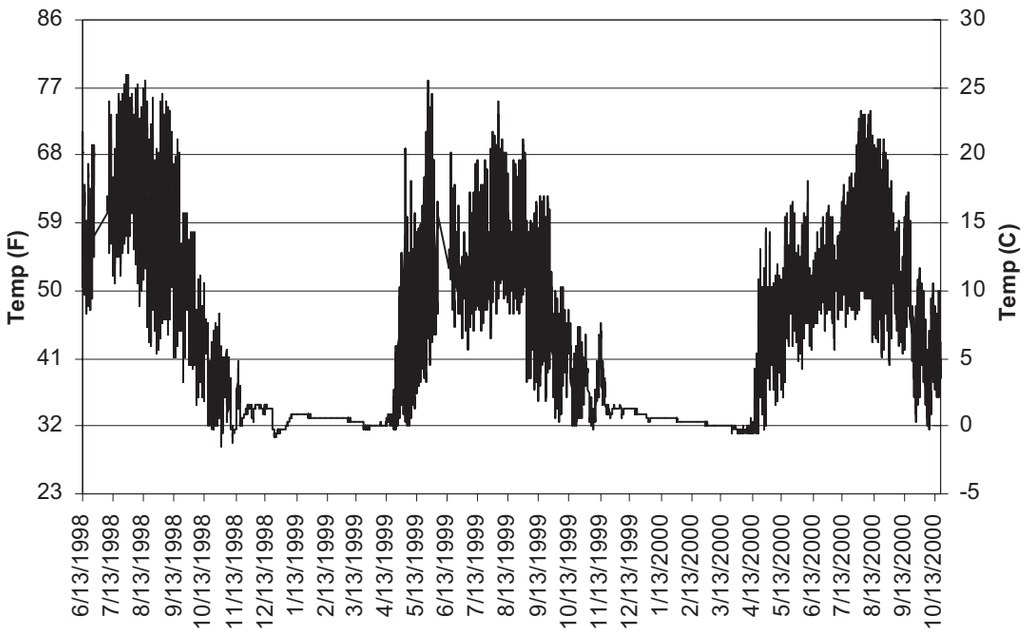

Figure 2. Soil temperatures 2 cm below the surface at site 1 in the Flathead National Forest. *Relatively flat lines* from November to April indicate snow cover.

seeds from being carried out of the area and the spraying of isolated satellite population, as they are found in outlying areas.

The successful control in Flathead County, although unplanned, is an excellent example of how an integrated control program for a new weed can be implemented. In this case, herbicides contained a new infestation and suppress seed production in the core area long enough for the biological control agents to establish and build up populations capable of dispersing and overwhelming the suppressed population.

Acknowledgements

We are deeply grateful to the efforts of Carol Horning who supported our program by collecting and shipping the cinnabar moth to Montana and to Eric Coombs of the Oregon Department of Agriculture who provided much useful information based on his extensive personal experience with the tansy ragwort program and the cinnabar moth in Oregon. Finally, we wish to thank Terry Carter, the late vegetation manager for Flathead National Forest, and Ann Odor, Bill Chalgren and Dan Williams, vegetation managers in Lincoln County for their invaluable support that made this biological control program possible.

References

Bucher, G.E. and Harris, P. (1961) Food-plant spectrum and elimination of disease of cinnabar moth larvae, *Hypocrite jacobaeae* (L.) (Lepidoptera: Arctiidae). *Canada Entomologist* 93, 931–936.

Coombs, E.M., Bedell, T.E., and McEvoy, P.B. (1991) Tansy ragwort (*Senecio jacobaea*): importance, distribution and control in Oregon. In: James, L.F., Evans, J.O., Ralphs, M.H. and Child, R.D. (eds) *Noxious Range Weeds*. Westview Press, Boulder, CO, USA, pp. 419–428.

Coombs, E.M., Radtke, H., Isaacson, D.L., and Snyder, S.P. (1996) Economic and regional benefits from the biological control of tansy ragwort, *Senecio jacobaea*, in Oregon. In: Moran, V.C. and Hoffmann, J.H. (eds) *Proceedings of the 9th International Symposium on Biological Control of Weeds*. University of Cape Town, Stellenbosch, South Africa, pp. 489–494.

Coombs, E.M., McEvoy, P.B., and Turner, C.E. (1999) Tansy ragwort. In: Sheley, R.L. and Petroff, J.K. (eds) *Biology and Management of Noxious Rangeland Weeds*. Oregon State University Press, Corvallis, OR, USA, pp. 389–400.

Coombs, E.M., McEvoy, P.B., and Markin, G.P. (2004) Tansy ragwort, *Senecio jacobaea*. In: Coombs, E.M., Clark, J.K., Piper, G.L. and Cofrancesco, Jr., A.F. (eds) *Biological Control of Invasive Plants in the United States*. Oregon State University Press, Corvallis, OR, USA, pp. 335–344.

Cox, C.S. and McEvoy, P.B. (1983) Effect of summer moisture stress on the capacity of tansy ragwort (*Senecio jacobaea*) to compensate for defoliation by cinnabar moth (*Tyria jacobaea*). *Journal of Applied Ecology* 20, 225–234.

Crawley, M.J. and Gillman, G.P. (1989) Population dynamics of cinnabar moth and ragwort in grassland. *Journal of Animal Ecology* 58**,** 1035–50.

Diehl, J.W. and McEvoy, P.B. (1989) Impact of the cinnabar moth (*Tyria jacobaeae*) on *Senecio triangularis*, a non-target native plant in Oregon. In: Delfosse, E.S. (eds) *Proceedings of the 8th International Symposium on Biological Control of Weeds*. Istituto Sperimentale per la Patologia Vegetale, MAF. Rome, Italy, pp. 119–126.

Hanson. E. (2000) Plants, database 3/2000 Alphabetical listing of scientific and synonyms (Old Names). *USDA Forest Service Handbook, Forest Inventory and Analyses*. Portland Forestry Sciences Lab, Portland, OR, USA (p. 436).

Harris, P., Wilkinson, A.T.S., Thompson, L.S. and Neary, M. (1978) Interaction between the cinnabar moth, *Tyria jacobaeae* L. (Lep.: Arctiidae) and ragwort, *Senecio jacobaea* L. (Compositae) in Canada. In: Freeman, T. (eds) *Proceedings of the 6th International Symposium on Biological Control Weeds*. University of Florida, Gainesville, FL, USA, pp. 174–180.

Harris, P., Wilkinson, A.T.S. and Myers, J.H. (1984) *Senecio jacobaeae*, tansy ragwort (Compositae). In: Kelleher, J.S. and Hulme, M.A. (eds) *Biological Control Programmes Against Insects and Weeds in Canada 1969–1980*. Commonwealth Agricultural Bureaux, UK, pp. 195–201.

Hawkes, R. B. (1973) Natural mortality of cinnabar moth in California. *Annals of the Entomological Society of America* 66, 137–146.

Hawkes, R.B. (1981) Biological control of tansy ragwort in the state of Oregon, U.S.A. In: Delfosse, E.S. (ed) *Proceedings of the 5th International Symposium on Biological Control of Weeds*. CSIRO Entomology, Brisbane, Australia, pp. 623–626.

Julien, M.H. and Griffith, M.W. (1998) *Biological Control of Weeds. A World Catalogue of Agents and their Target Weeds*, 4th edn. CABI Publishing, Wallingford, UK, 223 pp.

Myers, J.H. (1980) Is the insect or the plant the driving force in the cinnabar moth-tansy ragwort system? *Oecologia* 47, 16–21.

Turner, C.E. and McEvoy, P.B. (1995) 71/Tansy ragwort. In: Nechols, J.R., Andres, L.A., Beardsley, J.W., Goeden, R.D., and Jackson, C.G. (eds) *Biological Control in the Western United States*. Publication 3361. Division of Agriculture and Natural Resources, University of California, USA, pp. 264–269.

van der Meijden, E. (1979) Herbivore exploration of the fugitive plant species: Local survival and extinction of the cinnabar moth and ragwort in a heterogeneous environment. *Oecologia* 42, 307–323.