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Biology and host specificity of the *Chondrilla* root moth *Bradyrrhoa gilveolella* (Treitschke) (Lepidoptera, Phycitidae)

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Abstract

The biology and ecology of *Bradyrrhoa gilveolella* (Treitschke), recently introduced into Australia as a possible biological control agent for the composite *Chondrilla juncea*, is described for Greece and compared with its known biology in southern Russia. The moth occurs from eastern Europe to southern Russia. In Greece it has two full and possibly a partial third generation each year. Its larvae live in cases below the soil surface and feed on the rootstocks of *Chondrilla* spp., destroying the thinnest plants. Heavy larval infestations on *Chondrilla* occur erratically in eastern Greece, being dependent on sites on sandy or very friable soils that are only occasionally disturbed; populations in hotter southern Greece appear to be less stable than those in the cooler northern regions. The larvae are heavily attacked by the fungus *Beauveria bassiana* as well as by *Bracon* sp., *Copidosoma* sp. and *Syzeuctus* sp. (Hymenoptera) and by the Tachinid *Germaria graeca* (Br. & Berg.); these cause a total larval and pupal mortality of up to 80%. Host specificity studies, during which the roots of various wild and cultivated composites and 62 cultivated plants were exposed to the moth larvae, showed that only *Chondrilla* and the closely related genus *Taraxacum* were attacked. A field survey showed that *Taraxacum* was not a host under natural conditions. All forms of *C. juncea* were equally readily attacked by *B. gilveolella* larvae.

Introduction

The biology of *Bradyrrhoa gilveolella* (Treitschke), a Phycitid moth whose larva feeds on the rootstock of species of *Chondrilla* (Compositae, Cichoriaceae), was studied in detail in southern Russia in the late 1920s and early 1930s when the cases produced by the larvae on *Chondrilla* were investigated as a source of rubber (Sakharov, 1930; Kozulina & Rudakova, 1932; Dirsh, 1933). The present investigation was prompted by the possibility that this moth could serve as a biological control agent for *C. juncea*, skeleton weed, an important weed of wheat cultivations in south-eastern Australia. Most of the field observations were made during an ecological investigation of *C. juncea* and its associated organisms in eastern Greece, where climates are similar to those regions of Australia where skeleton weed infestations occur. The host specificity of the moth and its safety as a biological control agent were demonstrated by testing the larvae against a wide variety of plant species under laboratory conditions in Montpellier, France, and Thessaloniki, Greece. A brief account of the biological control potential of *B. gilveolella* has already been published (Wapshere, 1973*a*).

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Taxonomy and description

The genus *Bradyrrhoa* Zeller comprises more than twenty species, almost all of which have been collected in the Mediterranean region and in Asia Minor and Russian Armenia. *B. gilveolella* was first described by Treitschke in 1832 and a complete description of all stages of the moth was given by Kozulina & Rudakova (1932). The adult moths, male and female, are 11–13 mm long with a wing span of 25–28 mm and creamy buff in colour. The anterior wing is traversed by three brown bands; at rest the wings are tightly folded to the body. The larva has a finely stippled integument with few setae. The crochets of the prolegs, except for the last pair, are arranged in a biordinal uniserial circle. The tridentate mandible has an anterior cutting lobe. Hatchlings are 1–2 mm long, with brown heads. Initially the body is pink but later it becomes ivory-cream in colour. Final stage larvae are 20–26 mm long, with the head capsule 1·6–2·6 mm wide and the pronotal shield 2·6–2·8 mm wide. The obtect pupa is 11–14 mm long and 3 mm in width. The light brown tegument is finely foveolate, but has a smooth appearance. The eggs are prolate spheroids 0·65–0·80 mm long and 0·45 mm in diameter, with a reticulated chorion, and are creamy white in colour when laid.

Host-plants

The host-plants of only two species of *Bradyrrhoa* are known, both being Cichoriaceae. *B. lyratella* Chrétien has been recorded on *Andryala lyrata* (L'Homme, 1935) and *B. gilveolella* has only been recorded on *Chondrilla* spp. under field conditions. In southern Russia *B. gilveolella* occurs on *C. juncea*, *C. juncea* form *intybacea* (= *C. latifolia*), *C. brevirostris*, *C. ambigua*, *C. kossinskyi* (= *C. pauciflora*), *C. kusnezovii* and *C. mujunkumensis* (Sakharov, 1930; Kozulina & Rudakova, 1932; Dirsh, 1933). During this study it was observed on *C. juncea*, *C. juncea* form *acantholepis* (= *C. acantholepis*) and *C. ramosissima* in Greece.

Of these species of *Chondrilla*, *C. latifolia*, *C. acantholepis*, *C. brevirostris* and *C. ramosissima* are closely related to *C. juncea*. The other species belong to other sections of the genus.

Geographic distribution

B. gilveolella had been recorded before 1968 in southern Russia from Kazakstan and the Caucasus to the Ukraine, and adult moths had been captured in Roumania, Bulgaria, Yugoslavian Macedonia, Turkey and Sicily (Rebel, 1931; Mariani, 1939; Lattin, 1951; Amsel, 1952; Klimesch, 1968; Popescu-Gorj, 1960). During this study the insect was found, in addition, throughout eastern mainland Greece from the northern Pelopennessus to the Yugoslavian–Bulgarian border, and in northern and central Iran, Azerbaidjan (Tabriz) and Karadj, respectively.

During the five years' study of *C. juncea* throughout the Mediterranean region, the insect was never found on the plant in Portugal, Spain, southern France or Italy. The insect does not occur in the western Mediterranean region, although the record from Sicily, if correct, may indicate that adult moths may occasionally arrive from the East.

Biology

This account of the general biology of *B. gilveolella* combines the observations of Kozulina & Rudakova (1932) and those made during this study. That part of its biology which is peculiar to Greece will be described later.

The whole of the larval and pupal development takes place beneath the soil within a case attached vertically or obliquely downwards to the rootstock of *Chondrilla* on which the larva feeds (Plate IV). The adult moths emerge at night or at dawn from the case, and during the day rest immobile, gripping the *Chondrilla* stems. They fly at dusk and, in southern Russia, feed at the flowers of *Matricaria* sp. and *Heliotropium* sp. Adults have lived up to 15 days in the presence of *C. juncea* only and with a source of sugared water. Females at emergence contain oocytes in all stages of development and maturation recurs throughout their life. Commencing 2–8 days after emergence the eggs are laid in groups at frequent intervals. The number of eggs laid per female varies directly with size, and 286 is the maximum recorded (Kozulina & Rudakova, 1932). The Russian authors suggest that under natural conditions the eggs are laid on the soil around the plants of *Chondrilla*. However, in insectary cages they are found on the walls and cage supports and on *Chondrilla* stems. The hatchling descends by a silk thread from the support or stem to the soil and moves across the soil surface until it encounters a *Chondrilla* plant. After briefly nibbling the base of the stem, then the collar region, it attaches to the rootstock 5–10 mm below the soil surface and commences to feed vertically upwards and downwards alternately. The larvae feed irregularly on the cortex of the rootstock as far as the central cylinder, cutting the lactiferous vessels. The latex is ingested but not assimilated as it is later ejected in frass pellets or regurgitated (Sakharov, 1930).

Immediately after fixing to the rootstock the larva commences to spin its case which increases in width and length as the larva grows and extends its attack along the length of the rootstock. At first, the case is loosely spun in silk, but later it becomes considerably reinforced to form a thick waterproof tube consisting of a silk sheath the exterior of which is covered with coagulated latex, tiny pieces of root bark, frass pellets and soil particles. The case is 30–60 mm long and 5–7 mm wide, and varies in latex content depending on the species of *Chondrilla* serving as host. The highest latex content was found in cases from *C. brevirostris* (Rudakova & Kozulina, 1932). The larva readily moves up and down inside the tube.

When fully grown the larva extends the tube to the soil surface to form an exit chimney of fresh silk and frass pellets. Before pupation the larva closes this tube with silk both above and below itself, leaving an operculum, and pupates within this chamber. The adult ultimately emerges via the chimney.

The duration of the developmental stages in the insectary at temperatures between 20°C and 29°C was as follows: egg 6–10 days; larva 45–60 days; and pupa 7–10 days. Development from egg to adult therefore takes 60–75 days.

Ecology of *B. gilveolella* in Greece

There are considerable differences between the environment of *B. gilveolella* in southern Russia studied by the Russian authors and that in Greece which forms the basis of this study.

Climatically (Table I) the southern Russian areas are extremely continental in type with 2–4 winter months of low to very low sub-zero temperatures, but with three months of warm to hot summer and very low rainfall (< 300 mm) except in the Ukraine (550 mm). In Greece the climate is typically Mediterranean with a mild wet winter, long hot dry summer and less than 500 mm rainfall. There are occasional frosts in winter in northern Greece but they are rare in southern Greece .

The main hosts of *B. gilveolella* in Greece are the thin-rooted *C. juncea* and *C. acantholepis*. *C. ramosissima* which inhabits dry, stony hillsides is a subsidiary host of less importance. The principal hosts of *B. gilveolella* in southern Russia are the thicker-rooted species, *C. ambigua* (Sakharov, 1930), *C. brevirostris*, *C. kossinskyi* and *C. mujunkumensis*. The latter three species support many more larvae than *C. juncea* when growing together (Kozulina & Rudakova, 1932).

In southern Russia the *Chondrilla* plants occurring on stable sands and well drained clay-sands supported the highest densities of *B. gilveolella* larvae; infestations were relatively lower on unstable sands and dunes and where strong vegetative cover had developed (Kozulina & Rudakova, 1932). This was also the case in Greece, particularly where a close carpet of the grass *Cynodon dactylon* occurred.

TABLE I. *Maximum and minimum temperatures (°C), and rainfall, of areas where* Bradyrrhoa gilveolella *occurs in southern Russia and Greece*

	Southern Russia								Greece			
	Kiev (Ukraine)		Astrakhan		Ashkhabad (Karakum)		Kazalinsk (Kazakhstan)		Athens (Southern Greece)		Thessaloniki (Northern Greece)	
Temperature												
Jan	−2·8	−8·9	−5·0	−10·0	3·3	−3·9	−8·9	−15·0	12·2	5·6	9·4	2·8
Feb	−1·1	−7·8	−2·2	−7·8	8·3	0·6	−6·1	−15·0	12·8	6·1	11·1	2·8
March	3·3	−3·3	3·9	−4·4	12·8	3·9	1·7	−8·3	15·6	7·8	15·0	6·1
April	11·1	2·8	13·9	4·4	21·1	9·4	14·4	−2·8	19·4	11·1	18·9	9·4
May	20·6	10·0	22·2	12·8	22·8	15·6	24·4	11·1	25·0	15·6	23·9	14·4
June	25·0	12·8	27·2	18·9	33·3	19·4	30·0	16·1	29·4	19·4	28·9	18·3
July	25·6	14·4	29·4	20·6	36·1	21·7	32·2	18·3	32·2	22·2	32·2	21·1
Aug	24·4	13·3	27·8	18·3	35·0	19·4	29·4	16·1	32·2	22·2	31·7	20·6
Sept	19·4	8·9	20·6	11·7	30·0	14·4	23·3	9·4	29·4	18·9	27·8	17·2
Oct	11·7	3·9	13·3	4·4	22·2	7·8	13·9	1·7	23·3	15·6	22·8	13·3
Nov	3·3	−1·7	4·4	−1·1	13·9	3·3	2·8	−5·0	17·8	11·1	16·1	8·9
Dec	−1·1	−6·1	−1·1	−5·6	8·3	0·0	−4·4	−9·4	13·9	7·8	11·1	4·4
Average	11·7	3·3	12·8	5·0	21·1	9·4	12·8	1·7	21·7	13·9	20·6	11·7
Rainfall	550 mm, most rain in summer.		160 mm, arid; little rain throughout year.		222 mm, arid; rain in winter.		122 mm, very dry, most rain in winter.		401 mm, dry summer, wet winter.		482 mm, dry summer, wet winter.	

Data from Meteorological Office, 1967. Tables of temperature, relative humidity and precipitation for the world. Pt 3. Europe.—2nd edn, London, H.M. Stationery Office.

Stable soils of pure sand similar to those of southern Russia are restricted to very small patches throughout mainland Greece, *Chondrilla juncea* and its various forms being found on a wide variety of friable and well drained soils, including sands, sandy clays, pebbly, stony calcareous, schistic and granitic soils and even more clayey soils, provided they are friable or develop cracks during the dry summer. Infestations of *B. gilveolella* are less dense on the less sandy soils and the insect is rare or absent on *Chondrilla* plants in wet low-lying soils even when friable. The distribution of *B. gilveolella* is therefore more restricted by its habits and soil conditions than that of its main *Chondrilla* hosts in Greece.

In general, *B. gilveolella* is scarcer in southern Greece than in the north. Its distribution in Greece is very erratic, due to the lack of suitable soils, and to the fact that nearly all the friable soils on the plains and sub-mountain regions are under continuous wheat cultivation. Even so, the insect was frequently absent or occurred on only 1–10% of the plants in seemingly suitable undisturbed situations. At only a few sandy sites, dunes, embankments and road verges was the infestation level above 50%. In cultivated sands or clayey-sands where *Chondrilla* reappears each year in the crop, up to 20% of the plants become infested by *B. gilveolella* by late summer, the populations being only slightly lower than those in uncultivated situations, but these infestations are destroyed by subsequent ploughing. The highest infestations of *B. gilveolella* occurred on recently abandoned sites having a high density of small, poorly growing *Chondrilla* plants. The density of *B. gilveolella* declines rapidly as the time since abandonment of cultivation increases, even though *Chondrilla* plants are still present in appreciable numbers, until on long abandoned sites (even on sandy soils) only a very small percentage of plants are infested by the moth larvae. In such sites the soil has either become compacted by the passage of grazing animals or there is a strong development of pasture cover.

Annual life-cycle

Throughout southern Russia *B. gilveolella* has one generation from May–June to September and another from late July–early September until May–June of the following year. The larvae of the winter generation remain quiescent from November to March. There is a considerable overlap between the generations in summer because of the long period over which the adult moths emerge (Kozulina & Rudakova, 1932).

In northern Greece the annual cycle is essentially similar, with moths of the overwintering generation emerging in May and June and those of the summer generation emerging from the end of August to early October. The larvae of the winter generation remain quiescent from December to March. Due to the shorter winter in Greece the distinction between the two main generations is less marked, and throughout most of the year larvae of all sizes and at all stages of development are found together.

Four similar batches of ten larvae of 10–18 mm collected early in March in the field in northern Greece and placed in glass containers with *Chondrilla* rootstocks were kept respectively at 5, 10, 15 and 20–22°C, in 70–80% r.h. Below 10°C the larvae remained quiescent. They fed actively only at temperatures above 15°C and developed normally between 20 and 22°C. The optimum temperature for development was later found to be 24°C. The larvae would readily recommence feeding every time the temperature rose above the 15°C limit and they were able to survive for at least six weeks on cut sections of *Chondrilla* rootstock at daily temperatures between 10 and 20°C without apparent harm.

In northern Greece from 15 December to 1st April soil temperatures at a depth of 5 cm are usually below 10°C, rarely rising above 15°C and then only for a few hours (Abazoglou, 1968; Kyriazopoulos, 1946–1958; Livadas, 1959–1965). There, during the winter, the larvae would remain fully quiescent. Soil temperatures rise sharply from April to August when the monthly average at 5 cm soil depth under grass is 15–32°C, and in the warmer parts of northern Greece it is possible for *B.*

gilveolella moths emerging at the end of April or in early May to give rise in late July–early August to new adults which would then produce a second summer generation. This late summer generation would reach the adult stage in October–November, or more likely overwinter in an advanced larval stage. However, there are usually very few pupae available to initiate such a cycle.

The annual cycle in southern Greece is similar to that in the north except that emergence of the overwintering generation commences slightly earlier (late April to early May) and a partial additional summer generation can occur. At most sites the numbers of larvae in the spring were very small, and larvae and pupae of the summer generation were again scarce before late August. Nevertheless, in November a heavy population of larvae at all stages was observed to enter hibernation at many sites in south-eastern Greece. By the following spring the population of larvae had declined to very low levels. These events were observed closely during two successive seasons at Thebes, a typical southern Greek site (Table II).

Even in northern Greece (*i.e.*, Nikomidinon) (Table II), there was some evidence of a progressive reduction in larval population through winter, into early summer,

TABLE II. *Winter disappearance of* Bradyrrhoa gilveolella *larvae in Greece*

	% infestation of *Chondrilla* by living larvae*	
	On all plants including seedlings	On older, established plants
Thebes (southern Greece) abandoned wheat field, calcareous sandy-clay.		
3.xii.69	6·9	43·1
16.iii.70	0	0
13.v.70	0·5	1·1
13.viii.70	0	0
Nikomidinon (northern Greece) long abandoned field, coarse sand-loam.		
27.xi.69	10·6	18·3
28.iii.70	2·3	3·4
11.vi.70	1·8	1·8
6.viii.70	8·5	8·5

*Results based on the examination of 50–300 plants, the numbers depending on presence of seedlings and season.

TABLE III. *Survey of* Bradyrrhoa gilveolella *in northern Greece during winter*

Place	Site	Date	% *Chondrilla* infested with larval cocoons	No. larvae per infested plant (mean)
Xanthi	Orchard: coarse sandy soil	4.xi.71	15	1·0
Rentina	Road-side: sandy soil	22.xi.71	50	1·3
Kalokastron–Nigrita	Old wheat field: sandy clay	11.i.72	60	0·4
Nigrita	Field edge: sand	12.i.72	60	0·6
Aghias Paraskevi (Nigrita)	Wheat stubble; sand	14.i.72	80	1·0
Epanomi	Sand dunes	25.i.72	50	0·5
Olympias	Sandy soil from granite and schist	17.ii.72	50	1·6
Iraklia	Sand embankment	23.ii.72	50	1·6
Nikomidinon	Old watermelon field; sandy clay	7.iii.72	25	1·0
Kalindra–Muries	Road cutting; schistous sandstone	17.iii.72	30	0·5
Katerini	Sand embankment	22.iii.72	30	1·0
Larissa–Trikalla	Road cutting; stratified sandy loam	23.iii.72	50	1·0
Kalambaka	Sandy loam embankment	24.iii.72	50	0·5
Micri–Prespa Lake	Canal bank; sand	4.iv.72	40	0·9
Near Olinthos	Road cutting; coarse sand from granite and schist rocks	19.iv.72	30	0·8
Athyra–Evropos	Road-cutting; sandy clay	26.iv.72	25	0·8

though the population had returned more or less to its original autumn level by August (Table II). At the even colder northern sites nearer the Bulgarian border at Paradisos (near Xanthi) and Iraklea, a large population of advanced larvae and pupae of the overwintering generation was found.

A detailed survey from the northern border of the country to Larissa and Trikala, carried out from October 1971 to May 1973, showed that *B. gilveolella* larvae were present at 16 separate sites during the winter in this region with 15–18% *Chondrilla* plants infested at mean levels of 0·4–1·6 larvae per plant (Table III). All 2000 larvae collected during this period looked healthy and none showed any external sign of parasitisation or fungal disease: no dead larvae were found, even among those collected from wet soil after several rainy days. Thus on unploughed sites a considerable population of *B. gilveolella* overwinters in northern Greece.

These observations, summarised in Table IV, indicate a strong relation between winter climate and the stability of *B. gilveolella* populations. Populations are stable in the cooler parts of northern Greece and are highly unstable in the hotter parts of southern Greece.

TABLE IV. *Winter decline of larval populations of* Bradyrrhoa gilveolella *and climate in Greece*

Regions of Greek mainland	Decline of larval populations of *B. gilveolella*	Climatic sites	Average daily maximum and minimum temperature and rainfall, December–February: Temperature (°C) Maximum	Temperature (°C) Minimum	Rainfall (mm)
Southern	Marked	Athens	13·0	6·5	56
		Khalkis (for Thebes)	13·7	5·6	61
Central and northern	Less marked	Larissa	11·2	1·7	51
		Thessaloniki	10·6	3·3	41
North-eastern	Slight or absent	Xanthi	8·6	1·1	64
		Edirne	6·7	−0·8	61

Data from Meteorological Office, 1967. Tables of temperature, relative humidity and precipitations for the world Pt 3. Europe—2nd edn. London. H.M. Stationery Office.
The figures for Xanthi are estimated by interpolating between those of Thessaloniki and Edirne (Adrianople) in Turkey close to the Greek border.

Parasites and pathogens

B. gilveolella is parasitised in Greece by several species of Hymenoptera and by a Tachinid fly (Table V). The Hymenoptera, an Ichneumonid, *Syzeuctus* sp., a Braconid, *Bracon* sp., and a polyembryonic Encyrtid, *Copidosoma* sp., are parasites of the larvae. A Tachinid, *Germaria graeca* (Br. & Berg.) (Echinomyiinae), infests the larvae and emerges from the moth pupae. This is the first host record for this species. A Chalcid, *Peltochalcidia benoisti* Steffan, was also bred from *Bradyrrhoa gilveolella* pupae, but it appears to be a hyperparasite of the Tachinid.

Copidosoma sp. is the most common parasite, and up to 30% of the moth larvae of the winter generation were parasitised in northern Greece. *Syzeuctus* sp. occurred in up to 10% of the host larvae but *Bracon* sp. was less important. The Tachinid *G. graeca* was widespread but generally at a low rate of parasitisation (5%). However, at occasional sites in northern Greece up to 27% of the winter generation of moth pupae were parasitised by it. There is a good synchronisation between the parasites and *Bradyrrhoa gilveolella*, the parasites hibernating in the host and emerging during the same period as the moths. Sometimes *Syzeuctus* sp. pupates in the pupa of *B. gilveolella*.

In southern Russia (Kozulina & Rudakova, 1932) an Ichneumonid, cited as *Syzeuctus maculatorius* (F.) (without authority), a Braconid, *Chelonus* sp. and an Encyrtid,

TABLE V. *Combined effect of parasites on* Bradyrrhoa gilveolella *in Greece*

Place	Date	Larval parasites: No. larvae examined	Larval parasites: Rate of parasitisation (%)	*Copidosoma* sp.	*Syzeuctus* sp.	*Bracon* sp.	*Beauveria bassiana*	*Cordyceps* sp.	Pupal parasites: No. pupae examined	Pupal parasites: Rate of parasitisation by Tachinids (%)
Paradisos (Xanthi)	7.viii.70	22	50	+	+		+			
	8.viii.70	23	47	+	+					
	15.vi.70	31	70	+	+		+		26	23
Irakleia (Serrai)	10.viii.70	11	27	+			+	+		
	11.viii.70	16	25	+	+	+				
	7.xi.70	51	14	+			+		3	100
	16.xi.70	38	18	+			+			
Iasmos (Serrai)	9.viii.70	22	19	+	+					
Sidirokastron	10.viii.70	19	21	+						
Thebes	13.viii.70	4	75	+						
	3.xi.70	82	16	+			+		60	43
Vari (Attiki)	16.viii.70	18	50	+					29	3
	4.xi.70	27	0						2	100
Kalivia (Attiki)	4.xi.70	17	18	+					2	100

Encyrtus sp., were recorded as larval parasites and an undetermined Tachinid and Ichneumonid were reared from pupae. Thus the parasite complex of *B. gilveolella* in Greece is similar to that of southern Russia.

Two entomophagous fungi, *Cordyceps* sp. and *Beauveria bassiana*, also attack the larvae of *Bradyrrhoa gilveolella* in Greece (Table V). *Cordyceps* sp. was of minor importance. On the other hand, *Beauveria bassiana* was the most important biological factor reducing the larval populations of *Bradyrrhoa gilveolella*. The larvae present all the classic symptoms of fungal infestation and are readily infected. The pupae are rarely attacked. During '*in vitro*' rearing of *B. gilveolella* larvae in Greece, the fungus was most damaging at or above 20°C; below 10°C symptoms did not develop. In northern Greece in winter there is very little indication of the disease, but it develops rapidly among the surviving larvae in spring and in those of the summer generation.

Table V shows that the combination of parasitic Hymenoptera and fungal diseases can cause a 50–70% reduction in the larval population and the Tachinid can destroy 20–40% of the remaining pupae. The highest rates of parasitisation and disease, equal to mortalities in each generation of 60–80%, are found in older, more stable sites such as Paradisos, which serve as population reservoirs for the moth.

Damage to C. juncea

A larva of *B. gilveolella* feeding on the vertical rootstock of *C. juncea* will cut out a cortical section of the rootstock 2–4 cm long and as far as the central cylinder in depth, cutting into the cortical vessels and interrupting the flow of nutrients. The larvae also destroy the regeneration buds if they occur in the feeding area. The feeding also reduces to a certain extent the overwintering reserves of the plant in the rootstock.

Generally, in Greece, there are only 1–2 larvae per infested plant, but more heavily infested sites will have plants supporting 3–4 and occasionally as many as 10 larvae. The effect of larval feeding on the plant depends on the size of its rootstock. Very thin roots may be cut across, thus killing the top growth. Thin to medium size plants are badly damaged but very thick plants (with 1·5–2 cm diameter rootstocks) can apparently withstand the attack of 3–5 larvae without obvious ill effects.

Heavy infestation by *B. gilveolella* would thus alter dense stands of thin *Chondrilla* plants progressively to stands comprising a few thick rooted plants that would still be infested with 1–2 larvae each, *i.e.*, the typical situation for much of northern Greece.

Host specificity

As already noted, *B. gilveolella* has only been recorded as feeding on *Chondrilla* spp. under natural conditions. However, to demonstrate its specificity and safety as a biological control agent *B. gilveolella* was tested against a series of Cichoriaceae and composites related to *Chondrilla* (Harris & Zwölfer, 1968; Wapshere, 1973*b*) and against 62 cultivated plants of importance to Australia, specified by the Australian plant quarantine authorities. It was in fact tested against 77 plants occurring in 21 families (listed in Table VI). Of the Cichoriaceae the most closely related to *Chondrilla* are other members of the Crepidinae, the most important of which for Australia is lettuce, *Lactuca sativa*.

The testing method was as follows: larvae of medium to large size (8–20 mm) were collected from *Chondrilla* plants in Greece, extracted from their larval cases and placed close either to the roots of growing plants or near root portions of the test plants.

In the test using living plants 3–6 living larvae were placed on each of four plants of each of a test group of 2–3 plant species and on four *C. juncea* control plants at ambient temperature (18°C night, 26°C day). If the plant species were acceptable as food, the roots were attacked after a short time by the larvae, which commenced feeding and constructing a new case. Otherwise the root was not attacked and the larvae moved rapidly away. After 15 days the top parts of the roots of the test plants

TABLE VI. *Plant species tested for specificity of* Bradyrrhoa gilveolella

Compositae		
Liguliflorae		
Cichoriaceae		
Crepidinae	*Lactuca sativa*	Lettuce
	Taraxacum officinale	Dandelion
	Sonchus arvensis	Corn sow-thistle
	S. oleraceus	
Scorzonerinae	*Scorzonera hispanica*	
Cichorinae	*Cichorium endivia*	Endive
Tubiflorae		
Heliantheae	*Helianthus annuus*	Sunflower
	H. tuberosus	Jerusalem artichoke
	Dahlia sp.	
	Zinnia sp.	
Heleniae	*Tagetes* sp.	
Anthemidae	*Chrysanthemum indicum*	
	C. leucanthemum	
Calenduleae	*Calendula* sp.	
Cynareae	*Carthamus tinctorius*	Safflower
	Cynara scolymus	Artichoke
Chenopodiaceae	*Beta vulgaris*	Beet
Convolvulaceae	*Ipomoea batatas*	Sweet potato
Cruciferae	*Brassica oleracea*	Cabbage
	B. rapa	Turnip
Cucurbitaceae	*Cucurbita maxima*	Pumpkin
	Cucumis sativus	Cucumber
	C. melo	Rock melon
	Citrullus vulgaris	Water melon
Gramineae	*Triticum* spp.	Wheat
	Hordeum vulgare	Barley
	Avena sativa	Oats
	Secale cereale	Rye
	Oryza sativa	Rice
	Zea mays	Maize
	Sorghum vulgare	Sorghum
	Saccharum officinarum	Sugar cane
	Lolium perenne	Perennial ryegrass
	Phalaris tuberosa	Phalaris
Juglandaceae	*Juglans regia*	Walnut
Leguminosae	*Pisum sativum*	Garden pea
	Phaseolus vulgaris	French bean
	Vicia faba	Broad bean
	Glycine hispida	Soy bean
	Medicago sativa	Lucerne
	Trifolium subterraneum	Subterranean clover
	T. repens	White clover
	Acacia dealbata	Wattles
	A. floribunda	
	Medicago tribuloides	Barrel medic
	M. littoralis	Strand medic
Liliaceae	*Asparagus officinalis*	Asparagus
	Allium cepa	Onion
Linaceae	*Linum usitatissimum*	Linseed, flax
Malvaceae	*Gossypium* spp.	Cotton
Moraceae	*Ficus carica*	Fig
Myrtaceae	*Eucalyptus globulus*	Gum
	E. camaldulensis	Gum
Oleaceae	*Olea europaea*	Olive
Pinaceae	*Pinus radiata*	Monterey pine
Rosaceae	*Malus sylvestris*	Apple
	Pyrus communis	Pear
	Prunus domestica	Plum
	P. persica	Peach, nectarine
	P. armeniaca	Apricot
	P. cerasus	Cherry
	P. amygdalus	Almond
	Cydonia vulgaris	Quince
	Fragaria vesca	Strawberry
	Rosa spp.	Garden rose
Rutaceae	*Citrus sinensis*	Orange
	C. limonia	Lemon
	C. paradisi	Grapefruit

TABLE VI. *Plant species tested for specificity of* Bradyrrhoa gilveolella—*continued*

Solanaceae	*Solanum tuberosum*	Potato
	Lycopersicum esculentum	Tomato
	Nicotiana tabacum	Tobacco
	Capsicum annuum	Capsicum
Umbelliferae	*Daucus carota*	Carrot
	Pastinaca sativa	Parsnip
	Apium graveolens	Celery
Urticaceae	*Humulus lupulus*	Hop
Vitaceae	*Vitis vinifera*	Grape

were examined for damage. After one month the root was examined fully to determine whether any feeding had taken place.

All the plants of the family Compositae in Table VI except *Taraxacum officinale* and *Sonchus oleraceus* were tested using this method, as also was *Glycine hispida. L. sativa* was tested both in the rosette stage and in the flower shoot stage.

The other '*in vitro*' method was simpler and more rapid and was used for the remainder of the plants in Table VI. Six or ten larvae were placed between 15-cm sections of well developed rootstock in a glass dish (25 cm diam. × 8 cm deep), the bottom of which was covered by a sheet of filter paper. Two tests were made simultaneously. In the first, two dishes each contained three sections of the root of the test plant on the filter paper (starvation test); in the second, a choice test between the test plant and the normal host, the two dishes each contained two sections of the root of the test plant and two sections of *C. juncea* rootstock alternately placed. In total each test plant was offered to 12 or 20 larvae, respectively, for each type of test.

The larvae were placed in the dishes which were covered by a glass plate and maintained at 20–22°C under a daily lighting regime of 12 h diffuse light and 12 h darkness. After 24 h the glass plate was slid open slightly to allow aeration but care was taken that the rootstock did not dry out. Each test was run for seven days, during which period larvae would certainly have attached to a normal host-plant. The activities of the larvae were checked every two days and finally the root portions were examined to detect any attack, attachment or feeding. As well as the remaining species listed in Table VI, *L. sativa* and *Cichorium endivia*, already exposed to *B. gilveolella* as living plants, were also tested by this method.

The results were very clear for all tests. On all occasions healthy *B. gilveolella* larvae rapidly attacked and fed on the rootstocks of *Chondrilla juncea* and soon after commenced to spin their larval cases using the latex and root particles as already described. By the end of the test typical cases had been constructed along the root sections and the larvae had developed within these cases. On the other hand none of the other plants in Table VI tested in this way was attacked in the same manner except for *T. officinale*. There was no attempt to feed on the plants, except for *Ficus carica* and *Pinus radiata* on which the larvae very temporarily attempted to use some tiny bark fragments to add to the silk web of the case. With *Saccharum officinarum* the larvae entered into the pith at the cut end of the collar region, fed upon it and spun cases, but when the end of the section was plugged fresh larvae made no attempt to feed on the uninjured root epidermis.

By the end of seven days the larvae in all the '*in vitro*' starvation tests, except that with *T. officinale* rootstocks, were already beginning to die from starvation. In the living plant tests the larvae not on *C. juncea* were all dead within 30 days. In the 'choice tests' the healthy larvae had all attached to the *C. juncea* rootstocks by seven days but none had attached to or fed on the rootstock of the alternative plant species.

B. gilveolella larvae readily attacked and attached to cut rootstocks of *T. officinale* and formed a normal case. However, these events proceeded at a slower rate than with *C. juncea*, the normal host. To discover whether *T. officinale* could serve as a host under field conditions, 250 *T. officinale* plants in the vicinity of *Chondrilla* plants infested by *B. gilveolella* were dug up and examined in spring in Greece. On none of the rootstocks of *T. officinale* was there any sign of *B. gilveolella*; none had old cases and none showed the longitudinal scarring characteristic of *B. gilveolella* feeding.

The adaptation of *B. gilveolella* to *C. juncea* forms

C. juncea is a polymorphic apomict (Rosenberg, 1912) with many different forms. In Australia there are three forms: narrow, intermediate and broad leaved (Hull & Groves, 1968). In Europe there are many more and in Greece there are two main forms or perhaps two species, *C. juncea* and *C. acantholepis* as well as many others. In order to determine whether the Australian forms were attacked equally as readily as the Greek form, five forms were exposed to *B. gilveolella* (*i.e.* Greek *acantholepis*, the three Australian forms and the French 'Aniane', a form typical of the western Mediterranean region). The tests were carried out using the living plant method and the Greek *acantholepis* was used as control since the larvae were collected from this form. There was no difference between forms; *B. gilveolella* attached readily, fed on and formed cases equally quickly on all forms of *Chondrilla.*

Discussion

The above results show that *B. gilveolella* is a sufficiently specific insect to introduce to Australia to control skeleton weed (*C. juncea*). They confirm the contention of the Russian workers, Sakharov (1930) and Kozulina and Rudakova (1932) that *B. gilveolella* is specific to *Chondrilla* spp. under natural conditions. They also show that, as noted by Kozulina & Rudakova (1932), although *Taraxacum* species can serve as a host under laboratory conditions it is not a host in the field. Furthermore, during the study of various Cichoriaceae, including two other species of *Taraxacum*, *T. koksaghyz* and *T. multiscaposum*, as well as *Chondrilla* spp. in southern Russia, *B. gilveolella* was never found on *Taraxacum* spp. nor on other Cichoriaceae except *Chondrilla* spp. (Pravdin, 1957).

Unlike the other *Chondrilla* organisms studied to date as biological control agents (Hasan, 1972; Caresche, 1973; Caresche *et al.*, 1974; Caresche & Wapshere, 1974, 1975) there is no evidence of adaptation of *B. gilveolella* to geographic forms of *C. juncea* and there was therefore no necessity to search for strains adapted to the Australian forms of *C. juncea.*

The populations of *B. gilveolella* in Greece are basically unstable. For example, there is the continuing population decline in abandoned agricultural sites due to increasing compaction of the soil and progressive changes in the vegetation, and the considerable population losses caused by the yearly autumn cultivation of wheat fields, where the greater part of the *Chondrilla* infestations occur in eastern Greece. The best sites are therefore transitory, becoming less favourable as they are grazed by livestock (sheep and goats) or because of man's activities, and to maintain a *B. gilveolella* population in Greece new sites need to be continually created, chiefly by cultivation and subsequent abandonment. In addition to the above instability there is the winter disappearance of moth larvae, most marked in southern Greece, and related to climate, and finally the re-invasion of Greece in summer, particularly in the south.

It does not seem possible that the medium to heavy infestations of larvae observed on *Chondrilla* at the end of summer, in undisturbed sites and on *Chondrilla* growing in the proportionately much greater area of wheat stubble could be derived from the small spring population in Greece. It is reasonable therefore to assume that during the summer flight period there is a large influx of moths from the sandy plains of Roumania and Bulgaria, and that these moths lay eggs and reinfest *Chondrilla* throughout Greece. There is, as yet, no direct evidence for such an influx.

The cause of the continuing decline and winter disappearance of the larvae, so pronounced in southern Greece, is unknown. It is not due to heavy parasitisation or disease, since few larvae killed by parasites or by *Beauveria bassiana* are found in the field, nor is it due to lack of food, since *Chondrilla* rootstocks are always present. The only conclusion is that *Bradyrrhoa gilveolella* larvae are in some way ill-adapted to relatively hot Mediterranean climates with winter rainfall, and that southern Greece is near the extreme southern limit of the range of this moth in Europe, populations being unstable there for that reason. Possibly the effect of this poor adaptation is aggravated by the lack of sandy soils in southern Greece, because most populations of *B. gilveolella* entering winter there occur in soils which are more clayey than those of the sites in northern Greece.

If in fact *B. gilveolella* is ill-adapted to hot Mediterranean climates and is dependent on more northerly populations to maintain itself in Greece, this would explain the absence of the moth in the western Mediterranean despite the presence of *C. juncea* forms which are readily attacked. There are no *C. juncea* populations in the north of western Europe large enough to support an adequate population of migrant moths..

The effectiveness of *B. gilveolella* as a biological control agent will depend on its adaptation to the environmental conditions of the *C. juncea* infestations in Australia (Wapshere, 1973*a*). Unlike the Greek situation the Australian infestations are on soils ranging from sand to sandy and closely similar to the soils in which maximum infestations of *Chondrilla* by *B. gilveolella* are observed in southern Russia. In this regard *B. gilveolella* would be well adapted to the Australian environment. The main *C. juncea* infestations occur in the fallow or pasture phase of wheat rotation in Australia and these also are more similar to the recently abandoned situations in which the highest moth populations are found in Greece. On the other hand, the Greek climates are similar to those of a major part of the region infested by *C. juncea* in Australia, those of Larissa being equivalent to the cooler Canberra region, and of Thessaloniki to the warmer Wagga region; the climates of southern Greece where populations of the moth are particularly unstable (Athens) are somewhat similar to the heavily infested, hot, dry sandy Mallee region of south-east Australia. Therefore the effectiveness of *B. gilveolella* as a biological control agent for *C. juncea* in Australia will depend on a balance between its being favoured by the greater areas of sandy soil and of fallow/pasture than in Greece, and hindered by its poor adaptation to hotter Mediterranean climates. The moth has recently been introduced into Australia and studies of the course of its introduction will indicate the point at which a balance is achieved between the conflicting ecological requirements.

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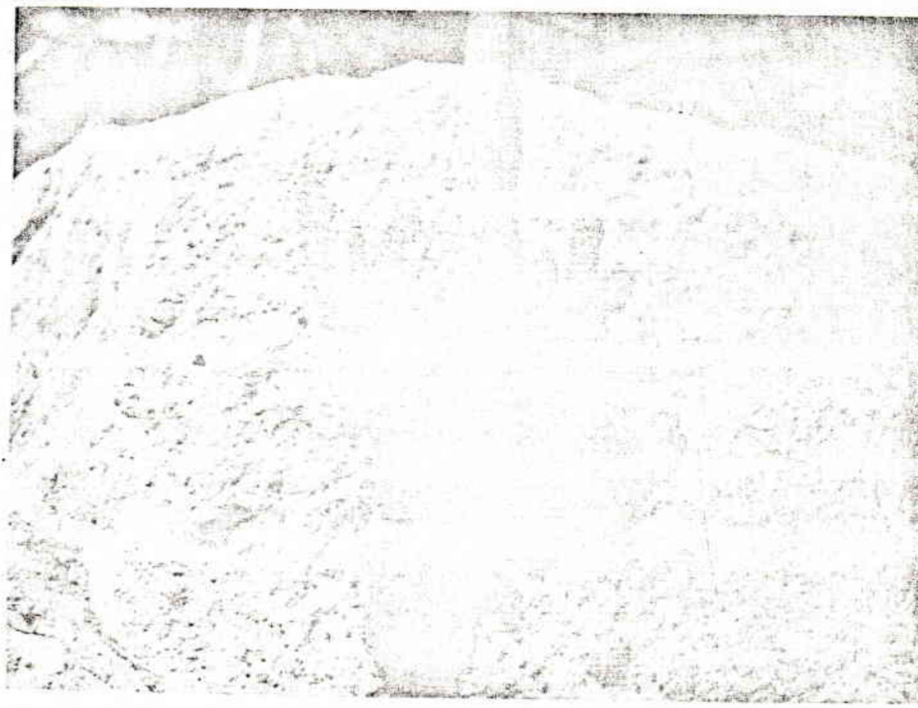

Larval and pupal cases of *Bradyrrhoa gilveolella* on *Chondrilla* rootstock.