

BIOLOGY OF *BRUCHIDIUS VILLOSUS*  
(COLEOPTERA:BRUCHIDAE) ON SCOTCH BROOM  
IN NORTH CAROLINA

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ABSTRACT

Scotch broom, *Cytisus scoparius* (L.), a weed in the Pacific Northwest, is rapidly invading open areas and ecologically sensitive dunes along the coast. Scotch broom populations also exist in the eastern United States, but are apparently stable and not expanding. The eastern Scotch broom populations may be kept in check by the broom weevil, *Bruchidius villosus* (F.), a bruchid found in eastern populations of broom but absent from those in the Northwest (Bottimer 1968). We studied the natural history and biology of the broom weevil in North Carolina. Our purpose was to relate the bruchid's life history to the phenology of the host plant and to quantify oviposition and seed destruction by the bruchids. Adult weevils were active around the plant from the first flowering in early spring until dehiscence of the seedpods in summer. The sex ratio of the beetles was nearly 1:1 throughout the adult activity season. The number of weevil eggs laid on the pods was correlated to the length of the pod and to the number of seeds in the pod. The larvae develop in and destroy the seeds of the broom plant. Seed destruction at two sites in North Carolina was more than 80%; a field experiment showed that seed destruction was dependent on the density of beetles in cages on the plants. Because of its impact on seed production, the broom weevil may be a viable candidate for biological control of broom in the Northwest.

Key Words: broom weevil, oviposition, seed destruction, Scotch broom, *Cytisus scoparius*

RESUMEN

La escoba escocesa, *Cytisus scoparius* (L.), una maleza del Noroeste Pacífico, está invadiendo rápidamente áreas abiertas y dunas ecológicamente delicadas a lo largo de la costa. Poblaciones de escobas existen también en el este de los Estados Unidos, pero aparentemente son estables y no se están expandiendo. Es posible que las poblaciones orientales de escobas estén bajo control gracias al gorgojo de escoba, *Bruchidius villosus* (F.), que se encuentra en poblaciones orientales de escoba pero está ausente en el noroeste. Estudiamos la historia natural y la biología del gorgojo de escoba en Carolina del norte. Nuestro propósito fue relacionar el historial de vida del gorgojo a la fenología de la planta huésped y cuantificar oviposición y destrucción de las semillas por los gorgojos. Los gorgojos adultos eran activos alrededor de la planta desde la floración primera al comienzo de la primavera hasta la dehiscencia de las cápsulas de semillas en el verano. La proporción sexual de los escarabajos fue casi 1:1 durante la temporada de actividad adulta. El número de huevos de gorgojo colocados en las cápsulas fue correlacionado al largo de la cápsula y al número de semillas en la cápsula. La larva se desarrolla y destruye las semillas de la planta escoba. La destrucción de semillas en dos lugares en Carolina del Norte fue más de 80%; un experimento de campo demostró que la destrucción de semillas dependía en la densidad de

las jaulas de escarabajos en las plantas. Debido a su impacto en la producción de semillas, el gorgojo de escoba puede ser un candidato viable para el control biológico de la escoba en el noroeste.

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Scotch broom, *Cytisus scoparius* (Fabaceae: Leguminosae), was introduced from western Europe into the Pacific Northwest as an ornamental and as a soil and coastal dune stabilizer. This woody shrub is well adapted to dry, disturbed habitats. Since its introduction, *C. scoparius* has become a pest by spreading and displacing valued forage and native plants (Andres & Coombs 1995). In addition, Scotch broom has made reforestation difficult in many areas in British Columbia, California, Oregon and Washington (Balneaves 1992). Historically, *C. scoparius* has been difficult to control because of its large and long-lasting seed bank (Bossard & Rejmanek 1994).

In western North Carolina the distribution of feral *C. scoparius* is restricted to isolated patches and its populations do not seem to be expanding (Syrett et al. 1999). One possible factor contributing to the limited spread of Scotch broom in this area is the weevil, *Bruchidius villosus*. Adult weevils lay eggs on the broom seedpods and the larvae feed on the seeds within the pod. Parnell (1966) studied the life history of *Bruchidius* on broom in England. However, little is known about the life history and biology of this potentially beneficial bruchid in North America. Because the broom populations in North Carolina are stable, the ecological agent that limits population growth in North Carolina could potentially be introduced into the Northwest to control this problem plant.

*Bruchidius villosus* shows potential as a biological control agent for *C. scoparius* due to its direct effect on the host's seed production. This study's purpose was to improve our understanding of *B. villosus*' biology as it relates to its host plant in western North Carolina. We compared the biology of the bruchid in North America with that in England to see how consistent the behavior and ecology of this species are in widely separated populations. Our studies focused on the overwintering of the weevils, on the relationship between beetle activity and host plant phenology, and on measurement of oviposition and destruction of seeds. An understanding of these basic aspects of this insect's biology is useful if this beetle is to be introduced as a biological control agent for Scotch broom in the Pacific Northwest.

## MATERIALS AND METHODS

### Site Descriptions

*Site 1.* The larger of the two stands of *Cytisus scoparius* used for this study was located on a hillside approximately 11 km east of downtown Asheville, North Carolina. The 69 × 24 m area has a northeastern exposure and contains 36 shrubs. The majority of the shrubs are 1-2.5 m in height. In addition to *C. scoparius*, the hillside is densely covered with two species of *Solidago*, *Lespedeza cuneata*, *Lathyrus latifolius*, and *Eupatorium hyssopifolium*. Several small *Robinia pseudo-acacia* and *Acer rubrum* also grow at the site. The *C. scoparius* shrubs at this site are exposed to full sun throughout the day.

*Site 2.* The second study site was located in a residential area on the edge of the Bent Creek Research and Recreational area approximately 16 km southwest of Asheville, North Carolina. The broom plants are old ornamentals that are no longer

being maintained. The area is approximately  $19 \times 12$  m and it contains 12 shrubs that are 1-2 m in height. The site has a dense ground cover of *Hedera helix*. Also growing on the site are *Lespedeza* sp., *Solidago* sp., *Clematis terniflora*, *Aster pilosus*, *Lonicera japonica*, *Celastrus orbiculatus*, *Quercus alba*, *Tsuga canadensis*, and *Prunus serotina*. The centrally located shrubs at this site receive little sun most of the day, whereas the shrubs at the edges of the site receive sun for about half of the day.

At each site, continuous temperature readings were made using a StoAway® Tid-biT® temperature logger. The loggers were placed at the base of mature *C. scoparius* shrubs with the temperature probes in the leaf litter. The temperature data were downloaded each week and transferred to computer.

### Overwintering

*Field Sampling.* To determine if the bruchids overwinter near the broom plant, the soil and leaf litter around the plants at each site were sampled by two separate methods. In January, three soil samples ( $100 \text{ cm}^2 \times 2.5$  cm deep) were collected at 30, 60 and 90 cm from the base of a mature broom plant at each site. Soil samples were placed in Berlese funnels over jars of alcohol. After the soil dried for two weeks, the alcohol and dried soil were examined for bruchids.

Litter samples were taken weekly from 26 Jan to 20 Apr 1998. Each litter sample was approximately  $100 \text{ cm}^2 \times 1$  cm deep. From each site a sample was taken at 30, 60 and 90 cm from the base of a mature plant. Each of the six weekly samples were emptied into a large tub and examined thoroughly with a hand lens for *B. villosus*.

*Laboratory Observations.* To observe activity of adult weevils during the winter, we set up eight  $10 \times 10 \times 8 \text{ cm}^3$  clear plastic observation cages. Each cage was filled with soil to a depth of about 5 cm and contained 8 to 10 weevils. Four of the containers were kept indoors at room temperature and four were kept outdoors under natural temperature conditions. Because the group kept indoors was near a window, both groups of beetles received the same natural photoperiod. Moisture was applied weekly to each container. If the bruchids were active during warm winter days, individuals kept indoors could be observed on the lid and walls of their cages more than individuals in the cages kept under natural temperatures. We checked the cages each week (13 Feb through 30 Mar) and recorded the number of bruchids located on the lid or side of the cage or on the soil. The number of beetles not visible was also recorded. We used a sign test for paired-sample data to test for differences between the activity of bruchids kept indoors and those kept outdoors.

### Seasonal Abundance and Host Phenology

Weekly beat and sweep samples were made at each site to quantify seasonal changes in the adult bruchid population. Samples were standardized throughout. Beat samples consisted of beating a branch of a broom plant over a white tray ( $0.5 \times 0.4$  m). Beetles falling into the tray were counted and collected using an aspirator. Three plants at each site were sampled by beating branches at the top, middle and bottom of each plant. Sweep samples consisted of 10 uniform sweeps of the vegetation surrounding the broom plants. The contents of the sweep nets were emptied into a white tray and beetles were collected using an aspirator and counted. Each week, the bruchids collected at the two sites were examined individually under a dissecting microscope and sexed (see Parnell 1964). In addition to sampling for beetles, the phenological stage of the broom plants was quantified. We paid particular attention to the stage of leaf, flower, and seedpod development.

### Oviposition and Seed Destruction

We dissected females collected on three dates (N = 7, 4 May—before pod set; N = 10, 19 May—just after pod set; N = 9, 1 Jun—when pods begin turning brown) and determined the development of their oocytes and checked for sperm in their spermathecae. Once oviposition was occurring in the field, we collected three to five seedpods from different heights and directions on four bushes at each of the sites. Using a dissecting microscope, we determined the number of bruchid eggs on each of the pods. We also measured the length of each pod (calyx to tip) and counted the number of seeds in each pod. We tested for a significant correlation between the number of bruchid eggs laid per pod and the number of seeds per pod. We also correlated the number of eggs with the number of infested seeds.

We also conducted a field-cage experiment to determine the effect of bruchid density on the seed destruction. The cages were (1 mm) mesh bags about 30 cm in diameter. We used four densities of female bruchids: 0 (control), 1, 4 and 8 female bruchids per bag. We tied and taped each bag around the end of a broom branch with 8 to 18 young (green) seedpods. Because the seedpods had been exposed to natural oviposition, we removed bruchid eggs from the seedpod exterior by hand prior to introducing female bruchids into the cages. To control for the effect of plant and location, each of the four densities were placed on branches of a single broom plant and the density treatments were randomly assigned to each cage. Four blocks (different broom plants) of the four treatment densities were left in the field. At the end of four weeks (24 May to 22 Jun 1998), the cages and branches were collected and examined in the laboratory to determine the number and size of the seedpods, the number of seeds, and the infestation rates. We used an ANOVA to test for differences in seed destruction among the treatment densities. Because the number of pods and seeds in each cage varied, we also used a regression analysis to determine the relationship between the density of weevils per seed and seed destruction.

### Parasitism

Once the seedpods had started to dehisce (late June through August) and the weevils were maturing, we collected five to ten pods from different heights and directions from four bushes at each site. The length and number of seeds were recorded for each pod. The pods were opened and we recorded the number of live and parasitized bruchids.

## RESULTS

### Overwintering

No *B. villosus* were found in any of the soil or litter samples from either of the sites during January and February. Except those insects that were in pods in the leaf litter sample, all beetles found in the litter samples were dead. Some pods from the previous year were collected in the litter samples and these contained a few live beetles (N = 7).

The adults kept in indoor cages were significantly more likely to be active (on cage lid and walls) compared with those in cages kept outdoors ( $P = 0.04$ ). In only two of twelve observations were a greater number of active weevils found in outdoor cages. Both of these were later observations (30 Mar and 6 Apr) when the beetles were becoming active in the field. Based on our sampling and cage experiment, it seems likely that the beetles overwinter away from the plants and may become active during the winter when temperatures are warm.

### Seasonal Abundance and Host Phenology

Adult weevils can be found on the plants from early April to the end of August (Figs. 1 and 2). Arrival of the weevils is closely correlated with the first bloom of the plant. We found beetles at each site during the weekly sample where flowers first appeared. At both sites we found a peak in the population during the flowering stage of the plant (beat samples Figs. 1 and 2). Another peak in the population from late June to August was observed in beat samples of the broom and in sweep samples of surrounding vegetation. The second peak corresponds to the darkening and dehiscence of the seedpods and probably represents the emergence of the new generation of weevils. Adults were active over a wide range of temperatures (Figs. 1 and 2). The overall sex ratio sampled was slightly male biased 542m:500f. The sex ratio of weekly samples fluctuated around 1m:1f throughout the adult activity (10 weeks with slight male biases and 9 weeks with slight female biases).

### Oviposition and Seed Destruction

None of the females collected 4 May, prior to pod formation on the plants, had mature oocytes although some (2 of 7) had mated. These females noticeably lacked fat deposits. Once pods were set, all females (N = 19, 19 May and 1 Jun) had some large mature oocytes and most (13 of 19) were mated. The mature oocytes were large compared with the size of the females and typically filled the abdominal cavity. The average number of mature oocytes found in gravid females was 10 (range 4 to 14).

For field collected seedpods (N = 100), the overall seed destruction was 82% (492/600). Eighty-six percent of the seedpods sampled had more than 60% of their seeds destroyed by weevils (Fig. 3). Seed destruction was similar at both sites [site 1: 85% (225/266); site 2: 80% (267/334)]. Not surprisingly, the number of seeds per pod increased significantly with the length of the seedpod (Fig. 4: N = 100;  $P < 0.001$ ;  $r^2 = 0.53$ ). There was a significant relationship between the number of bruchid eggs laid on the seedpod and the length of the pod (Fig. 5: N = 59;  $P < 0.001$ ;  $r^2 = 0.23$ ), with more eggs being laid on longer pods. Beetles also laid more eggs on pods with more seeds (Fig. 6: N = 59;  $P < 0.001$ ;  $r^2 = 0.18$ ), although the number of seeds was a less reliable indicator of the number eggs than was the size of the seedpod.

In the field cage experiment, there was a significant difference among the treatments with respect to the proportions of seeds infested with larvae (Fig. 7: ANOVA;  $F_{3,12} = 5.67$ ;  $P < 0.02$ ). There was also a significant relationship between the number of beetles per seed in the cage and the proportion of seeds damaged ( $P < 0.02$ ;  $r^2 = 0.35$ ).

### Parasitism

Parasitization occurred at relatively low rates at both sites, 14% (14/100) at site 1 and about 6% (6/102) at site 2. The parasites have tentatively been identified as *Dinarmus* sp. (Pteromalidae), known parasites of bruchids.

## DISCUSSION

### Overwintering

The weevils apparently overwinter away from the plant. We did not find any live *B. villosus* in the soil, litter or sweep samples during January and February, although a few live weevils were found in seedpods in litter samples and in seedpods still on the

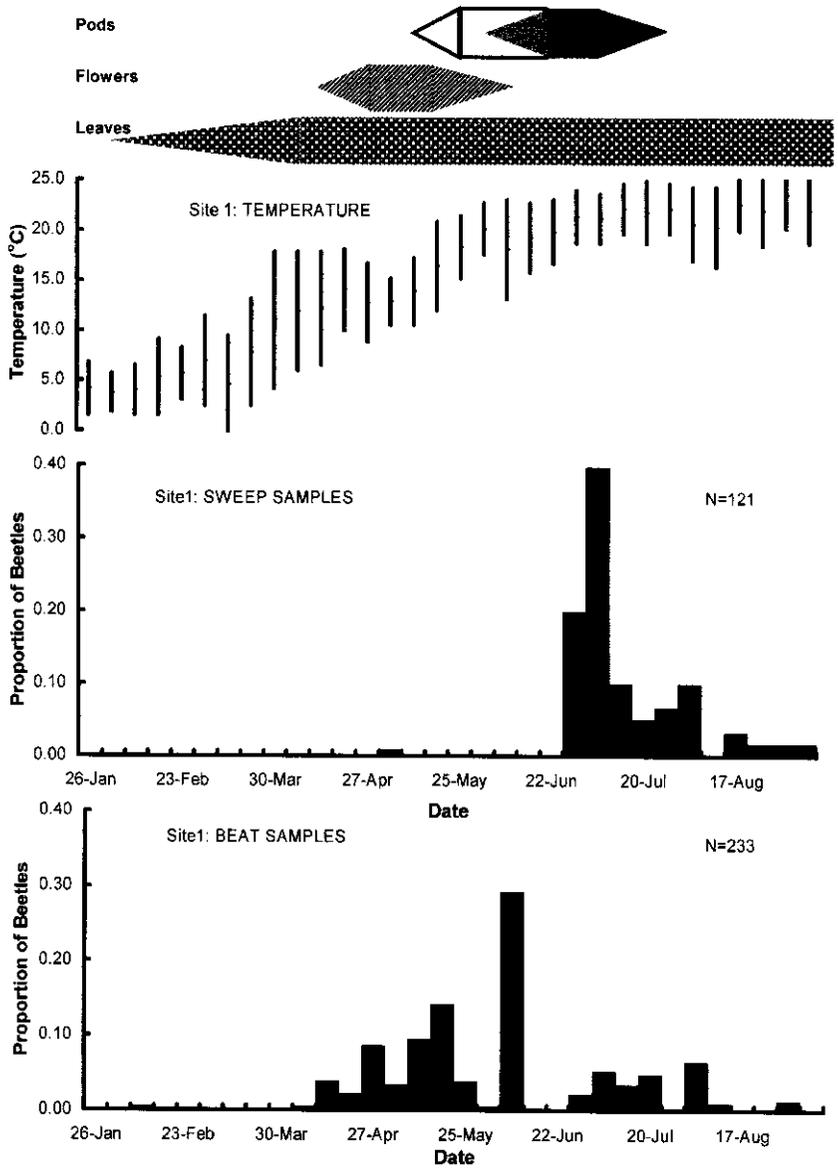


Fig. 1. Field sampling and temperature data for site 1, Asheville, NC. Bar graphs show the proportion of beetles in weekly beat samples (lower bar graph, N = 233 weevils) and sweep samples (upper bar graph, N = 121 weevils). Maximum and minimum temperatures (°C) for each week are also shown. Shaded horizontal bars at the top of the plot show the phenology of the broom plant at the site. Upper bar shows the development of seedpods, with the darker portion showing the dried dark pods. The middle hatched bar represents the presence of flowers. Lower dotted bar shows development of leaves.

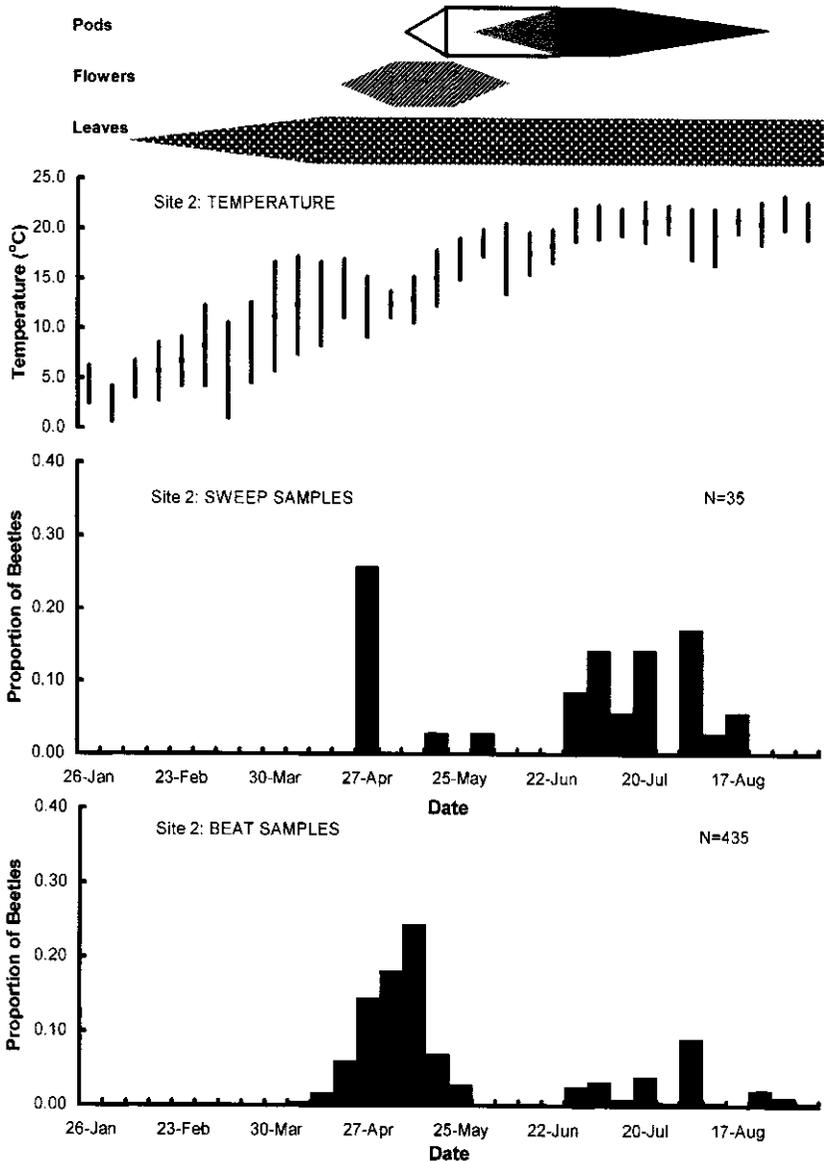


Fig. 2. Field sampling and temperature data for site 2, Asheville, NC. Bar graphs show the proportion of beetles in weekly beat samples (lower bar graph, N = 435 weevils) and sweep samples (upper bar graph, N = 35 weevils). Maximum and minimum temperatures (°C) for each week are shown. Shaded horizontal bars at the top of the plot show the phenology of the broom plant at the site. Upper bar shows the development of seed-pods, with the darker portion showing the dried dark pods. The middle hatched bar represents the presence of flowers. Lower dotted bar shows development of leaves.

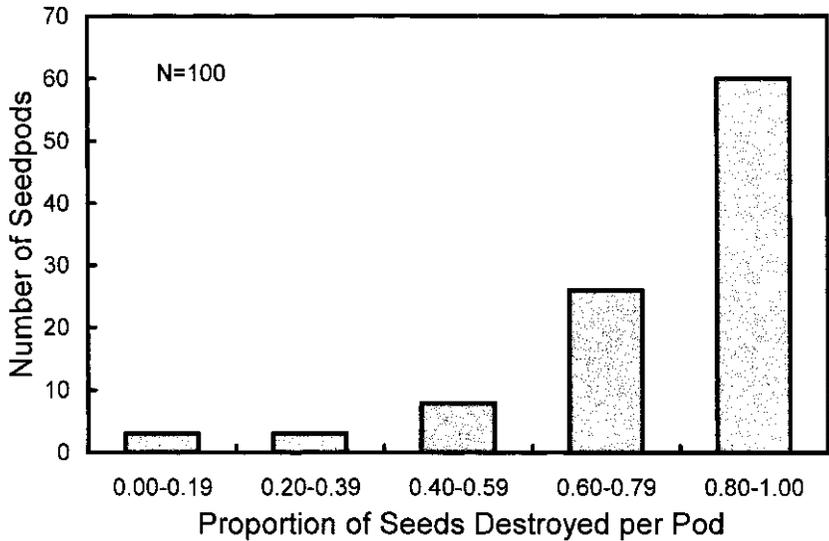


Fig. 3. Frequency distribution of seed destruction in broom seedpods by *Bruchidius villosus* in North Carolina. Each bar shows the number of seedpods found with proportions of their seeds infested with bruchid larvae or pupae. Of the seedpods examined, 86% had more than 60% of their seeds destroyed by weevils.

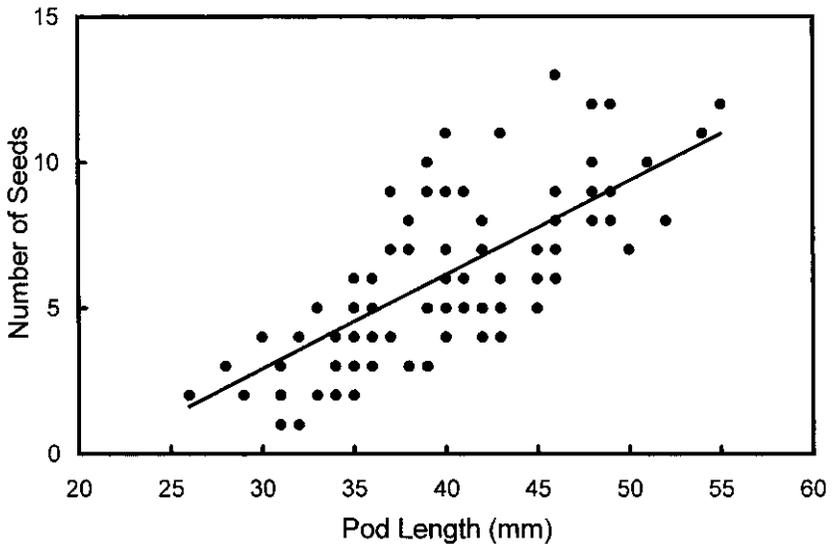


Fig. 4. Correlation between the length of the seedpod and the number of seeds within the pod for Scotch Broom. Pods ranged in length from 26 to 56 mm and larger pods tend to have more seeds ( $P < 0.0001$ ;  $r^2 = 0.53$ ). Trend line through the points is the least-squares linear fit to the data ( $Y = 0.32X - 6.79$ ).

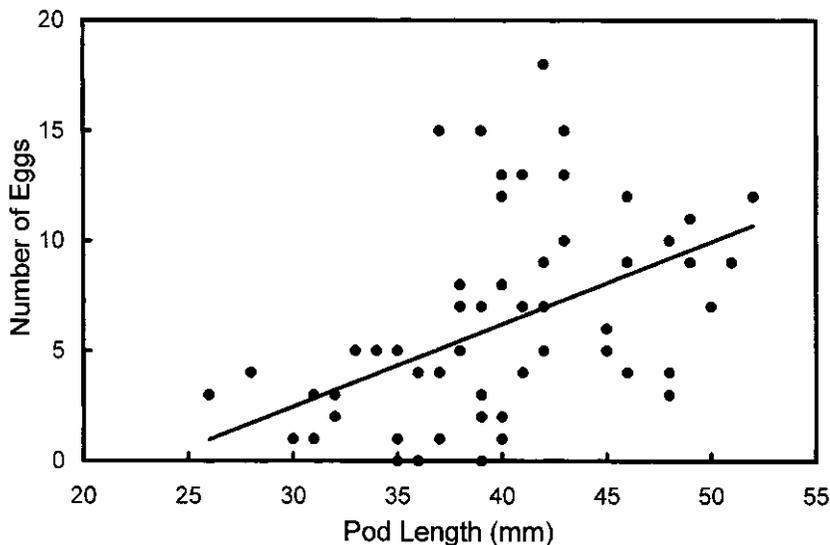


Fig. 5. Correlation between the numbers of *Bruchidius villosus* eggs laid on the exterior of seedpods and the length of the pod. Beetles laid significantly more eggs on longer seedpods ( $P < 0.0001$ ;  $r^2 = 0.23$ ). The least-squares linear fit to the data is plotted ( $Y = 0.37X - 8.72$ ).

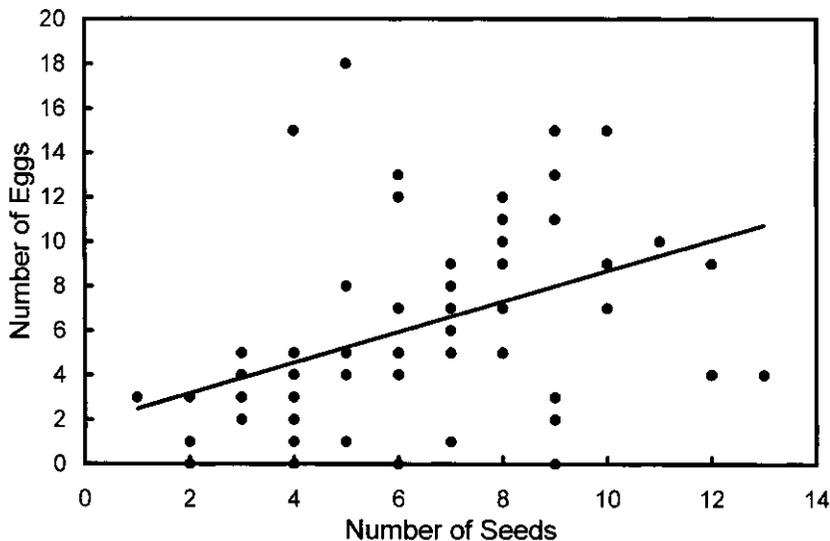


Fig. 6. Correlation between the numbers of *Bruchidius villosus* eggs on seedpods and the number of seeds within the pod. Beetles laid significantly more eggs on pods having more seeds ( $P < 0.0001$ ;  $r^2 = 0.18$ ). The trend line ( $Y = 0.69X + 1.82$ ) is the least-squares fit to the data.

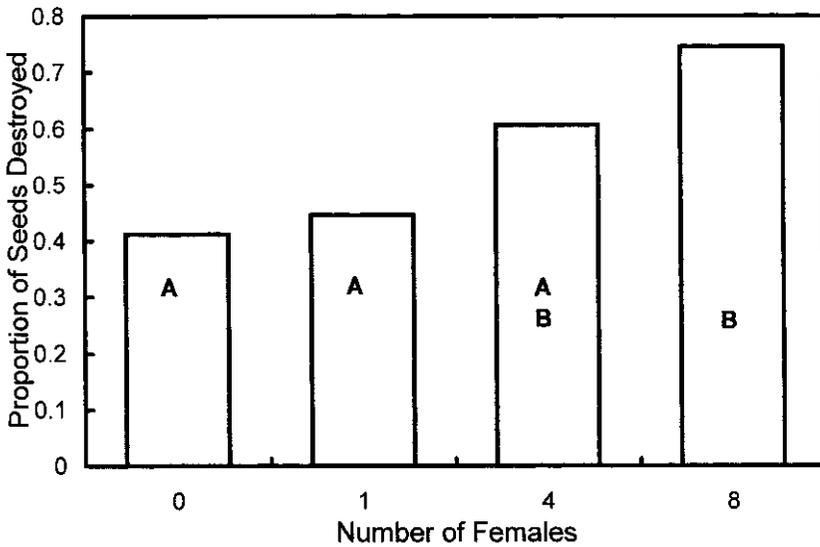


Fig. 7. Bars are the average proportions of seeds destroyed by *Bruchidius villosus* larvae when different densities of females were placed in field cages. There is a significant effect of female density on the proportion of seeds infested with bruchid larvae (ANOVA;  $F_{3,12} = 5.67$ ;  $P < 0.02$ ). Bars with different letters represent means that are significantly different (*post hoc* Tukey's studentized range test).

broom bushes in November and December the previous year. In a two-year study of *Bruchidius* in England (Parnell 1966), no beetles were discovered in large leaf litter samples. In our cage experiments more beetles were found on lids and sides of the cages under warm conditions (inside) compared with cages kept at colder temperatures (outside), suggesting that bruchids spend cold temperatures in the soil and become active if the temperature warms. Parnell (1966) found some beetles on flowering gorse early in the spring prior to the flowering of broom. The only time we collected weevils away from broom plants was later in the season. Although site 1 was densely covered in other legumes, *B. villosus* was not found in any beat samples of the vegetation surrounding the broom plants prior to or during the bloom of the broom plants. There was an increase in the numbers collected in sweep samples from vegetation around the broom plants in late June, July and August (Fig. 1). The beetles in these samples were probably newly emerged adults. Large numbers of bruchids apparently leave the host plant in late summer once they emerge from the seedpods. We still do not know where they go and how the bruchids overwinter.

#### Seasonal Abundance and Host Phenology

The phenology of the broom in North Carolina is nearly identical to that described for broom in England (Parnell 1966). Leaves bud in late January or early February. The first flowers appear in late March or early April with the first pods forming a few weeks later. The green pods begin to blacken in mid-May, and most of the pods have split and fallen from the broom plants by the end of August (Figs. 1 and 2). The weevils arrive simultaneously with the first flowering of the plant. Females have no visi-

ble fat deposits at this time and probably have used all their reserves during the overwintering period. Both sexes can be collected in flowers where they feed on pollen and nectar (see Parnell 1964). It seems likely that pollen would be used as a nitrogen (protein) source for egg yolk deposition. However, when we dissected females and examined their digestive tract, the tract was simple with no distended crop and we did not find pollen. Individual plants at our sites differed in flower set by a week or two. As the more advanced plants lose their flowers (begin to set pods), the beetles move to plants with newly opened flowers. When the seedpods are green, females deposit eggs on the outer surface.

#### Oviposition and Seed Destruction

In North Carolina, egg development within females occurs soon after females arrive at the plant. Prior to the set of pods in mid-May, ovaries were not developed and did not contain mature oocytes. Once the first pods appeared (19 May), nearly all the females collected had mature oocytes and were mated. Parnell (1966) found that all females were mature and had mated by the end of May. The number of mature oocytes we found in dissected females agreed with Parnell's (1966) description of 14 ovarioles in the ovaries. We never found more than 14 mature eggs in the abdomen of females (mean = 10), and all the mature eggs seemed to be in the same stage of development.

We found a significant relationship between the number of eggs laid on a pod and the size of the pod (length or seed number). Typically one larva requires a single seed to develop, and Parnell (1966) found that late-arriving larvae died. The first larva to reach the seed apparently prevents others from reaching and feeding on the cotyledons. Females probably can detect oviposition by other females, and the number of eggs laid is adjusted to minimize the loss of offspring due to competition within the pods. The larva hatches from the bottom of the egg where it is attached to the pod and excavates a small tunnel into the pod. Some of the tunnels can be 1 cm long before the tunnel enters the seed cavity. The destruction of the seeds by the weevils is high, over 80% at both sites. In California broom populations where *Bruchidius* does not occur, seed damage by another beetle (*Apion*) is variable and rises from 5 to 10% early in the season to 22 to 80% late in the season (Bossard & Rejmanek 1994). It seems likely that *B. villosus* could have a significant impact on seed production. However, seed destruction is dependent on the density of weevils. In cages without females, the average seed destruction was about 40% (Fig. 7), indicating that a number of eggs had hatched in some of the pods prior to our removing them for the experiment. The average increased to about 70% when there were 8 females in the cages. When we normalized the data and correlated females per seed with seed destruction, our data indicated that 1 female for every 1 to 2 seeds would be required to reach about 60 to 70% seed damage.

#### Parasitism

We do not know what stage of the bruchid is parasitized by the *Dinarmus* we found. However, the parasites apparently do not affect the bruchid until later larval stages because most of the parasitized bruchids had already consumed much of the seeds they occupied. Thus, the damage to the seeds by the bruchid will not be influenced by the activity of this parasite.

Our work shows that the biology of the North Carolina population is synchronized to the phenology of the plant and is similar to that found in Europe. Because *B. villosus* typically reduces the seed production by about 80%, this beetle is likely to have a

significant impact on broom populations. The number of eggs laid on seedpods is correlated with the size of the pods and number of seeds in the pods. Females probably distribute their eggs in an ideal manner (Fretwell 1972) to reduce competition between their larvae and those of other females. Based on cage experiments, the density of females must be fairly high to have 80% seed destruction seen in North Carolina broom stands. However, once populations of *B. villosus* reach sufficient densities they should make an important contribution to the biological control efforts directed at Scotch broom in the Pacific Northwest.

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