An analysis of the establishment and impact
of an exotic insect, *Rhinocyllus conicus* Froehling
(Coleoptera: Curculionidae),
on *Carduus nutans* L. and *Carduus acanthoides* L.
(Campanulatae: Compositae)
in Virginia
with notes on their biologies.

by

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GENERAL INTRODUCTION

The use of biotic factors in weed control has become accepted as inexpensive, efficient, enduring and ecologically sound. Huffaker (1959) cited successful examples of biological control of weeds: St. Johnswort, Hypericum perforatum L. has been reduced to less than one per cent of the former abundance in California by the activity of an imported chrysomelid, Chrysolina quadrigemina (Suffrian); Koster's curse Clidemia hirta D. Don on Fiji was so inhibited in growth by an introduced thrips, Liothrips urchi Karny, that it could no longer compete with native plants and was consequently brought under control; Prickly pears, Opuntia spp., have been controlled in Australia, India, Ceylon, Celebes, Hawaii and South Africa by a number of biotic agents. Wilson (1964) added to this list Linaria vulgaris Miller, Lantana camara and a number of other weeds which have been controlled by insects. Many projects are presently being undertaken in the field of biological weed control with further possibilities of success.

Kates (1972) stated that Carduus nutans L. and Carduus acanthoides L. infest a minimum of 150,000 acres of pasture in southwestern Virginia. [1]Of the 3,439,000 acres of pastureland in Virginia there are 1,350,000 acres in southwestern Virginia which have an annual hay value of $24,000,000.00. The state's total hay equivalent value is $96,292,000.00 which is 75% of the total forage value. Weeds are responsible for annual losses exceeding $28,000,000.00 and thistles

[1]Chappell, W. E. and R. D. Hendrick. 1968. Research proposal submitted to the Virginia Agricultural Foundation. p. 5.

are responsible for a primary portion of this loss. These two species of thistles are listed as noxious weeds in Virginia and are becoming problems to farmers whever they are found. Introduced from Europe (Fernald, 1950) to the east-central States in the early 1900's (McCarty, 1964), musk and plumeless thistles (C. nutans and C. acanthoides) are primarily a problem in pastureland. Heavy infestations exist which are impenetrable to grazing livestock, and areas with lesser densities are regarded as undesirable pasture. Livestock avoid thistle plants and much valuable pasture is unused. Feldman et al. (1968) showed that a single thistle plant has the potential production of 3,000 viable seeds. Thus one can visualize the possible spread of infestation if control is not applied.

The initial work on insect control of C. nutans and C. acanthoides began with the Commonwealth Institute of Biological Control (C.I.B.C.). Helmut Zwolfer of the European Station (Delemont, Switzerland) and Peter Harris of the Research Institute (Belleville, Ontario, Canada) combined their resources for work on the early phases of thistle control and are presently continuing their research. These workers completed the required host specificity, preference and phenology tests on a head infesting weevil, Rhinocyllus conicus Froel., and in 1968 they released the insect in Canada (Harris and Zwolfer, 1971).

In 1968 the V. P. I. & S. U. Entomology Department began the present biological thistle control project. [2]Harris was visited in

[2]Hendrick, R. D. 1971. Biological control of musk and curl thistle in Virginia, a progress report and evaluation, 1968-1971. Unpublished document. 1 - 6.

Canada, and the status of thistle research at the Belleville Research Station was reviewed. R. conicus had recently been cleared for introduction into Canada and colonies had been established. The colonies were examined, and test data was obtained in order to petition for release of the insect in Virginia.

Permission for release of R. conicus was received from the Plant Quarantine Division, USDA, in Washington, D. C. in early 1969. In March of 1969 Zwolfer was visited at Delemont, Switzerland, and agreements were made to have colonies of R. conicus shipped to V. P. I. & S. U. Various shipments were received but mortality was heavy. However, colonies of R. conicus were established in Pulaski Co., Va. and Russell Co., Va. in May of 1969. In July, 1970 a large stock of weevils was received and many sites were inoculated. The 1969 Pulaski site and three 1970 sites were chosen for the work undertaken by the author.

The objectives of the present study are to:

1) examine the extent of the thistle problem by actual observation and extensive literature reviews.
2) establish the feasibility of using R. conicus as a biological control agent by:
    a) determining the fecundity of the weevil under controlled laboratory conditions which will offer insight into the biotic potential of the insect.
    b) observing seasonal life history of R. conicus at Pulaski, Va. as a possible explanation of success and failure at various

other release sites.

c) evaluating establishment and dispersal of the insect at three sites representing three unique ecological situations.

d) measuring the destructive ability of R. conicus larvae within C. nutans capitula.

e) evaluating mortality factors as limiting conditions for success or failure of R. conicus release.

I. LITERATURE SURVEY

1. The Genus *Carduus*

The genus *Carduus* of the Cynareae tribe (Compositae) is estimated to be composed of approximately 120 species (Mulligan and Frankton, 1954), none of which is native to North America. Fernald (1950) recognized three species of *Carduus* as occurring in North America. *Carduus nutans* L., *C. acanthoides* L. and *C. crispus* L. have been recorded. However, *C. crispus* is not presently listed as a pest species in North America and will not be considered further in the text of this paper.

Arenes (1949) completed the most recent work on the genus *Carduus*. The description given by Mulligan and Frankton (1954) was in agreement with Arenes. In general, *Carduus* spp. are herbaceous biennials (and/or annuals depending upon local climates) with the following characteristics: stems bearing spiny wings; leaves conspiciously decurrent, spiny; heads clustered or solitary; phyllaries (bractlets of the head) are in many rows, imbricated, and usually spine tipped; florets tubular and perfect, usually purple; achenes oblong, with shallow longitudinal grooves, glabrous; pappus having many rows of naked (not plumose) hairs. The plants were cited by Fernald (1950) to reach heights of one meter.

Simple pappal hairs differentiate *Carduus* genus from the closely related *Cirsium*, true thistle, which are also found in North America (Fernald, 1950).

Carduus thistles were called plumeless thistles by Fernald (1950), but this term was also used to specifically designate *C. acanthoides* L.

(Mulligan and Frankton, 1954 and McCarty, et al. 1969). Fleetwood's (1964) and Higgins' (1966) reference to Carduus nutans as plumeless thistle reflects the possible confusion which can develop unless parameters are defined. The Weed Society of America (1962) has standardized the term, plumeless, as the accepted common name for C. acanthoides L. Further references in this manuscript will concur with the Weed Society.

There are no accurate records as to how Carduus thistles arrived in North America, but it is most probable that they were imported with livestock, birdseed and agricultural seeds that had been shipped from the thistle's native range.

Fowler (1878) reported C. nutans spreading from ballast at Chatham, New Brunswick, Canada. Mulligan and Frankton (1954) suggested that C. nutans was introduced into Saskatchewan, Canada in rape seed from Argentina. In instances of known histories of invasions, Carduus seeds have been transported in livestock bedding and in the hair of animals. [3]William Kegley (1972) of Pulaski, Virginia related how the initial infestation of C. nutans occurred on the farm which he recently purchased. Approximately sixteen years ago (1956) a Pulaski farmer received a shipment of cattle from the mid-west where thistles were in abundance at that time. The bedding was removed from the truck in which the cattle were transported and placed in a localized area. The following year the bedding refuse produced a dense population of thistles (C. nutans). No efforts were made by the farm owner to

[3]Kegley, W. 1972. Oral communication.

destroy the "beautiful flowers," and consequently they spread rapidly from this original innoculative site. C. nutans now infests all of the pasture on the Kegley farm and the pasture-land of the other farmers throughout the area.

Originally Carduus thistles were found only in Europe, Asia and North Africa (Wunderlin, 1969). Doing et al. (1969) recorded Carduus from North and South America, New Zealand and Australia as sites of introduction. They have been recorded in Canada as well as in the U. S. C. nutans or C. acanthoides are recognized as pest weeds throughout many of the livestock areas in the U. S., but accurate records of complete distribution are not available. The distribution will be given later for each of the two species.

Doing et al. (1969) reported that Carduus seeds were found regularly in samples of grass seeds from New Zealand and the United Kingdom when the seeds were analyzed at the seed testing laboratory of the Australian Department of Agriculture, Sydney, Australia. No doubt the weed seeds are offered world-wide dispersal by sale of seeds from infested areas. According to Feldman et al. (1968) if a single seed was allowed to germinate, it could potentially produce approximately 3,000 progeny. To further complicate the pest problem, seeds produced by Carduus thistle are transported by tiny "parachutes" of pappal hairs which I have observed traveling hundreds of yards. Dispersal of a mile or further seems very plausible if wind conditions are favorable. When one considers that just a single viable seed is sufficient to establish a colony and infiltration of a mile radius can occur in just one year, the pest qualities of *Carduus* can easily be comprehended.

A. Carduus nutans and C. acanthoides as noxious weeds

Braccini (1941) recognized these weeds as worthless forage for any livestock long before they became pests in the United States. The rosette of musk thistles smothers out pasture and crop plants; as mature plants *C. nutans* reduces the area available for grazing of stock; interferes with harvesting of crops, and lowers the value of hay and wool (Leonard, 1964). Kates (1968) stated that the weed's spiny character prevents cattle from grazing too close to it. In 1972, Kates added to his previous statements: "One thistle plant to 16 sq. feet (2722 per acre) reduced pasture yields an average of 23% or 570 lbs. of dry foliage per acre."

Many states have mandatory weed control laws. Specific weeds are legislatively declared as "noxious" and placed on a list for state enforced control. Musk thistle prompted Nebraska to adopt the first mandatory weed control laws in 1966 (Carlson, 1968). *C. nutans* was recognized as a noxious weed in Virginia in 1966. (Acts of the General Assembly of the Common. of Va.,1966).

Although *C. acanthoides* L. does not have the historical significance that musk thistle has, it is considered a very undesirable plant. Virginia recognizes plumeless thistle as a noxious weed. The nature of *C. acanthoides*' effect on the productivity of pasture is equivalent to that of *C. nutans*.

B. Traditional control measures

A number of methods to control *C. nutans* have been developed following the recognition of the weed as a pest. Mechanical, cultural, and chemical control have proven limited in their ability to cope with the musk thistle problem. The merits and inadequacies of these preceeding systems should be acknowledged.

a. <u>Mechanical control</u>: Mechanical control of weeds in its simplest form is the use of a hoe, shovel or sythe to destroy the plant. Practicality in using this method should be considered. The use of a hand device is recommended on a small scale but can hardly be expected to handle a problem surpassing the magnitude of 150,000 acres in Virginia alone (Kates, 1972). On a large scale tractors are used to mow and clip thistles. The disadvantages here are threefold:

1. it is expensive.
2. the best time for clipping thistles is just before the blooms develop. Unfortunately at this time a farmer is usually swamped with other higher priority work.
3. certain areas where thistles grow in rough or steep terrain are not negotiable by any form of machinery.

Mechanical control is practical but not applicable to all situations.

b. <u>Cultural control</u>: <u>Carduus</u> <u>nutans</u> L. is not a highly competitive plant (McCarty and Scifres, 1969), and it would be practical to capitalize on this characteristic of the weed. Musk thistle is found growing most favorably on abused land (Harris and Zwolfer, 1971). Bare soil is needed for the seeds to develop; therefore, good thick stands of forages will help in the weed control programs (Kates, 1972; McKellar, 1955). Overgrazing or abuse of any other nature may permit the establishment of dense stands of thistle. Control will not be complete or reasonable if the land on which the infestation occurs is not properly maintained.

c. Chemical control: Voluminous accounts have been published regarding the chemical control of musk thistle. A number of chemicals have been tested and described as effective. Most researchers favor 2,4-D as a means of chemical control (Freeman, 1957; Delahunty, 1961; Teel, 1963; Higgins, 1966; Feldman and McCarty, 1967; Iowa State Coop. Extens. Serv., 1968; and Kates, 1968). Feldman *et al.* (1968) found that 2,4-D gave excellent control in Nebraska when applied in early spring (April 30 and May 10); however, spring spraying may be hazardous in terms of damage to desirable plants (Kates, 1972). Higgins (1966) and Kates (1972) recommended late fall applications of 2,4-D for best results. During these periods the most active and vulnerable physiological stages of *Carduus* are found. Following stalk elongation, tolerance to 2,4-D is increased.

Although 2,4-D is most universally recommended, picloram and dicamba consistently gave the best results not only on April 30 and May 10 but also on April 20 and June 1 (Feldman *et al.*, 1968). McKellar (1955) stated that the "water base salts of MCP are preferable to those of 2,4-D." MCPA and MCPB were recommended by Delahunty (1961) and Leonard (1964). Feldman *et al.* (1968) did not evaluate MCPA or MCPB. There is need for further comparative studies.

Teel (1963) commented that best results are obtained when entire areas are treated chemically. Spot treatments are inferior and practically useless due to the influx of seeds from adjacent areas and dormant seed in the soil, combined with many of the thistles behaving as biennials. Treatments must be applied over a series of seasons as the seeds remain viable for a number of years (Kates, 1968). Personal observations indicate that although timing of chemical application has been determined to be most successful in the plant's early stages of development, applications are not always properly administered. On August 12, 1971 sprayers were observed applying herbicides in Frederick Co., Va. Plumed seeds were obvious and achenes were being blown away by the wind produced by the applicator. The thistle plants had completed reproduction and were beginning to die. Therefore, the chemical treatment was absolutely worthless.

The use of chemicals to control C. nutans has proven to be effective; however, considering the vast acreage of thistle infestations it could be a very expensive method. Marginal land is rarely treated - the expense outweighing the benefits; therefore, an infested marginal area acts as a source of inoculum for adjacent areas. Infestations which are not accessible to the standard spraying equipment have to be treated by hand or by aerial means, methods which would entail extraordinary expense. Therefore, such badly infested areas go untreated.

Chemical control is not the universal panacea. It is limited in its application as are its contemporary methods, cultural and mechanical control in that they are expensive, temporary and must be universally applied.

The control of _Carduus nutans_ as previously discussed is applicable to plumeless thistle with the following exception. _C. acanthoides_ is more tolerant of herbicides and requires a higher rate of chemical application (Kates, 1968).

Plumeless has not yet acquired the national notoriety that musk thistle has, consequently there has been a lesser amount of research on its control. Although chemicals have a lesser effect on this hardy weed, mechanical and cultural controls have a virtually identical effect on the two species.

C. Carduus nutans

i. Introduction

Doing et al. (1969) recognized four subspecies of Carduus nutans L. C. nutans ssp. nutans is considered to be the most universally distributed subspecies. They do not consider C. nutans present in the United States. The plant that Americans know as C. nutans is termed C. thoermeri ssp. thoermeri by Doing. A number of workers in the United States identify our plant as C. nutans, and no records of C. thoermeri have been found in North American literature. Consequently, it is assumed that C. thoermeri is a species which has been split from C. nutans.

Wunderlin (1969) differentiated between two varieties of C. nutans. C. nutans L. var. leiophyllus (Petronic) Arenes has glabrous leaves, heads 4.4 - 5.3 cm in diameter, and glabrous phyllaries except for minute hairs on the upper surface. C. nutans var. nutans has pubescent leaves, heads 1.1 - 3.9 cm in diameter and phyllaries with white, cobweb-like hairs.

In this paper the term Carduus nutans refers to the C. nutans group of Wunderlin (1969). No attempts have been made to identify plants below the species level.

ii. Terminology

Carduus nutans L. is known by a number of common names. The most frequently encountered term for C. nutans is "musk thistle" which refers to the sweet odor associated with the blossom (Iowa State University, Cooperative Extension Service, 1968). "Nodding thistle" (Fernald, 1950;

Doing et al, 1969; Delahunty, 1961; Leonard, 1964 and Lacefield and Gray, 1970) is the name preferred by Australian and New Zealand workers but is also found in use by Americans and Europeans. "Nodding" refers to the characteristic large, single, heavy heads which bend the stem and "nod" in the breeze. The plant has also acquired a new name in Virginia. Some farmers call it "smart thistle" in regards to a characteristic the plants exhibit. When clipped, C. nutans will often bolt again (usually a number of smaller, lateral bolts) and quite frequently the plant will bolt a third time if clipped again. Each successive stem is lower and eventually the thistle will bloom only inches from the ground and safe from standard mowing equipment; hence the name "smart thistle." In agreement with the accepted terminology of the Weed Society of America (1962) the term musk thistle will be used in further reference to C. nutans in this manuscript.

iii. Description

Fernald (1950) described C. nutans L. as: "biennial, 0.4 - 1 m high; heads solitary, hemispherical, nodding, 3 - 5 cm. broad, showy on long partly naked peduncles; phyllaries lanceolate, the outer reflexed."

Musk thistle has a single tap root which is large, fleshy, corky, and hollow near the ground (Nebraska Department of Agriculture, 1971). Reproduction occurs by seed, not by vegetative propagation from roots as does Canadian thistle, Cirsium arvense (L.) Scop. (Sagar and Rawson, 1964 and Hodgson, 1971).

McCarty et al., (1969) described the achenes of C. nutans. "The achenes are about 2 by 4 mm, weigh 0.4 g/100 and displace 0.004 cc/achene. They are light tan with dark brown striations on the longitudinal axis. The achenes are attached to long strands of nonbranched pappus."

There are observations in this manuscript regarding the ready transportation afforded musk thistle achenes by their pappus. Delahunty (1962) differed with this common assumption. Following extensive wind tunnel studies Delahunty found that the pappus and seed are very poorly attached upon maturity. Consequently, lengthy transportation is not favored, and most seeds fall in the immediate vicinity of the parent plant. However, Delahunty conceded that many achenes were transported great distances by the pappus. The latter observation could easily refer to thousands of seeds; therefore, dispersal by this means should be considered as an active means of transport.

The leaves of C. nutans are dark green with light green midribs - most have a white margin. They are alternate, smooth, coarsely lobed, with three to five points per lobe and are wavy in appearance (Nebraska Department of Agriculture, 1971).

Musk thistle thrives on calcareous soils (deWit, 1967) and waste lands (Teel, 1963). It will become established wherever ground cover is disturbed, and competition is at a minimum (Feldman et al., 1968). Infestation occurs in both low fertility and richly-fertilized land. Doing et al. (1969) described C. nutans as a pioneer plant in disturbed environments on calcareous, sandy or loamy material enriched in nitrogen. Thistles occur in a high degree of establishment in a site rich in nitrogen and completely free of competing foliage. The initial heavy infestation of *C. nutans* frequently is an area which was previously covered with cow manure, that had been removed from a local barn. The waste material smothers the grass and greatly enriches the soil with nitrogen. Musk seeds which had been present in the area germinate and thrive in this new situation. Several sites of this nature are obvious on Bill Kegley's farm in Pulaski Co., Virginia.

iv. Distribution

Doing *et al.*, (1969) have researched the most recent world-wide distribution of *C. nutans*. Musk thistle is found throughout the United States, Canada, central South America, Europe, North Africa, western Asia, New Zealand and Australia. It has been known from the United States for over fifty years (Wilson, 1968).

No comprehensive records for state-wide distribution of *Carduus nutans* exist. The following distributional citations do not presume to be complete, but they are presented as references to what is presently found in the literature regarding distribution. The Iowa State University's Extension Service (1968) listed *C. nutans* as being found in the eastern United States, ranging from New Brunswick and Quebec to Pennsylvania, Missouri, Nebraska and Iowa. Wunderlin (1969) recorded *C. nutans* as occurring in spotty infestations in Illinois. Shaver (1957) recorded it as rare in Tennessee. Nebraska has listed musk thistle as a noxious weed since 1959 (McCarty *et al.*, 1969). In 1963 Kansas declared *C. nutans* a pest species (Teel, 1963). The available literature does not record the complete range of *C. nutans* in the United

States. It must be widely distributed throughout the plains if it has already established the role of noxious weed in Nebraska and Kansas.

Kates (1968) gave the range of C. nutans in Virginia as depicted in Fig. 1. He noted that as much as 80% of the pastureland in some areas is infested with musk and curled thistles. The distribution of musk thistle is not uniform throughout the area which is known to be infested. I have found extremely heavy infestations of C. nutans in the following counties in Virginia: Frederick, Loudoun, Montgomery, Pulaski, Giles and Warren counties. Personal observations indicate spotty infestations elsewhere in the state, but uniformity of infestation intensity appears to be greatest in the preceding counties.

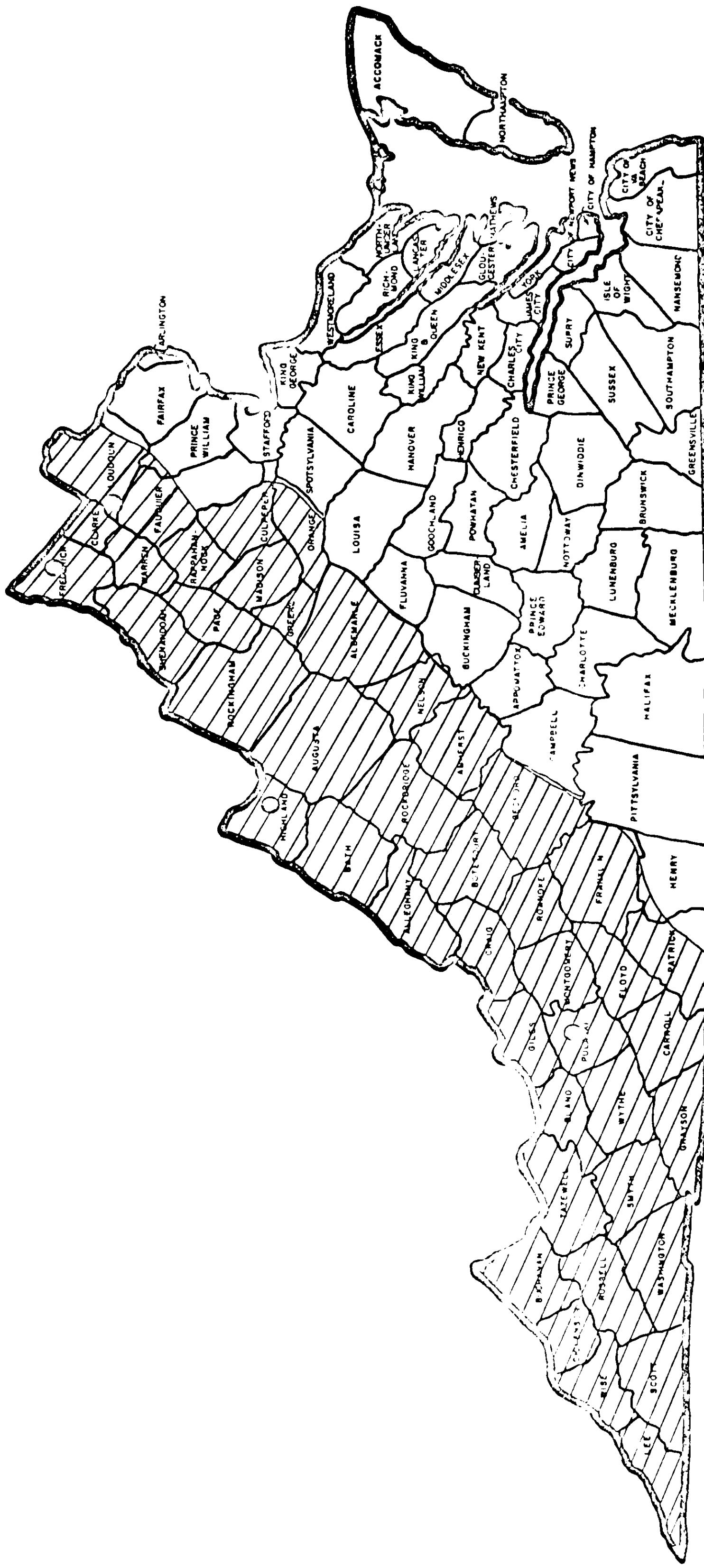
v. Life cycle

Carduus nutans L. has been described as a biennial (Fernald, 1950; Doing et al., 1969 and Fuller, 1969), as a biennial or an annual (McCarty, 1964), and as a summer or winter annual or biennial (McCarty and Scifres, 1969). McCarty and Scifres (1969) completed an extensive study in which they concluded that in southeastern Nebraska musk thistle rarely grows as an annual but usually behaves as a biennial or winter annual. Lacefield and Gray (1970) found McCarty and Scifres' (1969) work to be accurate also for C. nutans in Kentucky. In Virginia, Kates (1968) listed musk thistle as a biennial which occasionally behaves as an annual.

Feldman et al., (1968) stated that an average C. nutans plant produces 10,000 to 11,000 seeds of which one-third may be plump and properly filled, having a 93 to 95% germination. Nilson (1968)

Figure 1. Distribution of _Carduus_ _nutans_ L. and _Carduus_ _acanthoides_ L. in Virginia (from Kates, 1968).

(Study areas are indicated by ⊙)


ACCOMACK
NORTHAMPTON
CITY OF HAMPTON
CITY OF VA BEACH
CITY OF CHESAPEAKE
NANSEMOND
ISLE OF WIGHT
SURRY
SOUTHAMPTON
SUSSEX
PRINCE GEORGE
GREENSVILLE
DINWIDDIE
BRUNSWICK
MECKLENBURG
LUNENBURG
NOTTOWAY
AMELIA
CHESTERFIELD
HENRICO
CHARLES CITY
JAMES CITY
YORK
NEW KENT
GLOUCESTER
MATHEWS
MIDDLESEX
KING & QUEEN
KING WILLIAM
ESSEX
RICHMOND
NORTHUMBERLAND
WESTMORELAND
KING GEORGE
CAROLINE
HANOVER
SPOTSYLVANIA
STAFFORD
PRINCE WILLIAM
FAIRFAX
ARLINGTON
LOUDOUN
CLARKE
FREDERICK
FAUQUIER
WARREN
SHENANDOAH
CULPEPER
RAPPAHANNOCK
MADISON
ORANGE
LOUISA
GOOCHLAND
POWHATAN
CUMBERLAND
FLUVANNA
BUCKINGHAM
PRINCE EDWARD
CHARLOTTE
HALIFAX
APPOMATTOX
CAMPBELL
PITTSYLVANIA
HENRY
PAGE
GREENE
ALBEMARLE
ROCKINGHAM
AUGUSTA
NELSON
AMHERST
ROCKBRIDGE
HIGHLAND
BATH
ALLEGHANY
BOTETOURT
BEDFORD
FRANKLIN
ROANOKE
CRAIG
MONTGOMERY
FLOYD
PATRICK
CARROLL
GILES
PULASKI
BLAND
WYTHE
GRAYSON
SMYTH
TAZEWELL
BUCHANAN
RUSSELL
WASHINGTON
WISE
SCOTT
LEE

reported a range of 1 to more than 100 heads per plant. Lacefield and Gray (1970) extended this range up to 561 heads per plant with a maximum production of over 120,000 seeds. Variations exist in accordance with local habitats, but the vast number of seeds produced illustrates the potential reproductivity of _C. nutans_.

D. Carduus acanthoides

i. Introduction

The literature available on *Carduus acanthoides* L. is much less voluminous than references on *C. nutans*. In most instances the biology, ecology, history, emigration, dispersal and control of *C. acanthoides* coincides with the description given for *C. nutans*. Discrepancies will be delineated when possible.

Mulligan and Frankton (1954), and Fernald (1950) described *Carduus acanthoides*. Their descriptions have been reviewed by the author to verify the identification of study plants. The former publication identifies the Canadian *C. acanthoides* as var. *acanthoides*. Fernald's description fits the characteristics of the thistle found in Virginia. The very common *C. acanthoides* var. *acanthoides* has a typically purple bloom. It exists in two other forms which are designated by their flower color. Forma *albiflora* (L.) Gross, is white and forma *ochranthus* Wallr. produces a creamy yellow bloom (Hegi, 1918). Forma *albiflora* has been collected by the author at the V. P. I. & S. U. Shenandoah Valley Research Station at Steele's Tavern, Virginia in July 1972 (Fig. 2), but forma *ochranthus* has not been observed in the study areas. The plant which occurs in our study areas is *Carduus acanthoides* L. var. *acanthoides* in accordance with the description given by Mulligan and Frankton (1954). Any future reference in this manuscript to *C. acanthoides* will imply that it is var. *acanthoides*, and not one of the variant color forms.

Figure 2. *Carduus acanthoides* var. *acanthoides* forma *albiflora* (L.) Gross, observed at the V.P.I.& S.U. Shenandoah Valley Research Station at Steele's Tavern, Virginia (July, 1972).

ii. Terminology

Fernald (1950) did not give a common name for Carduus acanthoides L. Kates (1968 and 1972) used the term curled thistle. Mulligan and Frankton (1954) and McCarty et al. (1969) referred to C. acanthoides as plumeless thistle. Harris and Zwolfer (1971) preferred the term welted thistle, although Mulligan and Frankton (1954) used this term in reference to Carduus crispus L. Iowa State University's Extension Service (1968) referred to C. acanthoides as curled and plumeless thistle. The Weed Society of America (1962) has standardized plumeless as the preferred common name. This term will be used in future references to C. acanthoides.

iii. Description

Fernald (1950) gave the following description for Carduus acanthoides L.: "annual or biennial; heads erect, single or clustered at tips of spiny-winged branches; involucre hemispherical, 1.5 - 2.5 cm in diameter; phyllaries linear, the outer more or less herbaceous and spreading; corolla about 18 mm long."

The height achieved by C. acanthoides has not been observed to equal that of C. nutans L.; however, plants 6 to 7 feet tall have been observed. The most easily recognized traits for separating C. nutans and C. acanthoides are depicted in Figs. 3 and 4. C. acanthoides has a winged branch going all the way up to the blooms which are smaller than musk blooms and usually occur in clusters (Fig. 4). C. nutans has a bare stem supporting solitary blooms (Fig. 3).

Plumeless thistle achenes are 1 by 3 mm, weigh 0.2 g/100 and have

Figure 3. Carduus nutans L.

Figure 4. Carduus acanthoides L.

a volume of 0.0024 cc/achene. Striations on the longitudinal axis of plumeless thistle achenes are not as prominent as in musk (McCarty et al., 1969). It is assumed that available seed transportation provided by the pappus of C. acanthoides is very similar to that previously discussed for C. nutans.

C. acanthoides leaves are like musk thistle leaves, but are narrower, more deeply lobed, more finely divided and their undersides are hairy (Nebraska Dept. of Agriculture, 1971).

Ecological considerations for Carduus acanthoides coincide with those of C. nutans except for the following points. Moore and Mulligan (1956) and Fuller (1969) agreed that C. acanthoides exhibited a preference for well-drained, sandy loam, while C. nutans is found to grow more favorably in low lying grassy pastures having heavier soil and a higher moisture content. Mulligan and Frankton (1954) agreed that C. acanthoides grows best in well-drained areas which occur over limestone and shale substrates. They also commented that plumeless thistle grows well in the vicinity of gravel pits. Personal observations are in agreement with the latter authors. C. acanthoides has been found growing out of slag from limestone quarries (Fig. 5) and rocky shale areas which supported no other plants (Fig. 6). Plumeless thistle appears to spread much slower than musk thistle but being similar to musk in habit it is considered a serious threat (Nebraska Dept. of Agriculture, 1971).

iv. Distribution

The distribution of C. acanthoides L. is not well documented, but it is known to occur in Europe (Fernald, 1950). Its original range

Figure 5. *Carduus acanthoides* L. growing in slag from limestone quarry (Frederick Co., Va.; July, 1972).

Figure 6. *Carduus acanthoides* L. growing in rocky shale (Rockingham Co., Va.; July, 1972).

probably coincides with that of _C. nutans_.

In North America _C. acanthoides_ is reported by Fernald (1950) to occur from Nova Scotia to Nebraska and south to Virginia and Ohio, but it is regarded as being only sporadic. Mulligan and Frankton (1954) documented the collection of plumeless thistles in the Canadian provinces of Nova Scotia, Quebec, Ontario and British Columbia. Harris and Zwolfer (1971) quoted the same Canadian distribution. The Nebraska Department of Agriculture (1971) reported _C. acanthoides_ as occurring in the eastern part of Nebraska in localized areas of heavy infestation.

Kates (1968) gave the range of plumeless thistles as coinciding with the distribution of _C. nutans_ (Fig. 1). Personal observations throughout this range find it better established in mountainous, rocky areas with poor soil and other areas where competition is minimal. Plumeless thistle has been found in heavy sporadic infestations throughout Western Virginia.

v. Life cycle

The life cycle of _Carduus acanthoides_ L. is assumed to be very similar to _C. nutans_ L. but the following differences are evident. Plumeless thistles do not grow as tall as musk thistles and their blooms are not as large; however, they produce clusters of blooms which appear to outnumber those produced by _C. nutans_. No comparative documentation of seed production has been discovered in the literature. _C. acanthoides_ does not bloom as early as _C. nutans_, but it continues to bloom for a longer period of time. In other respects plumeless and musk thistles are very similar in their life cycles.

E. Natural hybridization between *Carduus acanthoides* and *C. nutans*

There have been a series of papers published on the natural hybridization between *Carduus acanthoides* L. and *C. nutans* L. Moore and Mulligan (1956) were the first to recognize this cross in North America as it occurred in Grey County, Ontario, Canada although it had been known in Europe for many years. They followed up their original paper with three articles (Moore and Mulligan, 1958 & 1964; Mulligan and Moore, 1961). In 1962 Moore and Frankton published an account of hybridization occurring in the tribe Cynareae, and in 1969 Fuller summed up all of the previous researchers works with an extensive computerized study in Nebraska.

All of the literature cited agrees on a central theme - *Carduus acanthoides* and *Carduus nutans* have different chromosome numbers, ie. *C. acanthoides* L., 2N = 22; *C. nutans* L., 2N = 16. In sites where hybridization occurs all intervening numbers of chromosomes are found. There is a clear correlation between chromosome number and hybrid indexes, in that hybrids similar to the one parent species were shown to have a chromosome number approaching that of the parent plant which they resembled (Moore and Mulligan, 1956).

Mulligan and Moore (1961) showed that there is a numerical supremacy of *C. acanthoides*-type hybrids in a hybrid area, and such hybrids are more adapted for survival. Ecological and gametic selection appears to be favoring production of plants with the morphology and gametic structure of *C. acanthoides*.

It is quite apparent in areas where both species of thistle occur in Virginia that there has been natural hybridization. No attempts were made in the studies of this manuscript to count chromosomes. Many study areas in Virginia produced plants which superficially did appear to be hybrids. In the control of these two noxious weed species hybridization may well explain many descrepancies.

2. *Rhinocyllus conicus*

A. Introduction

After extensive unrewarding attempts to control musk and plumeless thistle in Virginia by conventional means, it was decided that the problem was well suited for a biological control project. Since both thistle species were introduced from Europe, their success is primarily attributed to the lack of natural parasites, which limit density and dispersal in their home range. No North American biotic factors have adapted to the plants sufficiently to act as controlling factors.

A logical first step toward establishing biological control is to examine the insects attacking them in their native areas. H. Zwolfer (1965) published a listing of phytophagous insects attacking these weeds in Europe. A number of these insects have been considered as possible candidates for release in Virginia. [4]Coulson (1972) recently compiled a list of insects associated with *Carduus* thistles. *R. conicus* was the first insect released in Virginia as a potential biological control agent against *C. nutans* and *C. acanthoides*. Zwolfer (1967) published a comprehensive literature review.

[4]Coulson, J. R. 1972. Insects associated with *Carduus* thistles. U. S. D. A., Ent. Res. Div. Beltsville, Maryland (Xeroxed copy received June 8, 1972).

B. Background research leading to the release of *Rhinocyllus conicus* in Virginia

After a lengthy, voluminous series of tests by Zwolfer (1967 and 1969), H. Zwolfer and P. Harris of the C. I. B. C. were granted clearance for the release of the head-infesting weevil, *R. conicus*, in Canada. In July 1968 it was released on *Carduus acanthoides* near Belleville, Ontario and *C. nutans* near Regina, Saskatchewan. Successful establishment was obtained at Regina (Harris, 1971).

[5]Beginning July 1, 1968 the Virginia Agricultural Foundation funded project number 808171 - 0 to be supervised by W. E. Chappell and R. D. Hendrick of V. P. I. & S. U. over a three year period. [6]Initiation of this project began with a trip to the Biological Control of Weeds Project at Belleville, Ontario, Canada. P. Harris was consulted regarding *R. conicus*. Testing data for the weevil were obtained and the insect was observed in a nearby release site. Using the testing data obtained from P. Harris, a request to introduce the weevil into Virginia was submitted to the Plant Quarantine Division, U. S. D. A., Washington, D. C. Permission to release *R. conicus* was granted in early 1969.

In March, 1969 foreign stations were visited to review the work being done on the biological control of thistles. During this tour H. Zwolfer was visited at Delemont, Switzerland. An agreement was made in which Zwolfer would collect and ship *Rhinocyllus conicus* to

[5]Chappell and Hendrick, (1968), 1 - 11.
[6]Hendrick. 1971. 1 - 8.

V. P. I. & S. U. for repayment of costs involved.

In late May, 1969, 800 Rhinocyllus conicus, collected near Munchhouse, France, arrived from Zwolfer's station. Two hundred weevils survived the shipment and these were released in two groups of 100 each - one at Bill Kegley's farm in Pulaski Co., Virginia on C. nutans and the second on Turner Gilmer's farm in Russell Co., Virginia on C. acanthoides. Establishment was later observed to be successful at both sites.

Later shipments arrived in 1969 and were released in groups of 100 - 200 with little success. In July of 1970 a shipment of 8,800 R. conicus were received from Delemont. These weevils had been collected in the French Rhine Valley. They were released in groups of 450 - 1,000 at suitable sites and they achieved spotty success in establishing colonies.

In May 1971 a shipment of 1200 R. conicus arrived from Rome. Being delayed in shipment and already physiologically active the insects suffered heavy mortality (approximately 90%). These weevils were released on C. acanthoides in Roanoke, Virginia. This was the last European shipment received at V. P. I. & S. U.

C. Taxonomic position of *Rhinocyllus conicus*

Zwolfer (1967) summarized the taxonomic status of *R. conicus*. *Rhinocyllus* (subfamily Cleoninae, family Curculionidae) was grouped by Hoffman (1954) together with five other genera into the tribe Lixini. Csiki (1934) had previously placed *Rhinocyllus* in the tribe Rhynocyllini, incorporating itself and the genus *Bangasternus*. Reitter (1921) had provided the basis for establishing Rhinocyllini by showing that *Rhinocyllus* and *Bangasternus* were uniquely different from all other genera. Therefore, Zwolfer (1967) adopted the taxonomy of Reitter and Csiki and placed *Rhinocyllus* in the tribe Rhinocyllini.

The genus *Rhinocyllus* is composed of five predominantly Mediterranean species associated with composits of the tribe Cynareae (Zwolfer, 1967).

Zwolfer (1967) gave the following synonyms for *Rhinocyllus conicus* Froel.: *R. antiodontalgicus* Gerbi, *R. latirostris* Latr., and *R. olivieri* Gyll. Hoffman (1954) agreed with Zwolfer's list of synonyms; however, the literature also recorded other names for *R. conicus*. Reitter (1891) listed the name *R. odontalgicus* Oliv. which is also cited in Heyden *et al.* (1883). Csiki (1934) added *R. thaumaturgus* Rossi. and Luigioni (1929) completed the list of synonyms with the addition of *R. cardui* Don., *R. morosus* Oliv. and *R. sulcifrons* Dej. The histories of all these synonyms are not known. It is of interest to note that Fowler (1891) pointed out that *R. odontalgicus* Oliv. and *R. antiodontalgicus* Gerbi were species names derived from the supposed medicinal values of *R. conicus*. The weevil was once regarded as a specific cure for toothache.

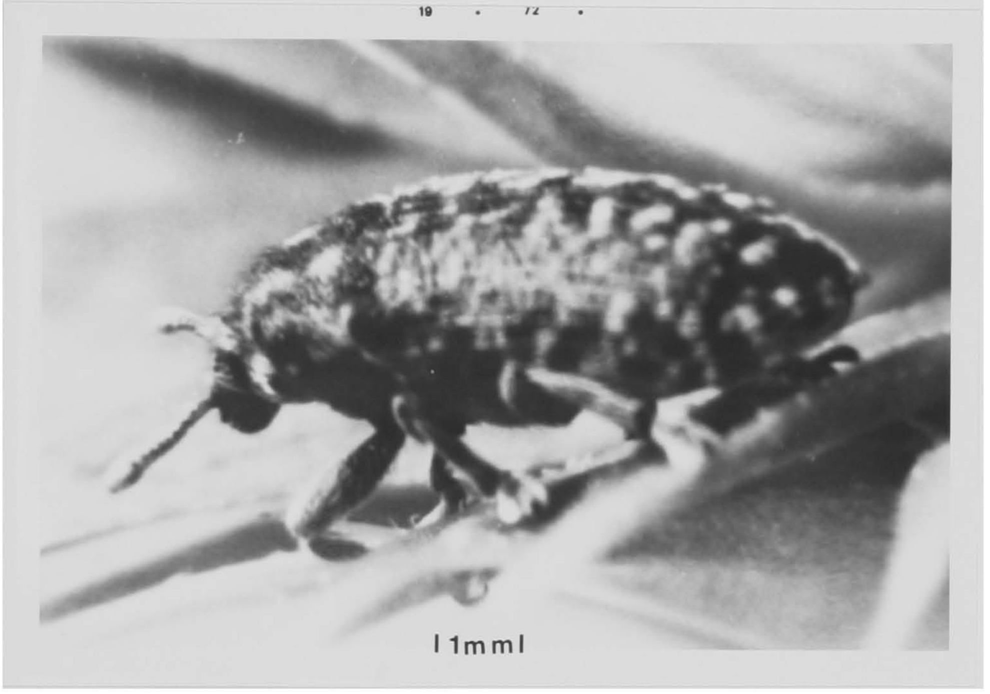
D. Description of Rhinocyllus conicus

Being a native of many Eurasian countries, Rhinocyllus conicus has been described in numerous languages. The best description obtained from the literature was that of Hoffman (1954). This description has been verified by examination of the weevil. Hoffman's description is the primary basis for the following description, with excerpts taken from the following authors: Gutfleisch (1859), LaCordaire (1863), Fowler (1891), Seidlitz (1891), Griffini (1896), Joy (1932), Porta (1932), Mellini (1951), and Linssen (1959).

Rhinocyllus conicus (Fig. 7) is an elongate, black, convex weevil 3 - 7 mm long. The body ventrally and dorsally is covered with a dense pubescence which is a basic ash color but spotted with bronze patches. The pubescence is erect. The head is convex with a flat, pitted front; interocular distance is narrower than the rostrum; ocular lobes are well developed and rounded. The rostrum is blunt; retracted posteriorly; enlarged anteriorly; narrowest in the middle; angled along the edges with a triangular depression at the base of the eyes; and covered with a dense, coarse pubescence. Antennae are bronze colored. The second segment of the funicle is equal to or shorter than the first. The antennae are tipped with an oval 3-segmented club. The eyes are laterally positioned.

The prothorax's lateral margins are lined with long, erect hairs. It is wider than long; arched at the edges and covered with numerous depressions. Elytra are twice as long as wide and much larger than the prothorax; subparallel for 3/4 their length, each terminates posterior-

Figure 7. Rhinocyllus conicus Froel.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ly with a rounded tip. When the elytra are closed a small V-shaped notch is evident at their posterior median junction. Tibiae are straight and the tarsae are short and bronze colored.

E. Distribution prior to introduction into North America

R. conicus is distributed over southern and central Europe, north to Great Britain and Finland, southward to parts of northern Africa (Mediterranean islands included) and eastward to western Asia (Zwolfer, 1967). However, as Zwolfer (1967) pointed out it is important to recognize that the weevil is not found throughout the entire range of *Carduus nutans*. Ghani (1965) did not find *R. conicus* in Pakistan and Aslam (1963) did not mention the genus *Rhinocyllus* in his study of the Indo-Pakistan Cleoninae. The weevil tolerates an extreme diversity of climates and seasonal variations, which was an important factor considered in its selection for release in North America.

F. Life History of R. conicus

In his 1967 report Dr. H. Zwolfer summarized almost all available information on the life history of R. conicus. The information presented herein will be taken from Zwolfer since his literature citations have been examined as well as a more extensive literature survey, which has yielded no additional information of value. Where additions are necessary the authors will be cited; otherwise, the following information will have been taken from Zwolfer (1967).

In the Mediterranean region of southern France and north eastern Spain adults of R. conicus have been observed on their host plants in the second half of April with the first eggs appearing on Carduus as early as May 5. In the Upper Rhine Valley near Basle-Mulhouse-Colmar adults were found to be abundant on the host plant in the first half of May and were found until August. Larvae could be found from late May to August; pupae until mid-September. This area's climate closely parallels that of Virginia; consequently the phenology for Virginia is very similar to that of the Upper Rhine Valley.

The number of generations that R. conicus produces in a year is questionable. It appears most likely that in climate zones where the season begins early there will be a second generation. However, this is not always advantageous as Harris and Zwolfer (1971) discovered in Canada. A second generation was produced, but it did not complete development prior to cold weather. Consequently, the larvae and pupa died during the winter.

The female R. conicus lays her eggs externally on the lower surface of the bracts of the capitulum. There seems to be a preference for the basal area of the receptacle. A single egg is covered by a tiny (about 1.5 mm in diameter) mass of masticated plant material (Fig. 8). Frequently a number of such masses will be found clumped together; however, upon close examination it can be seen that each egg has its own individual covering. The egg covering acts as an abuttment which aids the neonate larvae in entering the plant tissue.

The egg hatches in 6 - 8 days and the larvae burrow through the bracts and into the receptacle where development occurs. Destruction of the receptacle by burrowing larvae constitutes the beneficial aspect of the weevil. The mining is considered harmful to the plant's seed production. The larval period lasts 25-30 days.

Prior to pupation the larval R. conicus forms an ovoid pupal cell, with extremely hard walls, within the receptacle. The walls of this cell are composed of frass and feces. Following a pupation of 8-14 days the teneral adult emerges but remains within the pupal cell for several weeks. Emergence of the new adults has been observed from the seed-producing side of the bloom, not from the under surface of the receptacle. Following departure from the pupal cells the new adults immediately go into diapause until the following spring (Zwolfer, 1967). Mellini (1951) and Harris and Zwolfer (1971) noted that the adults do not overwinter within these pupal cells. They emerge to seek refuge elsewhere. Harris and Zwolfer (1971) stated that the normal overwintering site for R. conicus is in soil litter. The adults overwinter and emerge in April or May to renew the life cycle. Upon emergence the

(Photo by L. T. Kok)

Figure 8. *Rhinocyllus conicus* egg masses on bracts *Carduus nutans* bloom (June, 1972).


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weevils begin feeding, which is mandatory for egg development. Feeding is usually restricted to peripheral tissue of the stem, peduncles and leaves according to Zwolfer (1967). Personal observations indicate that midribs of leaves and bracts of the involucre are preferred feeding sites. Damage by adult feeding is insignificant. Mating takes place and eggs are laid, thus completing the life cycle.

G. Mortality factors

Zwolfer (1967) cited that the eggs of *R. conicus* are parasitized by a Chalcidoidea species in Europe. Mellini (1951) listed *Tetrastichus* sp. and *Bracon urinator* F. as parasites of the larvae. Hoffman (1954) and Scherf (1964) added *Hoplocryptus nigripes* Grav. as a larval parasite. [7]Zwolfer indicated that egg mortality due to predaceous Hemiptera and parasitism by *Pterandrophysalis levantina* Nowicky may be as high as 55% in Europe. He also cited *Eurytoma* sp. as a parasite of larvae and pupae.

Some eggs are also lost by the action of rain washing them off of the plants prior to larval emergence. In Europe there is also a loss of *R. conicus* larvae from competition with other head infesting insects but this is not known to occur in Virginia.

[7]Zwolfer, H. 1971. Personal communication of December 21.

II. Observations on Carduus biology in Virginia

In Pulaski Co., Va. (1971) observations were made on *C. nutans* growing on Bill Kegley's farm. The rosettes began to bolt in late April with the first blooms appearing in the latter days of May. Determinant blooming was observed to continue through August. Heights of plants ranged from 2-8 feet and numbers of blooms varied according to plant height and competition. Dissemination of seeds began in late June and continued until all the plants had died (late September).

Musk thistle height as indicated in the literature is inconsistent with personal observations. I have observed *C. nutans* in Virginia over 9 feet tall (Fig. 9).

Life cycle observations on *C. nutans* and *C. acanthoides* indicate that the weeds behave as McCarty and Scifres (1969) have described for musk thistle in Nebraska. The plants rarely grow as annuals but usually behave as biennials or winter annuals. Consequently, we can best describe them as facultative biennials.

Figure 9. Carduus nutans plants occurring in Warren County, Virginia.

III. *Rhinocyllus conicus*, a critical evaluation of the insect's value as a biological control agent for *Carduus nutans* and *C. acanthoides* in Virginia

1. Introduction

No quantitative evaluations of *R. conicus*' destructive potential had been made, and fecundity, mortality factors, dispersal ability, and seed destruction under Virginia's environmental conditions are virtually unknown. Zwolfer (1967) said that "Larvae of *R. conicus* which feed in the heads of *Cirsium* spp. destroy mostly all [sic] the achenes. Within the big heads of *Silybum* or *Onopordum* the destruction of the achenes appears to be less marked." However, he does not give any specific data as to seed destruction. The credibility of using the weevil as a control measure for *Carduus acanthoides* and *C. nutans* rests upon the establishment of its destructive credentials and reproductive potential on these thistles. It is my intent to evaluate the response of the weevil under Virginia conditions in order to develop a better insight as to the potential value of *R. conicus* as a bio-control agent. Most data in this thesis has been from weevil infestations on *C. nutans*, as successful establishment of *R. conicus* colonies on *C. acanthoides* has been limited and those colonies which have been successful are too distantly located for daily observations.

2. Fecundity and longevity of Rhinocyllus conicus under controlled environmental conditions

A. Introduction

[8]In 1971 the population of Rhinocyllus conicus at Pulaski Co., Va. was estimated to be approximately 100,000. This was extraordinary after having released only 100 weevils at the site only two years previously. Three generations of weevils had been produced at this time, but the population estimate was questionable. Therefore, in order to properly evaluate the reproductive potential of R. conicus it would be helpful to have an estimate of the weevil's potential fecundity. The intent of this project was to establish the mean number of eggs laid per female under controlled environmental conditions. Observations were also made on the longevity of the weevils following emergence from diapause.

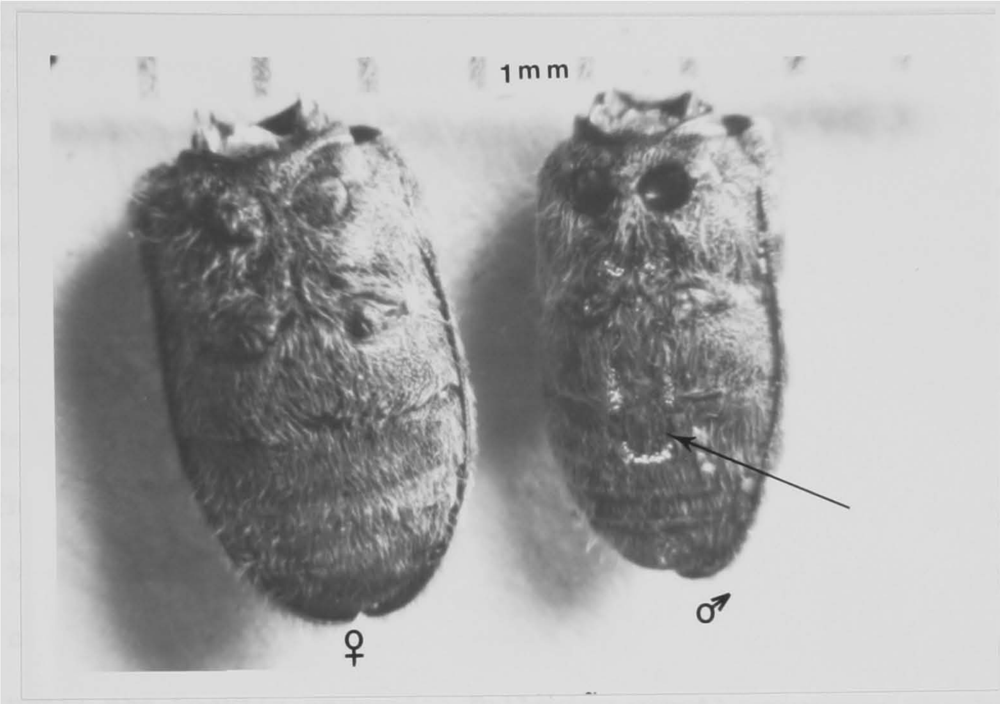
B. Materials and methods

Sexual segregation of weevils by morphological characters was a basic necessity in this project. The sex may be distinguished by examining some of the following characteristics. Ventral views (Fig. 10) of R. conicus show that the male has a distinct medial, longitudinal furrow on the anterior end of the abdomen. The female lacks this groove. The posterior dorsal sclerite of the female is a singular, fused plate. In the male there is a distinct transverse suture which divides this area into two sclerites which articulate on one another in copulation (Fig. 11). The suture is readily visible once the elytra are spread;

[8]Hendrick. 1971. 9.

Figure 10. Ventral view of <u>Rhinocyllus</u> <u>conicus</u> Froel. The arrow indicates a furrow characteristic of males.

Figure 11. Dorsal view of male and female <u>Rhinocyllus</u> <u>conicus</u> abdominal capsules. Arrow indicates the position of a suture characteristic of males.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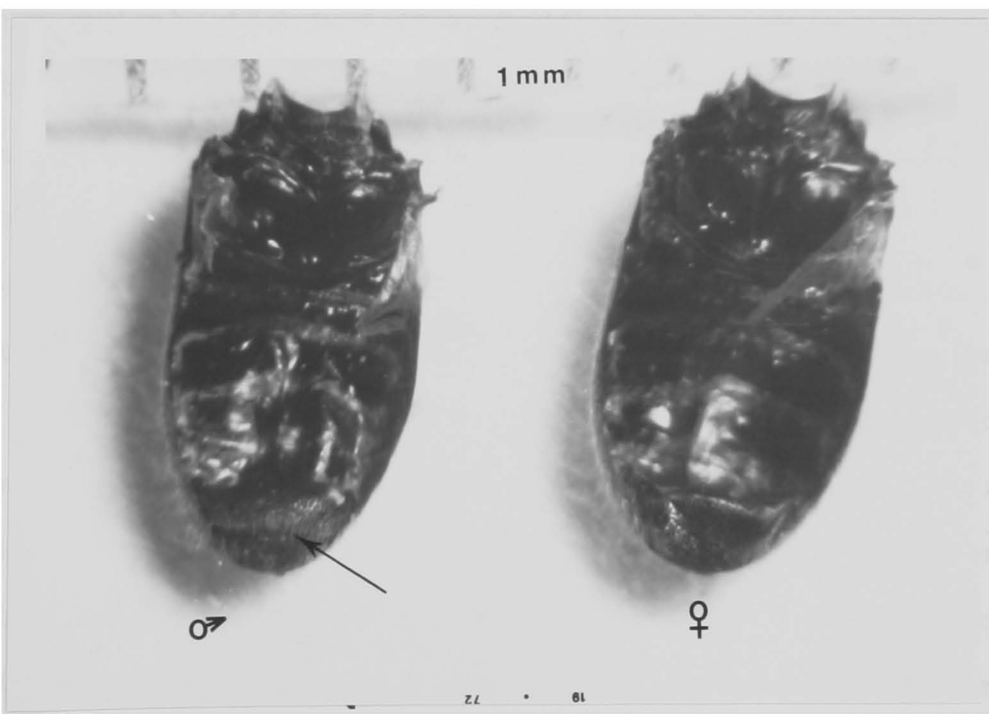
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however, this is difficult to do without harming the insect. In addition the female is generally larger than the male.

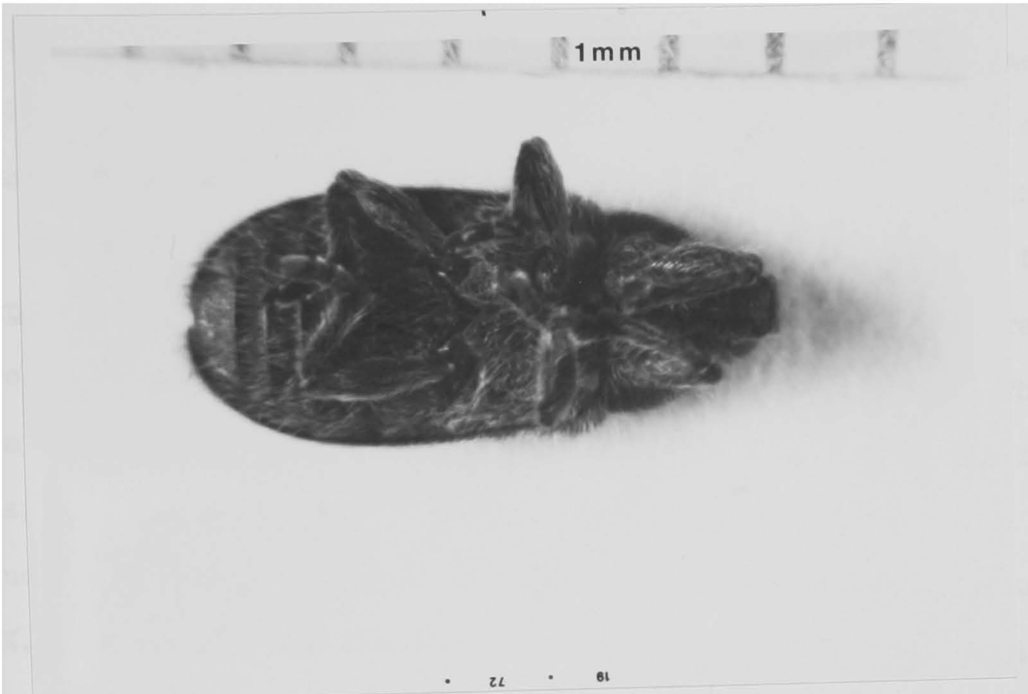
Although living weevils will often remain motionless to the point of appearing dead they are easily separated from dead individuals. A dead R. conicus extends its legs vertically (Fig. 12) whereas a motionless living insect holds its legs in such a manner that they are horizontal to the substrate (Fig. 13). Generally, a slight pressure on the prosternum will activate the weevil.

The insects used for the fecundity studies were new adults collected from the Pulaski release site in August, 1971. Infested thistle blooms were collected upon maturation and placed in a glass-topped sleeve cage until the weevils emerged. Following weevil emergence the insects were stored in one-gallon ice cream cartons (approximately 300 individuals per carton), which were covered with organdy and contained dried musk thistle blooms. The weevils were maintained at 65°F under seasonal day length until used. Individuals used in the final successful attempt survived approximately 200 days under these conditions.

Weevils were sexually segregated and single pairs were placed in pint containers which had the sides and bottoms lined with fine mesh wire. A soft plastic cap, which was used for closing the container, had a hole approximately $\frac{1}{2}$ inch in diameter cut out of its center. Musk thistle leaf petioles were wrapped with cotton and wedged into the hole such that the midrib extended out of the container. The container was then inverted and set on a baby food jar filled with water which enabled the leaf to be used for 3 days.

Figure 12. Ventral view showing the typical posture of a dead *Rhinocyllus conicus* adult.

Figure 13. Ventral view showing the typical posture of a living, but immobile *Rhinocyllus conicus* adult.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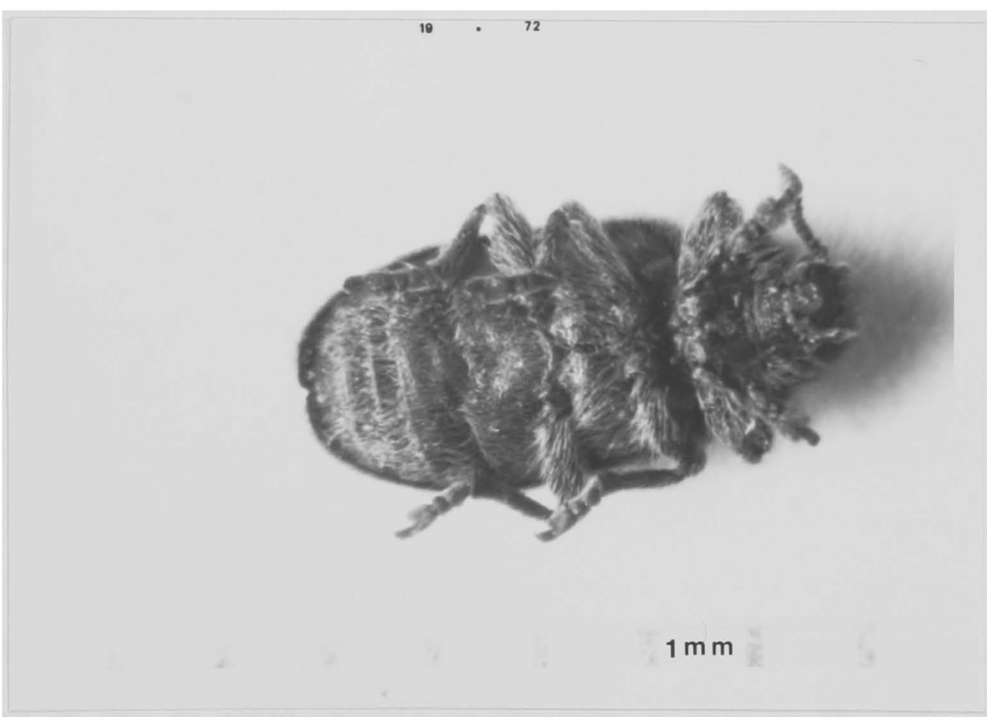
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Containers of thistle leaves and weevils were placed in controlled environment chambers. Two attempts failed as a result of equipment failure. A third attempt was successful although only 25 pairs of weevils were available for use. Temperature and humidity was monitored by use of a hygro-thermograph. The third attempt to perform this experiment began on March, 1971. The 25 pairs of R. conicus were taken from the holding cage, sexed and set up as described earlier. The temperature and photoperiod was manipulated to hasten emergence from diapause (Table 1). Humidity within the environmental chamber fluctuated between a diurnal maximum of 98% to a nocturnal minimum of 40%. The average humidity for a 24 hour day was 46%. The weevils were tended on a Monday - Wednesday - Friday schedule at which time data was taken for egg counts and mortality (Table 1 of Appendix).

C. Results and discussion

Rhinocyllus conicus began to show active signs of feeding and mating on April 25 after having been exposed to a 14.75 hour day at day-night temperature range of 80°F - 60°F. The first eggs noticed on thistle leaves appeared on May 15, and oviposition extended over a range of 81 days. The eggs laid by each female weevil ranged from 1 - 234, with a mean of 100.48. This rate of fecundity could easily explain a population increase from 100 to 100,000 in three generations. Figure 16 illustrates the distribution of oviposition over the 81-day range.

The few females which continued oviposition well after the peak period of May 29 could explain an observation made at the Pulaski release site. The number of generations produced by R. conicus at

Table 1.

Temperature ranges and photoperiod regimes used for breaking diapause in *Rhinocyllus conicus*

Date 1972	Photoperiod Hours	Temperature (°F) Day	Temperature (°F) Night
March 25	12.25	60	35
March 29	12.75	65	40
April 2	13.25	70	40
April 6	13.75	70	45
April 10	14.25	70	50
April 14	14.75	75	55
April 18	14.75	80	60

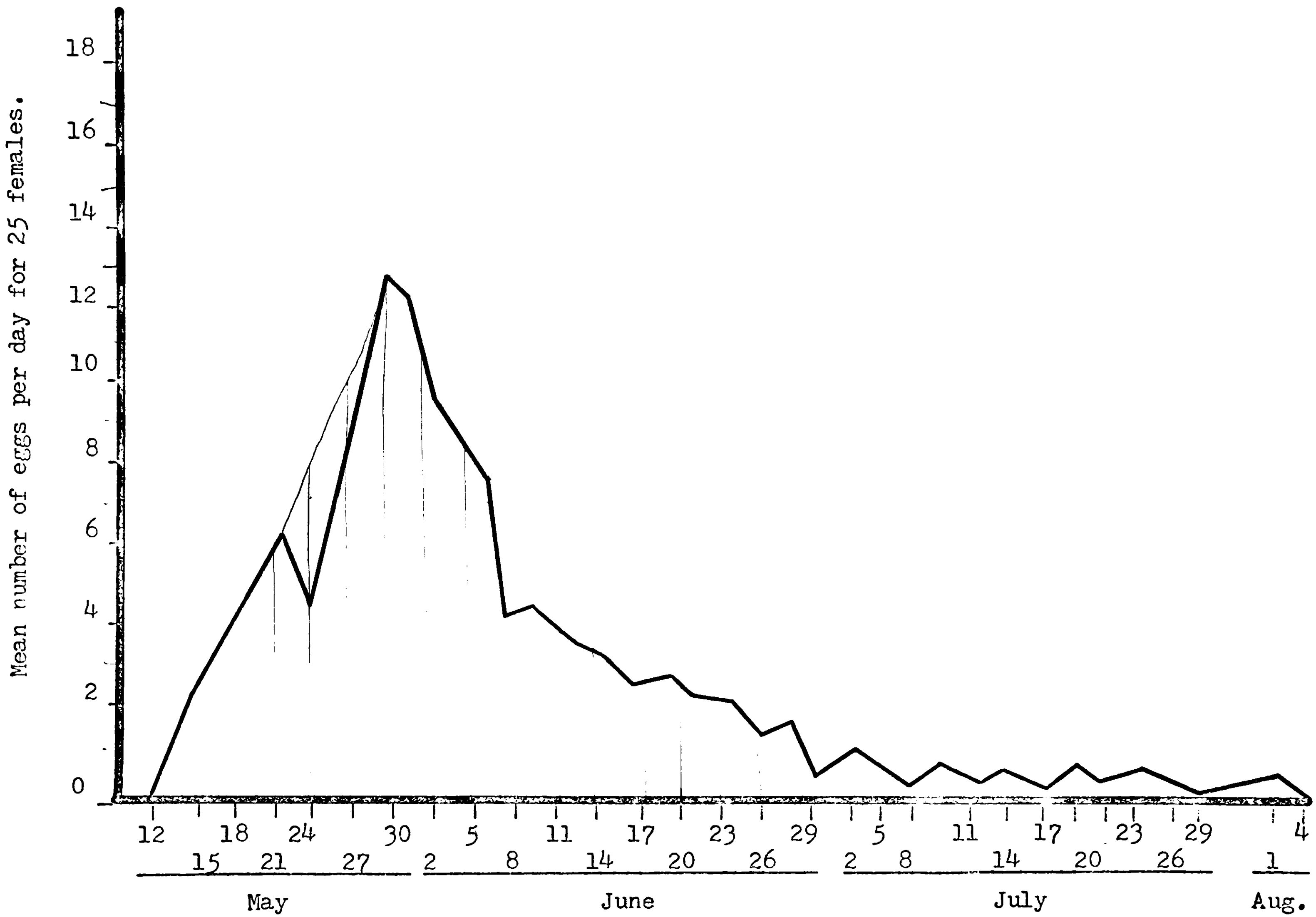


Figure 14. Fecundity of <u>Rhinocyllus conicus</u> under controlled environmental conditions.

Pulaski has been a major question. Fresh eggs have been found after the first generation of weevils have emerged from pupation. Therefore, speculations have been made that the new generation of weevils were ovipositing. New adults collected from the Pulaski site in 1972 were observed ovipositing on freshly blooming Carduus nutans heads in the greenhouse at V. P. I. & S. U. These weevils however, were not under normal field conditions. Oviposition at the greenhouse occurred on freshly bolting musk plants, which were not available at Pulaski, and the weevils were subjected to warmer temperatures and artificial lighting-factors which invalidate the laboratory observations. The extended range of oviposition indicates that the overwintering female weevil could be responsible for the late-summer eggs observed at Pulaski. If newly emergent adults oviposited, all available thistle blooms would be expected to contain eggs; however, new eggs were noted only in rare instances. Thus I believe that R. conicus is univoltine at Pulaski Co., Va. but overwintered females can oviposit throughout the thistle's growing season.

Feeding was first observed on April 15; therefore, this data is assumed to be the point at which diapause was broken. Mortality observations are based on April 15 until death. Post diapause longevity ranged from 20-125 days with a mean of 70.42 days. The life expectancy did not differ significantly relative to sex. Females survived a mean of 70.36 days while males lived an average of 70.48 days. Infrequent mating was observed but duration was not monitored.

3. Orientation of *Rhinocyllus conicus* to *Carduus nutans* relative to thistle density and bloom height

A. Introduction

[9]In 1971 the population of *Rhinocyllus conicus* at Pulaski Co., Va. was estimated to exceed 100,000. It was evident at this time that a very large population of weevils had developed and determination of the relationship between weevil attack, host size and density was of considerable interest.

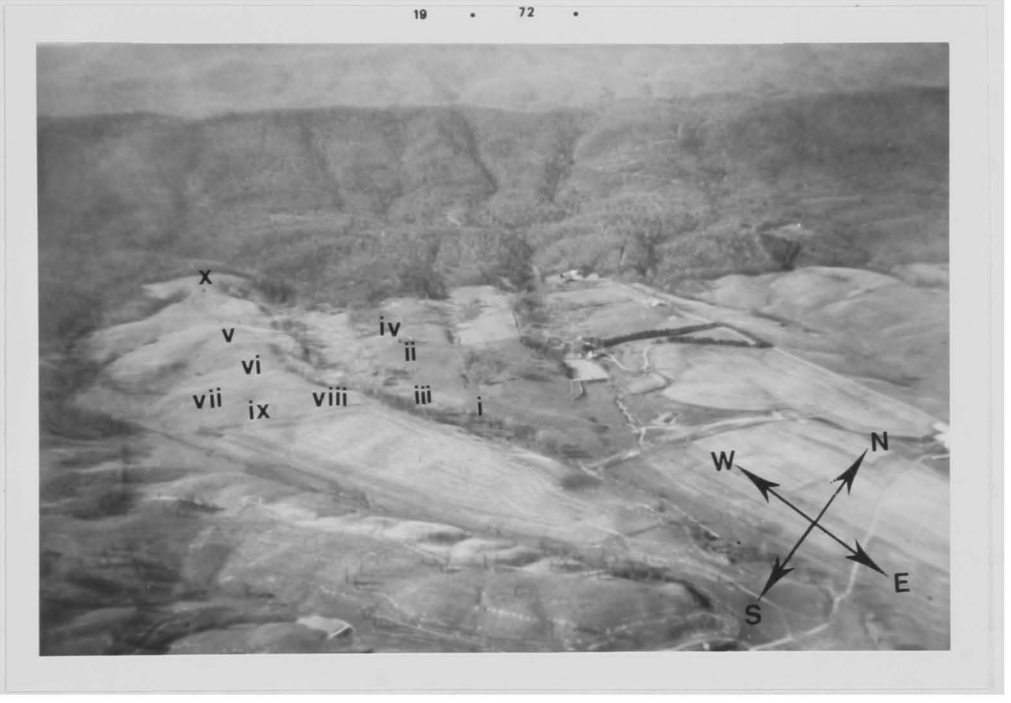
B. Materials and methods

A preliminary survey of ten study sites was undertaken at the Pulaski Co., Va. release area (Fig. 15). The boundaries of each site were measured for the localized area of thistle infestation in order to ascertain thistle density. Ten random 10 X 10 feet sub-plots were taken at each site and all bolting (vertical stems present) musk thistle plants in each subplot were recorded. The data obtained presents an index of mature plants for each site (data in Appendix, Table 2).

Following the density survey an intensive thistle infestation survey was undertaken. Each of the ten sites was visited, and a random selection of 200 plants was examined. The plants were categorized as to height and analyzed as 4 groups: 1 = 0-2.0 feet; 2 = 2.1-4.0 feet; 3 = 4.1-6.0 feet and 4 = 6.1-8.0 feet. Each of the 2,000 plants (one observation was discarded later) was examined and the following observations were recorded: total blooms, lateral blooms and infested lateral blooms, terminal and infested terminal blooms. Capitula were classified

[9]Hendrick. 1971. 9.

Figure 15. Location of study sites for thistle density and weevil infestation surveys. (Pulaski Co., Va.; July, 1972).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as infested if they: contained R. conicus eggs; displayed abortion of phyllaries (Fig. 16); displayed characteristic phyllary tufts displaced by R. conicus larvae or pupae (Figs. 17 and 18); or possessed obvious R. conicus pupation chambers.

Mean per cent infestation of blooms was determined for each height category, both of terminal and lateral heads (Table 2). Analyses of variance were utilized to evaluate total bloom infestation among heights (Appendix, Table 2). In all cases of analysis the four height categories were considered treatments. These data evaluations were compared to ascertain the orientation, if any, of R. conicus to hosts as a factor of height.

C. Results and discussion

R. conicus had attacked 26.7 % of all capitula. Only 18.2 % of the lateral blooms contained R. conicus, whereas 46 % of all terminal blooms were infested. Terminal heads are larger than laterals; however, as shown in section III the weevil does not necessarily orient towards larger blooms. Terminal blooms are more suitable oviposition sites, primarily due to their early maturation, which coincides with initiation of egg-laying.

The majority of the thistle plants were found to range in height from 2.1-6.0 feet (Table 2) with the 4.1-6.0 feet range accounting for the largest proportion. The range of observations for mean infestation relative to plant height (Table 2) varies from 56-1005 in the terminals and 38-947 in the laterals. Such a broad range of observations invalidates statistical evaluation of weevil orientation relative to

Figure 16. Aborted phyllaries in *Carduus nutans* bloom indicating development of *Rhinocyllus conicus* larvae.

(Photo by L. T. Kok)

Figure 17. Abnormal tuft of pappal hairs on mature *Carduus nutans* bloom; caused by pupation of *Rhinocyllus conicus*.

Figure 18. Typical appearance of mature Carduus nutans bloom infested with Rhinocyllus conicus larvae (Note pappal tuft indicated by arrow).

Table 2. *Rhinocyllus conicus* infestation of *Carduus nutans* in Pulaski Co., Va. (July, 1972).

	Terminal blooms			Lateral blooms	
Height category[1]	Observations	% of plants relative to height	Mean % of infestation	Observations	Mean % of infestation
4	77	3.9	69.5	65	26.7
3	1005	43.1	61.1	947	21.5
2	861	50.3	31.9	738	18.8
1	56	2.8	14.9	38	8.5
Total	1999	100.00		1888	

[1]Height categories: 1 = 0-2.0 feet; 2 = 2.1-4.0 feet; 3 = 4.1-6.0 feet and 4 = 6.1-8.0 feet.

plant height by use of range tests. However, mean infestation of terminal blooms lies on a gradient which correlates perfectly with bloom height (Table 2). Therefore an analysis of variance was utilized to ascertain existance of relationships. Appendix Table 3, part i. indicates a highly significant F for terminal blooms when height preference is compared, whereas a non-significant F is derived from a similar comparison of lateral blooms (Appendix, Table 3, part ii). The discrepancies, although not applicable to statistical evaluation due to range difficulties, are biologically significant. The non-significant relationship evident for lateral blooms and the highly significant relationship among terminal blooms can easily be explained- R. conicus begins ovipositing very early in the thistle's bolting stage (see III-6), at which time only terminal blooms are present. Therefore, the terminal blooms are attacked first - being lesser in number than the lateral blooms a greater percentage of the terminals are infested.

Total bloom infestation (Table 3) for each individual site when compared to thistle density at that site reveals no relationship between plant density and weevil presence. Apparently, weed density is not a primary orientation factor for R. conicus. Other factors must be considered if distribution within the weevil's range is to be explained.

Table 3. *Rhinocyllus conicus*-infested *Carduus nutans* blooms as related to density (Pulaski, July, 1972).

Site	Plant density[a]	% Total blooms infested
I	.09	31.75
II	.06	8.86
III	.09	21.61
IV	.05	24.90
V	.18	32.13
VI	.15	31.42
VII	.20	14.64
VIII	.20	25.61
IX	.41	24.13
X	.41	46.16

[a]Plant density is given in plants per square foot.

4. Larval feeding damage to seed production of Carduus nutans

A. Introduction

Zwolfer (1967) reported that the efficiency of R. conicus attacks on C. nutans depended on the size of the head and the number of larvae feeding within it. No quantitative evaluations of seed destruction have been found in the available literature. Before extensive work is performed in establishing the weevil in Virginia, it would seem appropriate to evaluate its impact on seed production.

B. Materials and methods

It would seem probable that the larger flower heads of Carduus nutans would produce more seeds than smaller heads. This assumption was the basic hypothesis for evaluating the effect of R. conicus larvae on seed production. The first part of this project was the collection of normal, uninfested blooms of Carduus nutans to establish a relationship between head diameter and production of theoretically viable achenes (plump, fully developed as described by Feldman et al., 1968). In order to determine the effect of weevil larvae, infested thistle heads were collected and damage evaluated in relationship to numbers of developing larvae within the receptacle.

Thistle blooms were collected from the Kegley farm in Pulaski Co., Virginia on July 7, 1971. The heads were selected randomly to fit specific criteria. The flower head had to be closed and the pappal hairs had to be brown to indicate that the bloom had completed development. Infested C. nutans blooms exhibit a unique characteristic at this stage of development. The central achenes of a normal bloom are ejected first; therefore, there is a distinct tuft of pappal hairs in the very center of the head. However, if the head is infested by R. conicus larvae a tuft of pappus will be evident whever the weevil forms its pupation chamber. Formation of the chamber pushes a small cluster of pappus outward thus forming a tuft, which may be, but in most cases is rarely centrally located (Fig. 17). By selection of blooms in this manner 100% of the 200 heads collected were found to be infested. On the same day 61 normal heads were collected; however, 5 of these were later found to be infested and included in the data. Therefore 205 infested and 56 normal, uninfested heads were collected (data in Appendix; Table 4).

Each head was on the verge of releasing its achenes which necessitated the need for individual containers. Pint ice cream containers were covered with organdy cloth, numbered consecutively and used to hold individual thistle heads. These heads were held for adult weevil emergence under temperature and light conditions similar to the field.

Weevils were removed as they emerged and retained for use in the fecundity experiments. Following weevil emergence (Aug. 4, 1971) the containers were opened and the expelled pappal hairs were removed from the seeds. Separation of achenes and pappus proved to be the most difficult part of this problem. The best technique was to use 1/8 inch (about 3 mm) mesh wire stapled and taped to the inside of a paper cylinder. Each thistle head was placed into the paper cylinder, and manual disturbance of the pappal hairs dislodged the achenes which fell through the wire screen and into an enamel pan. It was often necessary to rub the achenes against the wire mesh to force separation of achene and pappus.

Feldman _et al_., (1968) described plump fully-developed _C. nutans_ achenes as having a germination of 93 - 95%. Therefore, the achenes which appeared plump were the only seeds counted. A total count of seeds was not made for a number of reasons: 1/ underdeveloped seeds are extremely difficult to dislodge from the receptacle; 2/ separation of underdeveloped achenes and pappus would be much more difficult and time consuming as such achenes are firmly attached to the pappus; 3/ reproductive potential of the plant is the criteria to be examined; therefore, only viable seeds were considered.

Data on seed counts were collected during the fall and winter of 1971 and analyzed statistically. The raw data for these analyses is included in the Appendix (Table 4). The use of the V.P.I.& S.U.'s User's Guide, package programs of the Biomedical computer program (BMD) series was invaluable in setting up the statistical analysis.

A polynomial regression analysis was first instituted to determine the existance, if any, of a linear relationship between uninfested head diameter and mature seed production. Following the evaluation of this relationship a multiple regression analysis of variance was performed on the infested thistle heads using the following format. . . the three variables = Y, X_1, and X_2 representing dependant variable (Y = number of mature seeds), and independant variables (X_1 = head diameter and X_2 = number of emergent weevils) respectively. The multiple regression package program is BMD03R.

C. Results and discussion

Polynomial regression analysis of normal heads (Appendix, Table 5) was employed to ascertain the linear relationship between head diameter (X) and mature seeds produced (Y). The highly significant F is evident in the first degree regression, which indicates that a relationship between the two variables does exist. Regression of degree 1 (linear) had a correlation coefficient r = 0.72 whereas the 2nd degree regression produced an r = 0.74. Although the latter regression has a higher r value it is not sufficiently superior to the 1st degree r to warrant consideration of a curvilinear relationship between head diameter and mature seeds produced. Therefore, a simple linear relationship between the two variables will be acknowledged with r = 0.72.

An r = 0.72 does not indicate a strong correlation between the variables X and Y; however, this could probably be increased with a larger number of samples. It is sufficient to establish that there is a relationship between head diameter and mature seeds produced.

Upon examination of Appendix Table 6 we find that the multiple regression analysis of variance for the entire collection of 261 heads revealed a highly significant F value indicating a definite relationship existing among the three variables: head diameter (X_1), emergent weevils (X_2) and mature seeds (Y). A multiple correlation coefficient (r) of 0.72 is sufficient to show that such a relationship exists; however, it is not a very strong relationship. The mean head diameter was 29.24 mm and emergent weevils averaged 1.84 per head with each bloom producing an average of 447.05 mature, plump and seemingly viable seeds (Appendix; Table 6, part 1). Consequently, it is evident that the present level of infestation is not sufficient to drastically reduce seed production, even in infested heads.

A prediction formula for the multiple regression would be: $Y = 447.05 + 36.95 (X_1) - 9.67 (X_2)$. This formula indicates that in a random selection of 261 C. nutans blooms ranging in infestation levels from 0 to 17 the mean seed production per bloom is 447.05 with a mean of 36.95 mature seeds per mm of diameter. The - 9.67 indicates that each developing larva is directly responsible for destruction of 9.67 achenes. Thus the destructive nature of the developing larva is valid as would be expected, although it is disheartening to find that heads producing 17 weevils still produced viable seeds (e. g. a single head of 29 mm diameter produced 17 weevils and 308 mature seeds).

Head diameter (X_1) and emergent weevils (X_2) exhibited a $r = 0.28$ (Appendix; Table 6; part 2), which shows the relationship between head size and oviposition sites. It is evident that there is a very poor relationship between these two variables indicating that R. conicus adults do not favor larger heads for oviposition sites. Flower size is less important than the developmental synchrony between the thistle and weevil's life cycles. Oviposition occurs on the blooms which are available at the time with no distinct selection of larger blooms.

5. Mortality factors and Hymenoptera associated with Rhinocyllus conicus at the Pulaski Co., Va. site (1971 - 1972)

A. Introduction

The reproductive potential of an insect is composed of numerous factors other than fecundity. Given that an insect produces a specific number of eggs it is necessary to consider their possibilities for survival before any predictions can be made on population establishment and increase. Mortality as an essential component of biotic potential must be considered. In an attempt to evaluate the successful establishment of Rhinocyllus conicus at Pulaski Co., Virginia, an intensive study of mortality factors was initiated. Egg mortality was selected as the basis of this study for the following reasons: 1/ pre-oviposition mortality would require a quantitative assessment of the adult population while permitting normal dispersal and overwintering. Present insufficient knowledge regarding seasonal life history rendered this evaluation impossible. 2/ egg number is the basis of all surveys of release sites; therefore, egg mortality is more relevant to the interpretation of population estimates. Some hymenopterans collected from infested thistle heads are definitely known to be parasites of R. conicus; however, most are cited as possible parasites.

A number of parasites are known to attack R. conicus in its native range. [10]An egg parasite, Pterandorphysalis levantina Nowicky has been recorded by Zwolfer. R. conicus larvae are parasitized by: Bracon urinator F., Tetrastichus sp. (Mellini, 1951); Exeristes roborator (F.)

[10]Zwolfer. 1971.

(Zwolfer, 1967); Hoplocryptus nigripes Gra. (Scherf, 1964) and Habrocytus sp. and [11] Eurytoma sp. No reports of pupal and/or adult parasites could be found, and no observations on parasitism in North America have yet been published.

B. Materials and methods

On June 30, 1971 Rhinocyllus conicus-infested Carduus nutans blooms were collected from the Pulaski release site to obtain a stock of weevils for laboratory studies. Within a week after having collectively caged the specimens many parasitic hymenoptera were noted emerging from the thistle blooms. These were collected as they emerged and preserved in 95% ethanol for future identification. Emergence of weevils and parasites terminated in four weeks and isolated heads were then dissected. Pupation chambers of R. conicus were examined to evaluate parasitism.

On July 7, 1971, 214 C. nutans flower heads were examined in the field at Pulaski and found to be infested with R. conicus larvae (Fig. 18). These capitula were collected to evaluate seed destruction caused by the developing larvae. As each bloom was collected it was placed in an individual container after having been superficially examined for any externally feeding insects. Following weevil and parasite emergence the Hymenoptera were sent to the U. S. National Museum for identification.

In June 1972 an intensive study of mortality factors was initiated at Pulaski. A total of 12 areas within the release site was selected for this project. One was later destroyed, leaving 11 suitable for data

[11] ibid.

Figure 19. Location of mortality study areas on the Kegley farm (Pulaski Co., Va.; June, 1972).


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collection (Fig. 19). Twelve capitula (past full bloom) were selected at each site on June 13 and 14. Total number of eggs were counted and each frass deposit was marked with a black dot from a fine point magic marker. An aluminum tag, bearing the repetition number, head number, and number of eggs (e.g. I-2-8), was attached to each bloom. Mature flower heads were selected to reduce the possibility of additional oviposition. The blooms were inspected every 2 days after being tagged to remove any additional eggs; however, none was found. On July 18, 1972 the tagged heads were removed and brought back to the laboratory for study. All blooms were not recovered, but 115 of the 132 tagged heads were found. These were isolated in individual, organdy-covered, pint ice cream containers and held for weevil emergence. The eggs present on the blooms at the time of collection were counted in order to determine mortality due to wind and rain dislodging the frass deposits. Following the emergence of the weevils and parasites, the heads were dissected and death of larvae and pupa was confirmed. Dead larvae recovered were divided into two rough categories - early and late instars, based on the size of the larvae. Probable egg mortality was derived by summing known mortality factors and subtracting this quantity from the known number of original eggs. All mortality is based on the number of eggs originally counted (data in Appendix, Table 7).

The discovery of larval-pupal parasites dictated the need for investigating parasitism of _R. conicus_ life stages other than the larvae and pupae. Consequently all adult weevils that had been collected in 1971 were observed for parasitism, and 72 additional adults were collected from Pulaski on May 12, 1972 and held for parasite studies. Eggs were collected throughout the summer (May 12 = 185 eggs; May 15 = 264; June 1 = 424 and June 13 = 212), and held in small plastic petri dishes on moist filter paper until the eggs hatched or death occurred.

Musk thistle density data was taken in 1972 (see section III-3 Orientation of Rhinocyllus conicus . . .), and was considered in attempts to explain differences in mean mortality of R. conicus at different sites. Each mortality study site was examined and described in tabular form. Geographic location, ecological surroundings and climatic exposure are all considered as possible explanations for mean mortality deviations from site to site.

Statistical analysis of data involved the use of analysis of variance for comparison between: 1/ egg removal due to wind, rain, etc. and emergent adults (data in Appendix, Table 8); 2/ the mortality of R. conicus larvae and pupae within infested thistle blooms and the number of eggs laid on the blooms (as a measure of crowding effect) (data in Appendix, Table 9); 3/ the number of eggs present upon collection and emergent adult weevils (data in Appendix, Table 10). An analysis of variance of mortality among the 11 study sites was employed to ascertain statistical significance of discrepancies. Duncan's multiple range test was later used to delineate these discrepancies.

C. Results and discussion

A total of 1085 eggs was collected from Pulaski in 1972, and no parasites were obtained. Seven hundred and seventy nine adult weevils died from collections made in July of 1971, but no insect parasites emerged from them. Negative results were also obtained from the 72 adults collected in May of 1972. Thus, it appears that no indigenous egg or adult parasites have adapted themselves to *Rhinocyllus conicus* in Pulaski Co., Virginia.

Hymenoptera emerging from the infested blooms of the June 30, 1971 collection were identified by R. W. Carlson, C. F. W. Muesebeck, B. D. Burks and P. M. Marsh of the U. S. National Museum. Having been collected from a mass of infested *Carduus nutans* heads the following Hymenoptera (some have subsequently been established as parasites while others are considered as possible parasites) are listed as being associated with *R. conicus* larvae and/or pupae:

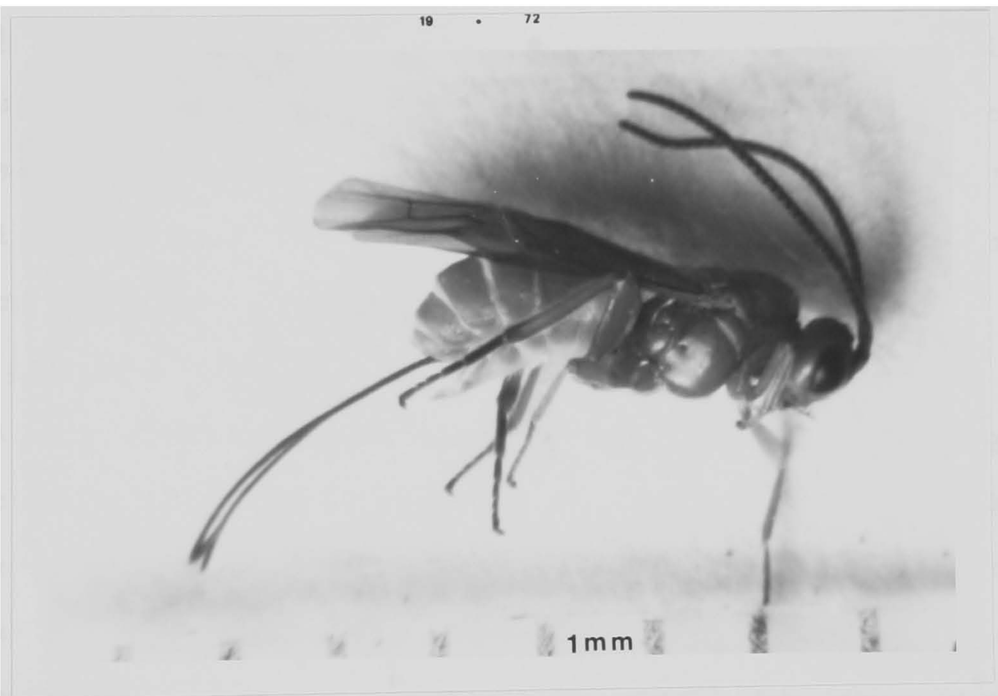
Hymenoptera	Number Recovered	Determined by:
Ichneumonidae		
Campoplex polychrosidis Vier.	7	R. W. Carlson
Gelis tenellus (Say)	1	R. W. Carlson
Gelis sp. (Say)	5	R. W. Carlson
Mesochorous discitergus (Say)	2	R. W. Carlson
Phaeogenes cynarea Bragg	1	R. W. Carlson
Isodromas lycaneae (How.)	2	R. W. Carlson
Dichrogaster aestivalis (Grav.)	1	R. W. Carlson
Eupelmidae		
Eupelmus sp.	1	B. D. Burks

	No. Recovered	Determined by:
Eulophidae		
Hyssopus thymus Giralt	1	B. D. Burks
H. benefactor (Crawford)	10	B. D. Burks
Eurytomidae		
Eurytoma tylodermatis Ashmead	5	B. D. Burks
Braconidae		
Bracon mellitor (Say)	22	C. F. W. Muesebeck
B. variabilis (Prov.)	2	P. M. Marsh
Aliolus curculionis (Fitch)	108	C. F. W. Muesebeck
Blacus sp.	1	P. M. Marsh

Two species of braconids were collected upon dissection of thistle receptacles. *Bracon mellitor* and *Aliolus curculionis* were collected from within the pupation chambers of *R. conicus*. As the thick walls of the pupation chamber are composed of frass and fecal material which are extremely hard when dry, it is evident that some of the hymenoptera were unable to escape from the cell in which they emerged. The presence of *B. mellitor* and *A. curculionis* within the pupation chambers verifies their role as parasites of *R. conicus*. Thorough examination of the chambers occupied by the parasites revealed no remains of the weevil larvae.

None of the hymenopterans collected has been listed in the literature as a parasite of *R. conicus* (Dalle Torre, 1901; Nikol'skaya, 1952 and Fulme, 1962). Verification of parasitism by any of the 15 Hymenoptera collected was not possible because *R. conicus* is a new

Figure 20. Bracon mellitor (Say) female.


19 • 72
1mm

host to the indigenous wasps and no records have been established in North America. European records of parasitism are incomplete; however, H. Zwolfer of Delemont, Switzerland is presently studying this facet of R. conicus mortality.

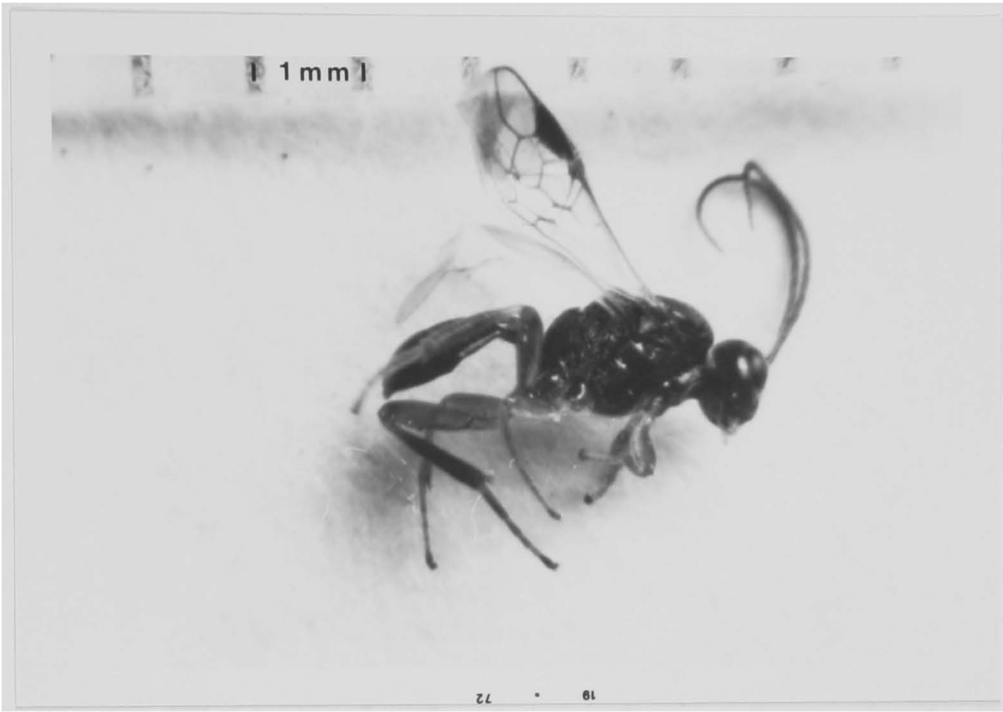
B. mellitor (Fig. 20) is recorded from 19 curculionid species (Adams et al., 1969), a number of which are similar in life history to R. conicus. These include: Anthonomous grandis Boh., the boll weevil; A. signatus Say, strawberry weevil; A. eugenii Cano, pepper weevil (Muesebeck et al., 1951); and Chalcodermus aeneus Boh., cowpea curculio (Muesebeck et al., 1958). B. mellitor is indigenous only to the U. S., Hawaii, and Mexico. It has a broad host range and seems to have become a facultative parasite of the recently established R. conicus.

Aliolus curculionis is also an indigenous braconid which has developed a facultative parasitic relationship with immature R. conicus. Muesebeck et al. (1951) described the range of A. curculionis as Ontario to Georgia west to Nebraska and Texas with no reference to its occurrence in Europe. Chestnut and Cross (1971) listed A. curculionis as the second most important parasite of the boll weevil, Anthonomus grandis, accounting for 12.3% of all parasites recovered from this pest. Two similar curculionid hosts were cited by Muesebeck et al. (1951): Anthonomous scutellaris Lec. (beach plum curculio) and Conotrachelus nenuphar (Hbst.) (plum curculio). The original hosts of A. curculionis are very similar in life habit to R. conicus, which helps to explain the ready acceptance of R. conicus as an alternate host.

A. curculionis (figs. 21 and 22) was the primary parasite found to

Figure 21. Aliolus curculionis (Fitch) male.

Figure 22. Aliolus curculionis (Fitch) female.


1 mm

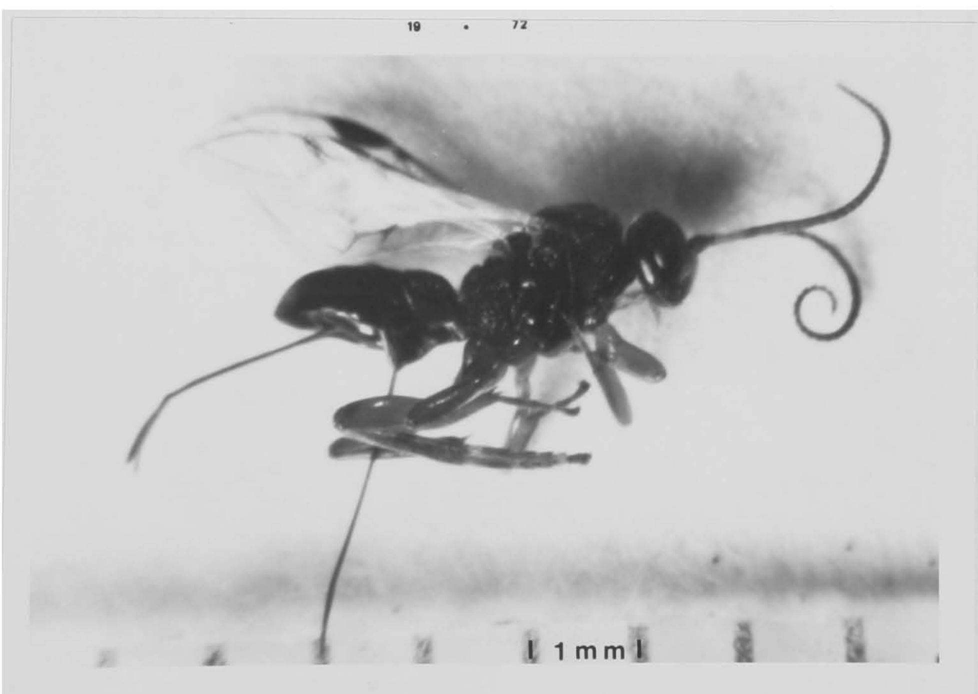

19 • 72
1 mm

Table 4

Mean values for mortality studies

of *Rhinocyllus conicus* (Pulaski Co., Va., 1972)

Factor	Total	Mean/head	% orig. eggs	Cumulative % mortality
Heads collected	115		———	———
Original eggs at labelling	1128	9.8	———	———
Eggs present upon collection	731	6.4	64.1	———
Egg mortality (Frass cover washed away and other causes*)	658	5.7	58.3	58.3
Dead larvae	51	0.4	4.5	62.9
Early instars	39	0.3	3.5	——
Late instars	12	0.1	1.1	——
Dead pupae	59	0.5	5.2	68.1
Parasites	41	0.4	3.6	——
Aliolus curculionis	30	0.3	2.7	——
Others	11	0.1	1.0	——
Adults	360	3.1	31.9	———

*Calculated by subtracting total observed mortality and adults produced from original observed eggs.

be infesting R. conicus. Dissection of the weevil's pupation chambers revealed that the pupal cocoon of the parasite completely filled the chamber. A. curculionis represented 73.2% of all parasites recovered from the mortality studies of 1972 (Table 4).

Campoplex polychrosidis Vier. is a known parasite of the plume thistle moth, Polychrosis carduana Busck (Muesebeck et al., 1951), which has been collected on musk capitula. No records were found of this parasite attacking curculionids, only lepidopterans are cited as hosts. A single C. polychrosidis was collected inside of a Rhinocyllus conicus pupation chamber, which indicates that it is a parasite of the weevil.

The 12 remaining Hymenoptera cannot presently be confirmed as parasites of R. conicus. They were recovered in small numbers from the collectively-stored musk blooms, consequently verification of parasite host by dissection of capitula was not possible as in the individually-contained heads. Massive collection and individual isolation of thistle blooms will be necessary before the parasites' thistle-feeding hosts can be recognized. Many insects feed on the musk thistle blooms and these may be the hosts of the 12 additional parasites.

The Gelis sp. parasites are listed as primarily attacking armyworms, thrips and ants (Viereck, 1916), all of which have been collected from the musk heads. G. tennellus (Say) is known to act both as a primary and a hyperparasite (Doner, 1936). As a primary parasite, it attacks a variety of hosts such as the lacewings (Chrysopa harrisii, C. nigricornis and C. rufilabris), lepidopterans (Hemerocampa leucostigma, white marked tussock moth), hymenopterans (Diprion similis, introduced pine sawfly and Neodiprion abietis, balsam fir sawfly) and coleopterans (Coleophora malivorella, pistol casebearer and C. pruniella, cherry casebearer), (Muesebeck et al., 1951). As a hyperparasite, G. tenellus was recorded from Microbracon pygmaeus, a parasite of the pistol casebearer (Doner, 1934) and numerous Apanteles species (Muesebeck et al., 1951). Because of the wide range of hosts of this parasite it could possibly be attacking R. conicus. However, its current population is too small (1 collected) to ascertain its relationship with insects feeding on musk heads.

Mesochorous discitergus (Say) was listed by Muesebeck et al. (1951) as a hyperparasite attacking Apanteles and other braconids. It has not been recorded as a primary parasite and should not be considered as a possible mortality factor of R. conicus.

Phaeogenes cynarae Bragg was recorded by Bragg (1971) as a parasite of Platyptilia carduidactyla and other plume moths, but not of coleopterans, and therefore should not be considered as a probable parasite of R. conicus.

Isodromas lycaenae (How.) was cited as a parasite of other ichneumonids and coleopterans (Muesebeck et al., 1951). It is doubtful that it parasitizes R. conicus as none of the recorded hosts is similar in life habit to the thistle infesting weevil. It is possibly a hyperparasite, but only two adults have been collected and no host correlations can be made.

Dichrogaster aestivalis (Grav.) is a parasite of chrysopids and hemerobiids (Muesebeck et al., 1951). Only one has been collected from the group of thistle blooms, and it should not be considered as a mortality factor of R. conicus.

The two eulophids, Hyssopus thymus Girault and H. benefactor (Crawford), are known only as lepidopteran parasites (Muesebeck et al., 1951). H. thymus was reported from: Rhyacionia buoliana (Schiff.) (European pine shoot moth), R. frustrana (Comst.) (Nantucket pine tip moth), and Dioryctria xanothoenobares Dyar (a conifer-feeding pyralid) Muesebeck et al., 1951. H. benefactor, a parasite of the pitch twig moth, Petrova comstockiana (Fern.), (Muesebeck et al., 1951) was listed as rare (Prentice, 1965). [12]The preceding lepidopterans have not been recorded from C. nutans. Therefore, the eulophids are probably attacking either other lepidopteran hosts or possibly R. conicus larvae.

A single eupelmid, Eupelmus sp., was recovered, but Muesebeck et al. (1951) did not record it as a parasite of coleopterans.

Fifteen Eurytoma tylodermatis Ashmead were collected from the mass of C. nutans capitula. Muesebeck et al. (1951) listed 39 hosts for this parasite. The host range includes the boll weevil and numerous other curculionids. The number of E. tylodermatis collected and the known host range indicate strong possibilities that it could be parasitizing R. conicus as an alternate host. However, none of these parasites emerged from the isolated heads. Their association with R. conicus is thus questionable.

Besides Bracon mellitor and Aliolus curculionis, two other braconid parasites were collected. A single Blacus sp. and two Bracon variabilis

[12]Coulson, 1972.

were found emerging from the bulk-collected thistle blooms. Muesebeck et al. (1951) listed B. variabilis as a parasite of Conotrachelus nenuphar (Hbst.), the plum curculio, and Tachypterellus quadriggibus (Say), the apple curculio, both of which simulate the life style of R. conicus. Although only two B. variabilis were collected and parasitism of R. conicus is not presently confirmed, future collections should produce more B. variabilis, and it is probable that it would be established as a parasite of the thistle weevil.

Since indigenous parasites have already accepted R. conicus as an alternate host it is possible that the rate of parasitism will increase and act as a population limiting factor. However, the present rate of parasitism (3.6%, Table 4) after four weevil generations indicates that the parasites will probably not reach a level which would significantly reduce the weevil population. A much higher rate of larval-pupal parasitism would seem more realistic if this is to become a potential major mortality factor.

Figure 21 depicts the 11 sites selected within the Pulaski release area to study the mortality factors of R. conicus. A summation of this study is included in Table 4. Major mortality occurs in the egg stage (58.3%), with only 9.8% mortality occurring as a combination of larval-pupal deaths. A total of 1128 eggs produced 360 adults for a 31.9% survival rate. This is a very high rate of reproduction, as these 1128 eggs could be produced by only 11 females (see III-2). Thus the weevil has the capacity for a continuing explosive population increase in spite of the present parasitism problem. The parasites seem to be exhibiting no more than a token mortality (3.6%) excluding the mortality occurring during diapause and adult dispersal. Egg destruction (58.3%) appears to be the most significant limiting factor.

The analysis of variance of the % mortality of R. conicus immatures among the 11 sites (Appendix, Table 10) produced a highly significant F value, indicating a strong relationship among sites. Following this analysis, Duncan's multiple range test (Table 5) was computed to determine site similarities and differences in mortality. From Table 5 one can observe that mean mortality ranges from 56.9 to 95.8% with no apparent relationship existing between plant density and mean mortality of R. conicus. Prevailing winds at the Pulaski release area are from the west - a factor which does not appear to have any bearing on the mean mortality. Generally, site location appears to have a bearing on mortality. Higher mortality occurred in the open treeless pasture with lesser mortalities around protected areas. The reason for this is unknown; however, it could be a result of exposure. Wind and wind-driven rain probably dislodge many eggs prior to larval emergence.

Egg mortality due to mechanical disturbance was not explored in depth, although it was found that 397 of the original 1128 eggs (Table 4) were not accountable upon collection of capitula. Over the six weeks interval, between labeling the blooms in the field and collecting them, 35.2% of the total eggs had been mechanically removed from the thistle blooms. This could account for a large proportion of the total, 58.3%, egg mortality (Table 4), although it is not known whether the eggs had hatched prior to removal from the bloom. Regression analysis of egg

Table 5. Mortality of *Rhinocyllus conicus* immatures at eleven sites within the Pulaski release area in 1972.

Site #	% mean mortality[a,b]		Plant density[c]	Site Description	Unshaded exposure[d]	Exposure to strong wind
IX	56.6	a	.41	Open pasture; trees on western perimeter	N, E, & S	no
VII	66.6	ab	.20	Trees on northern perimeter; ridges on western & eastern sides	E, W, & S	no
VI	66.6	ab	.15	Trees to the north; south facing slope much higher in altitude than all other sites	S, E & W	yes
IV	73.1	abc	.05	Open, treeless, ridge-line pasture	N, E, S, W	yes
XI	75.6	abcd	.50	Ridges on eastern & western boundaries trees to the north	E, W, & S	no
I	76.7	abcd	.09	Trees to the east	N, W, & S	yes
II	79.4	bcd	.06	Open pasture, one tree in area	N, E, W & S	yes
III	80.2	bcd	.09	Open, treeless pasture	N, E, W & S	yes
VIII	89.0	cd	.20	Open, treeless pasture	N, E, W & S	no
V	90.8	cd	.18	Open, treeless pasture	N, E, W & S	yes
X	95.8	d	.40	Open, treeless pasture	N, E, W & S	no

[a]Means followed by the same letters do not differ significantly by Duncan's multiple range test (P = .05).

[b]% mean mortality = (No. of adults/no. of original eggs) X 100.

[c]Plant density is given as plants/square foot (from Table 3).

[d]The letters N, E, W & S stand for North, East, West and South, respectively.

removal and emergent adults illustrated a nonsignificant relationship between these variables (F = 1.64, r = .01; Appendix, Table 11). This indicates that mechanical removal of eggs during the interim between original field count and final collection does not account for significant weevil mortality. Therefore, statistical analyses were then computed on the basis of original eggs.

Egg predators (e.g. Orius insidiosus was plentiful) could also have contributed to mortality although predation of eggs was not observed. Analysis of variance of regression between eggs present upon collection and emergent weevil adults (Appendix, Table 12) produced a highly significant F value with a correlation coefficient, r = .64, high enough to indicate a relationship between these two variables. However, an r = .64 is insufficient to establish that the remaining eggs produced all of the adult weevils. The analysis of variance indicates the close egg-emergent adult relationship but also implies that many larvae had probably already hatched prior to egg removal.

Infested thistle blooms had an average of 9.8 original eggs which produced a mean 3.1 adults (Table 4). However, one capitulum contained a maximum of 38 eggs (Appendix; Table 7, VI-5). Questions regarding crowding as a mortality factor were considered and analyzed (data in Appendix, Table 13). Mortality of R. conicus larvae and pupae compared to number of original eggs produced a highly significant F value. This indicates a significant relationship between the two variables. However a correlation coefficient (r = 0.31) reveals that this is a very weak relationship (Appendix, Table 14). This indicates that crowding is not a significant mortality factor at present. If the population continues to increase perhaps crowding will become important.

6. Observations on seasonal life history of *Rhinocyllus conicus* in Virginia

A. Introduction

The seasonal life history of an insect is an important criteria to be examined in evaluation of colonization attempts. Certain necessary environmental requirements are essential for specific insects; for example, the lack of adequate overwintering sites could very well act as a limiting factor in establishing colonies of *R. conicus*.

Mellini (1951) recorded *R. conicus* adults hibernating under tree bark and rocks. Zwolfer (1967) indicated that *R. conicus* adults emerge, leave their hosts and go into hibernation until the following spring. He observed that a few adults overwintered within the capitula of the host plant. [13]Hendrick noted that colonies of *R. conicus* became established more successfully in areas adjacent to trees, but offered no hypothesis regarding this observation. In an attempt to ascertain the most desirable site characteristics for a release the seasonal life history of the weevil needs to be examined.

Kegley's farm in Pulaski Co., Va. has been a phenomonally successful release site for *R. conicus*. Over a period of four generations the population has virtually exploded from an initial colony of 100 to a present population easily exceeding 100,000. Dispersal over a mile from the initial site has been verified. The Kegley farm must be considered the best study area in Virginia.

[13]Hendrick, 1971. p. 4.

B. Materials and methods

Observations at the Kegley farm in Pulaski began in June of 1971 and continued until new weevils emerged from thistle blooms in the summer of 1972. During the period of weevil activity actual observations were made at least three times weekly. When the weevils began to disappear from the thistle plants an extensive system of sampling was undertaken to locate them. The sampling consisted of:

1. sweeping the thistle plants and vegetation in the immediate area of the release site and the adjacent wooded areas throughout the summer and fall until frost.
2. taking D-vac samples of the same areas.
3. taking litter and soil samples of the field and forest areas.
4. examination of thistle stalks, loose bark on trees, and the undersides of rocks.

A standard heavy duty sweep net was used to take sweep samples. Ten samples of 100 pendulum sweeps each were taken once a week from August 10, 1971 until September 27, 1971, at which time they were halted by rains. A final set of samples was taken on October 29, 1971 before this technique was abandoned. There was a total of 8 sampling dates and 80 samples taken. These samples were brought back to the laboratory, placed in sleeve cages and examined.

D-vac sampling consisted of taking five 50-"suck" (1 sec. each) samples each of the 8 days along with the sweeps for a total of 40 samples. The suction device was used with a 1 ft.-diameter cone. Material collected in this manner was processed in sleeve cages.

Litter samples were taken by use of a D-vac, and a conversion cone which converted the hose from a 30 cm diameter to about 10 cm. A 45.7 cm metal square was used as the basic sample size. Five samples were taken at each sampling date. Litter samples were taken on Sept. 27 and intermittently throughout the fall and winter of 1971-1972. In all there were 50 soil samples taken in this manner. The objective was to determine if weevils could be found in the debris. Quantitative sampling would be of no value as weevils had not previously been found. Litter samples were placed on a Tullgren funnel for 48 hours, and the collection was then examined for adult R. conicus. The debris was removed and placed on a warming table consisting of a galvanized metal pan approximately 1 x 1.5 meters and 3 mm thick which was suspended in a wooden frame over a bank of twelve, 250 watt light bulbs. Living organisms responded to the heat of the lights by trying to escape and were easily located while moving about.

Soil samples were taken at the same time at the sites where litter samples were taken. Following removal of the litter from a sample site a hand spade was used to remove two inches of soil directly beneath the recently cleared site. The soil samples were also examined by use of the warming table.

The forested area adjacent to the release site was examined in an attempt to locate R. conicus. Dead trees were examined in hopes of finding weevils under the loose bark. Old dead thistle stalks were dissected, and all rocks in the area were overturned in search of the weevils. Extensive searches were conducted intermittently throughout the fall and winter of 1971-1972.To evaluate the success and development of R. conicus eggs deposited prior to bloom emergence, two (3 ft. x 3 ft. x 4 ft. high) cages (Fig. 23) were constructed using a 2 x 2 inch framework covered with one-eighth inch aluminum screening. These cages were set up on May 17, 1972 to cage two thistle plants. Eggs were counted on the plants and all weevils were removed. Egg counts and examinations were made on 3 successive dates to insure the removal of all weevils. Vandals destroyed one of the plants. Upon maturation the second plant was closely examined for signs of larval damage.

In Roanoke, Virginia a nylon mesh cage 6 feet wide; 6 feet tall and 8 feet long had been erected on the grounds of Woodrum Airport. This was an attempt to establish a colony of R. conicus which had been sent from Rome, Italy. One hundred and twenty-six weevils had been released on Carduus acanthoides and some reproduction had been observed. Following the death of the plants in the fall, efforts were made to recover some of the weevils for study purposes. All of the debris was removed from the cage and examined. Soil samples totaling 6.75 square feet (12.5 per cent of total area) were taken two inches deep. The cage was left standing to prevent the dispersal of any weevils which could have been overlooked. On March 20, 1972 the cage, constructed of 2 inch by 2 inch boards bolted together at their junctions, was dismantled and removed.

C. Results and discussion

Adult R. conicus weevils began to emerge from infested Carduus nutans heads in Pulaski Co., Virginia in July of 1971. Personal

Figure 23. Cage used for isolating _Carduus nutans_ plants prematurely attacked by _Rhinocyllus conicus_ (Pulaski Co., Va.; June, 1972).

observations in the field revealed new weevils present on July 17 and emergence continued until August 27. After August 27 no weevils were observed.

During the interval between July 17 and August 27, the only places where weevils were located were on the Carduus nutans capitula. Bull thistle, Cirsium vulgare (Savi) Ten., began blooming in mid-August at the site. Extensive examination of bull thistle revealed no R. conicus (egg, larva or adult), although the plant was cited as a host by Bargagli (1883) and Mellini (1951) in the Appenine mountains near florence, Italy. Mellini remarked that the weevil's attack on C. vulgaris was more pronounced than on Carduus nutans. Zwolfer (1967) pointed out that this was possibly due to the more favorable synchronization of the weevil with C. vulgaris in the Appenines. The different phenologies of the Appenine mountain weevil and the Upper Rhine Valley strain, which was released in Virginia, explain this differential preference of the weevil for thistles in accordance with the synchronization of life cycles.

The preceding observation also has a bearing on the number of generations that the weevil undergoes in a year. If C. vulgaris is acceptable as a host it would appear that the first generation weevils would be found in great numbers on the bull thistle plants. However, this was not the case in Pulaski Co., Va. as no weevils were found on bull thistles, although the insects were emerging in thousands from C. nutans blooms in their immediate vicinity.

Following the disappearance of the last emerging weevils on

August 27 all samples taken were negative. No weevil was found in eighty sweep samples, 40 D-vac samples and 50 litter and soil samples, coupled with extensive searching under tree barks, stones and old thistle stems in Pulaski Co. until they emerged and began feeding again in the second week of May, 1972.

Although the planned, systematic approach to locating R. conicus proved fruitless, a fortuitous find was made while working on another part of this project in Roanoke. In the fall of 1971 no weevils could be found in the cage in which they had been reared. Upon dismantling the cage in March it was discovered that the insects had crawled into the cracks between the boards to overwinter. In all, 309 weevils were recovered and many others lost due to an earlier unawareness in which two posts had been seperated rather hastily. Only 1 of the 309 weevils was dead. They were all in diapause and later proved to be in good condition.

The weevils had preferred the junctions of the 2 x 2's rather than the debris within the cage, as overwintering sites. Being six feet off the ground could indicate that the weevils tend to fly upwards in search of hibernation sites. Regardless of the height factor this discovery helps to explain the success of releases near wooded areas. R. conicus can safely overwinter under bark of trees as indicated by earlier reports. Debris and soil litter do not appear to be favored as overwintering sites; otherwise, some adults should have been recovered from the litter within the cage at Roanoke.

On May 4, 1972 the Kegley farm was visited. Musk plants were just beginning to produce their vertical stems (bolting) and no weevils were found. On May 11, 1972 R. L. Pienkowski observed the first R. conicus adults on a bolting plant. The weevils were actively feeding at this time and some oviposition was noted. The following day a survey of the thistles revealed that 80 per cent of all bolting plants had weevils feeding on them. No plants showed signs of bloom emergence at this time, although many were found to bear weevil eggs.

On May 17 the two thistle plants were encaged. The plant which escaped destruction by vandalism was observed bearing 42 R. conicus eggs. These eggs were on the new leaves of the terminal portion of the stem. No blooms were evident at this time. The cage was removed on July 20, 1972, and the plant was thoroughly examined for signs of weevil larvae. The eggs were no longer obvious on the leaves, and dissection of all 28 blooms produced negative results. Mark Beisler had earlier discovered that R. conicus larvae occasionally bore into the stem producing a small gall-like area which is very obvious (Fig. 24); however, examination of the encaged thistle's stems produced no larvae. Apparently the weevils began oviposition about a week too early in 1972 and many eggs died resulting from unfavorable placement on the host. Synchronization of life cycles between R. conicus and C. nutans may not be as harmonious as previously anticipated. Loss of eggs due to early oviposition may account for a large proportion of the mortality of R. conicus.

On May 11, 1972 the first weevils were found returning to C. nutans plants on the Kegley farm. The insects were later noted to be extremely

(Photo by R. L. Pienkowski)

Figure 24. *Rhinocyllus conicus* larva (indicated by arrow) and unidentified parasite larva within stem of *Carduus nutans* (Pulaski Co., Va.; July, 1972).

active in the afternoon (2:00 to 5:00 P. M.) and were observed flying during these hours on warm sunny days. Very little feeding damage to the plants was observed. However, a very interesting observation on feeding behavior was made. While actively feeding the weevil often jerks its body in a swaying side to side motion. This behavior was also noted in the laboratory when the weevil was disturbed continously each time it tried to walk. The reason for this behavior is unknown.

7. Establishment and dispersal of *Rhinocyllus conicus* at three release sites in Virginia

A. Introduction

At the initiation of this project twenty three releases of *Rhinocyllus conicus* had been made throughout the northern and western portion of Virginia.[14] Numbers of weevils released at each of the 23 sites varied from 100 - 1,000. Follow up of these releases was difficult since the sites were strung out throughout the entire length of Virginia (about 300 mi.). Consequently, surveying these sites usually consisted of a group of five or more people examining thistle plants in various portions of the release area. A need for quantitative assessment of weevil establishment was evident. However, a thorough survey of each site would have been extremely time consuming and practically impossible with the available man power. Therefore, three unique sites were selected for surveillance of establishment and dispersal of *R. conicus*.

B. Materials and methods

The areas selected for study were chosen primarily for their thistle flora and time of weevil release. The releases studied were in Highland, Loudoun and Frederick counties, Virginia. The study began in July of 1971 and involved an intensive survey of the three sites. A second survey was made in July, 1972 to evaluate degree of establishment over a one year interval.

The Highland site (Fig. 25) was selected because its prevalent

[14] Hendrick, 1971. Table 1.

Figure 25. The Devil's Backbone study site
in Highland Co., Va.
The arrow indicates the original release area.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thistle species was *Carduus acanthoides*, plumeless thistle. The only other species of thistle present was the ubiquitous *Cirsium vulgaris*. The bull thistles were not plentiful and were far less than the plumeless thistles. A towering jagged ridge, the Devil's Backbone, rises to the southeast of the study area, which is actually the base of the ridge. The site is very steep, rocky and of marginal value as pastureland. This study area will be referred to as the Devil's Backbone site.

Devil's Backbone can be reached by proceeding north from Monterey on Rt. 220 for 7 miles; turn left on state road 642 and travel for about 2 miles. The release site is on the northeast side of the road. The thistle infested area is a crude rectangle approximately 300 x 400 yards extending lengthwise from northeast to southwest. It is bordered on the northeast and northwest by hay fields and on the southeast and southwest by forest. The soil is a very shallow, dry, rocky covering for a calcareous stone foundation. At this site, 450 *R. conicus* were released on September 17, 1970 near the maple trees in the center of the area (Fig. 25).

Frederick Co., Va. is heavily infested with musk thistle, *C. nutans*, but there are also heavy infestations of plumeless thistles present. One release site, White Hall (Fig. 21), was considered ideal for a study area because of the mixture of musk and plumeless thistles present. Again there were a few bull thistles present, but they represented a very minor portion of the flora. Musk was the predominant thistle species.

(Photo by R. L. Pienkowski)

Figure 26. White Hall release site

in Frederick County, Virginia

The arrow indicates the original release area.


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The White Hall site is located on the northeast side of state road 671, 0.3 miles from its junction with state road 739 in Frederick Co., Va. The thistle infested area is too extensive to delineate as at Devil's Backbone. The plants are not limited to a single pasture, but are found throughout the immediate area. The release area is an old pasture which has not been used for a number of years. It is bordered: to the southeast by forest; to the southwest and northwest by state road 671 and similar unused, weedy pasture; to the northeast by an alfalfa field, and a wooded area beyond this. The soil is a shallow covering of red clay composition lying over a shale substrate. On September 3, 1970 1,000 R. conicus were released at White Hall. The spot selected for release was a clump of trees in the center of the study area (Fig. 26).

The third site chosen was selected for a stand of musk thistle which had no plumeless thistle present. Tippett's farm (Fig. 27) in Loudon Co., Virginia fulfilled the desired criteria. Bull thistle was sparcely present at the study area, but no plumeless was evident when the project began. However, in 1972 12 mature plumeless thistles were noted.

Tippett's farm can be found by proceeding north of Highway 50 on state road 619 for about 1 mile, then turning left at the Llangolen farm sign. The study area is located on the southwestern portion of the estate. It is a crudely pentagonal strip of weedy, fallow cropland. The thistle infestation extends approximately 220 feet northeast by southwest and approximately 400 feet northwest by southeast. It is bordered on the northeast by a tree-lined stream and extensive, abandoned, weedy pasture beyond this; on the southeast the thistle

(Photo by R. L. Pienkowski)

Figure 27. Tippett's farm release site

(Loudon County, Virginia)

X indicates the original release area.


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growth terminates in a thick secondary growth of boxelder and assorted weeds; on the southwest lies a corn field and on the northwest a tree lined fence row is backed by weedy, unused pastureland. The soil is heavy, red clay. One thousand R. conicus were released at Tippett's farm on September 3, 1970.

Several sampling methods were considered and many techniques were examined prior to the initiation of this program. Finally a modified version of quadrat-transect procedures described by Brown (1954) was decided to best fit the situation. By use of five brightly colored (red and white) poles 4 transects were set up. A single pole was placed at the center of the site and another pole at each compass point (N, E, W and S). The central point was marked by a stake in 1971 so the same transects would again be surveyed in 1972. Square samples, 10 feet on a side, were taken logarithmically. The first sample (designated as 0) was taken with the central stake being the center of the plot. Moving outward from the center, samples were taken every 10 feet for the first 100 feet; every 20 feet for the next 200 feet and every 50 feet thereafter until thistles could no longer be found. Up to ten thistles were examined at each sample plot. The number and species of thistles present were recorded along with the number of plants and heads infested (sampling data is in Appendix Tables 15, 16 and 17).

A climatological summary for the three sites was obtained from the U. S. Dept. of Commerce to compare the study areas meteorologically. Despite the extensive coverage of weather data in Virginia, the fluctuations of climate are often so localized that distribution of temperature and precipitation can only be presented in general terms. Parts of information regarding biotic zones and climatic factors are taken from Hoffman, 1969.

Aerial photos of White Hall and Tippett farm sites were taken but the Devil's Backbone site was not photographed from the air. Due to the location of the Devil's Backbone site, ground level photos are adequate for illustrating topography and weevil dispersal.

The three release sites that were chosen for this study had been inoculated with R. conicus in September, 1970. These weevils had been shipped from Delemont by H. Zwolfer, and were in diapause at the time of release. It has thus been possible to monitor the degree of establishment and dispersal of the weevils beginning with the first generation produced in 1971, when this project was initiated.

On July 26, 1971 a transect survey was taken of the Devil's Backbone site (Fig. 25). The follow-up survey was made on July 19, 1972. On July 27, 1971 White Hall and Tippett's farm were examined (Figs. 26 and 27, respectively). The next survey of these two sites was made on July 26, 1972. Data taken during these surveys are summarized in Tables 6-8.

C. Results and discussion

Within these transect areas the available thistle plants fluctuated most at White Hall (Table 7). The original area has not been managed, and the resultant dense weedy growth is competing against the thistles and reducing their numbers. The other two sites also show changes in thistle numbers examined, perhaps this is best explained as normal

Table 6. Number of *Rhinocyllus conicus*-infested thistle heads at White Hall Devil's Backbone, and Tippett's farm during 1971 and 1972.

Transect	Devil's Backbone		Tippett's farm		White Hall	
Direction	1971	1972	1971	1972	1971	1972
East	12	0	129	63	13	0
West	21	27	12	0	105	76
South	5	0	32	10	26	17
North	10	1	42	79	13	310
Total	48	28	215	152	157	403

Table 7. *Rhinocyllus conicus* infestation of thistles within 100 feet of initial release area at White Hall, Tippett's farm and Devil's Backbone during 1971 and 1972.

	Devil's Backbone		Tippett's farm		White Hall	
	1971	1972	1971	1972	1971	1972
No. of plants examined	290	226	262	303	339	86
No. of plants infested	12	6	51	48	60	23
% of plants infested	4.1	2.7	19.5	15.8	17.7	26.7

Table 8. Maximum distance of recovery (in feet) of *Rhinocyllus conicus* from initial release site at White Hall, Devil's Backbone and Tippett's farm during 1971 and 1972.

Transect direction	Devil's Backbone		Tippett's farm		White Hall	
	1971	1972	1971	1972	1971	1972
East	120	120	60	90	180	0
West	200	220	20	0	300	950
North	350	280	40	90	160	450
South	260	0	80	20	100	350

density fluctuations. From Table 7 it can also be observed that White Hall exhibited the only increase in plant infestation over the two year period. Table 6 illustrates the large increase in numbers of infested thistle heads at White Hall; whereas the other sites show significant decreases. In Table 8, the weevils are shown dispersing more readily at White Hall.

At White Hall, eleven *C. acanthoides* plants were encountered in the 1971 transects while only three were examined in 1972. During both of these years no weevil infestation was found on these plants, and only two infested *C. acanthoides* blooms were observed in the entire field in 1972. At Tippett's farm, no plumeless thistles were present in 1971; however, 12 were found in 1972. On these 12 plants only 4 infested blooms were found. *Rhinocyllus conicus* seems to exhibit a distinct preference for *C. nutans* at both of these sites. Synchronization of life cycles favors *C. nutans* over *C. acanthoides* as a host. Even when plumeless thistle was observed blooming alongside newly infested musk plants there was still a distinct preference exhibited for musk.

Of the three areas examined, White Hall has the best establishment of *R. conicus*. The other two sites appear to be undergoing a gradual decline in population numbers. Available climatological data (Table 9) does not explain the discrepancies. Highland County's temperatures range a few degrees lower than those of Frederick County, but the mean temperatures alone are not adequate explanation. Annual precipitation is greatest in Highland Co. (Table 9). However, precipitation during

Table 9. Available comparative climatological data*
for Highland and Frederick Counties, Virginia.

Climatological factor	Highland	Frederick
Mean no. of days with precipitation greater than or = 0.1 inches	76	79
Precipitation (inches) during presence of eggs (May-July)		
-1971	13.00	16.81
-1972	12.86	22.33
Total annual precipitation	40.05	37.43
Mean temperatures	49.2	55.2
Mean daily maximum	60.8	65.7
Mean daily minimum	37.8	44.6

*Source of data is the U. S. Dept. of Commerce, Environmental Science Services Administration, Washington, D. C.

the time interval when eggs were present on the plants was actually greatest in Frederick Co. (Table 9). This agrees with the results of mortality studies in Pulaski which indicate that mechanical dislodgment of eggs is nonsignificant (III-5). Although no data is available, the Devil's Backbone site in Highland is subjected to colder extremes than either of the Frederick sites and has a much shorter growing season (Hoffman, 1969).

Although being located in the same climatological area, Tippett's farm and White Hall have produced significantly different results. Tippett's farm has only a limited thistle infestation, whereas White Hall has thistles spread over a large area which offers a wide range of ecological niches. White Hall also has a large wooded area immediately adjacent to the release site which would afford better overwintering sites.

The Devil's Backbone area received only 450 weevils compared to 1,000 at the other sites. Consequently the infestation data should be expected to be approximately one-half of that obtained for the other site. However, if we compare the results of Tables 6 and 7 it can be seen that doubling the results for Devil's Backbone would not compensate the discrepancies. C. acanthoides does not appear to be a good host for the Rhinocyllus conicus strain which was released, and the synchronization differences coupled with the colder weather present at the Devil's Backbone could have acted as the limiting factors for weevil establishment. Perhaps the weevil can survive and selection will permit better establishment in the future, but the gene pool is diminishing and further hopes for the Devil's Backbone site are questionable.

8. General summary and conclusions

Newly emerged *Rhinocyllus conicus* were collected from infested thistle heads at Pulaski, Co., Va. in 1971. Fifty weevils were separated by sex and paired. Single pairs were maintained on *Carduus nutans* leaves, under controlled environmental conditions, until diapause was broken. Egg and mortality data were taken until all weevils had died. Females oviposited 1-234 eggs with a mean of 100.5 over an 81 day range. Life expectancy of post-diapause weevils (70.4 days) did not differ significantly between the females (70.4 days) and the males (70.5 days).

The extended range of oviposition (81 days) helps to explain field observations and to answer the question regarding generation numbers per year. At Pulaski, new eggs found in August, 1971 were probably attributable to overwintered adults, not newly emergent individuals. Therefore, *R. conicus* is considered a univoltine insect in Pulaski, Va. The rate of fecundity was found to be adequate to account for the estimated population increase from 100 to 100,000 in 3 generations.

Sampling of density and weevil infestation of 1999 blooming *Carduus nutans* plants on the Kegley farm in Pulaski Co., Virginia revealed that: 1/ *Rhinocyllus conicus* does not seem to be attracted to *C. nutans* as a function of the thistle's density; 2/ thistle height varied from less than 2 feet to more than 8 feet. Most plants were in the 2.0 to 6.0 feet range; 3/ 26.7% of all *C. nutans* blooms that were examined were infested with *R. conicus* larvae, pupae or eggs; 46.0% of all terminal capitula, but only 18.2% of the lateral blooms were infested.
4/ statistical evaluation showed a highly significant relationship among

the four height categories of C. nutans relative to weevil infestation for terminal blooms, but a non-significant relationship for lateral blooms. Explanation of this and the preceeding phenomona lies in the synchronization of weevil and thistle life cycles. Earlier blooms are more susceptible to attack. Terminal heads are the earliest to flower, thus the insect does not apparently seek out taller, more vigorous plants for oviposition.

Larval feeding damage was evaluated in Pulaski Co., Va. in 1971. Polynomial regression analysis favors a 1st degree (linear) relationship between head diameter and mature seed production in Carduus nutans capitula ($r = 0.72$). The relationship is statistically sound as indicated by the reasonably high correlation coefficient. Multiple regression analysis of the three variables: head diameter (X_1), emergent weevils (X_2) and mature seeds (Y) illustrates a highly significant relationship existing among X_1, X_2, and Y with $r = 0.72$. Prediction formula given by the analysis indicates that each developing larvae destroys 9.67 achenes; thereby assuring the destructive nature of the insect. Complete seed destruction did not occur and regardless of level of weevil infestation some mature seeds were produced.

It is evident that R. conicus larvae do limit viable achene production in C. nutans. However, the weevil's populations in Pulaski Co., Virginia has not reached a level commensurate of weed control by seed destruction alone. As pointed out by Huffaker (1959) direct control is not always essential. R. conicus does not appear capable of complete seed destruction but this does not necessarily mean that the weevil is not exhibiting a pressure on the weed ecologically. With partial destruction of thistle achenes perhaps C. nutans will lose its competitive edge. It is too early to conclude that R. conicus larvae do not do severe damage to the over-all population of musk thistle. The population of weevils in Pulaski Co., Va. has just in the last two years achieved a level high enough to hinder seed production. The biennial-annual behavior of the thistle, and the superflous residual seed population will dictate the need for further follow-up of this release site. However, these studies show that R. conicus larvae lower the number of viable seeds produced by C. nutans.

A series of studies was conducted at Pulaski Co., Va. in 1971-1972 to determine mortality factors of Rhinocyllus conicus on musk thistle. The study revealed a total of 15 parasitic Hymenoptera emerging from weevil-infested thistle blooms. Two braconid parasites, Aliolus curculionis and Bracon mellitor and one ichneumonid, Campoplex polychrosidis were found to be parasitizing R. conicus larvae and pupae. The other hymenopterans were questionable parasites as they were not positively identified as to their hosts. They were probably parasites of other insects on the thistle heads. Parasitism was found to account for only 3.6% of the total mortality with A. curculionis accounting for 2.7% alone. Therefore, A. curculionis will have to be considered in further life cycle studies of R. conicus. These Hymenoptera were native to the area and not imported with the weevil. No egg or adult parasites were found.

Further mortality studies revealed that crowding was not a primary cause of death to R. conicus larvae and pupae. Major mortality occurred in the egg stage (58.3%). Egg removal from thistle capitula by wind and rain did not correlate well enough with emergent adults to be considered as the major egg mortality factor, although 35.2% of the original eggs had been dislodged by the time that infested blooms were collected. Mechanical removal of eggs was shown to be statistically insignificant in egg destruction. Therefore it is evident that some eggs had hatched prior to removal.

Mortality of larvae and pupae within blooms was only 9.8% of the total eggs and is not highly important. A total of 1128 eggs produced 360 adults with a maturation potential of 31.9%, which explains the rapid population increase at Pulaski.

Weevil production per bloom was moderate. An average infested thistle bloom contained 9.8 original eggs and produced 3.1 adult weevils.

Mortality differed among the 11 study sites within the Pulaski release area; ranging from a low mean mortality of 56.5% to a maximum of 95.8%. Explanation of the differences apparently lies in the geographical location of each site. Unprotected areas had higher mortality than those adjacent to trees.

Over-all appraisal indicates that mortality is not exceptionally high, 68.1%, and the population should continue to increase until crowding and parasitism act to limit the weevil numbers. Parasitism by itself is a questionable limiting factor in that the parasitism, 3.6% should have been much higher in 1972 following an extensive weevil population in 1971. Predators are not known to attack the weevil larvae and pupae and interspecific competition does not occur; consequently, the mortality of R. conicus at Pulaski, Va. will probably remain very moderate.

The life cycle of R. conicus was monitored at the Pulaski Co. study area for a period of 14 months (June 1, 1972-July 27, 1972). Observations were made on the weevil from its emergence in the spring until it could no longer be found in the field. After its disappearance in August of 1971, a series of extensive samples was taken to locate the diapausing weevil. Examination of a known alternate host, Cirsium vulgaris, yielded no weevils although the insects had emerged by thousands all around the bull thistles. This observation supports the hypothesis that R. conicus is a univoltine insect in Pulaski Co., Va. All samples taken to locate the diapausing weevil proved fruitless, although a lucky find at another study area in Roanoke offers insight into the overwintering habits of the weevil. Finding the weevil in the cracks of the insect cage at Roanoke indicates the preference for these sites over the available trash and litter. This finding explains the better success in establishing colonies of R. conicus around wooded areas.

Observations were made at least three times weekly during the insect's active stage of life. Feeding damage was minimal and flight was observed to occur on warm, sunny days between 2:00 P. M. and 5:00 P. M. Oviposition was not well synchronized with C. nutans development and although R. conicus has been observed to survive as a stem borer no recovery was made from eggs laid on a non-blooming plants. These individuals which oviposit early fail to reproduce maximally, hence selection would be against them.

Three unique sites were selected for a two year study on R. conicus establishment and dispersal. White Hall, Devil's Backbone, and Tippett's farm were selected for their respective flora - mixture of plumeless and musk; pure plumeless and pure musk. The following results were obtained.

White Hall has the best degree of establishment and dispersal of three sites examined. Favored by climate, adjacent forests and the presence of musk thistle, Rhinocyllus conicus has become established and is beginning to spread. The Devil's Backbone and Tippett farm populations appear to be decreasing. Significant egg mortality due to mechanical dislodgement by wind and rain is doubtful. It is probable that the major population decrease at the Devil's Backbone is due to mortality during diapause and a non-preference toward plumeless thistle which is exhibited during oviposition. Plumeless thistle does not appear to be a preferred host where musk and plumeless thistles occur together. Although synchronization of weevil and weed life cycles is an important factor in this consideration, it is not the only reason. Preference for musk thistles is evident. In the pure C. acanthoides release site at the Devil's Backbone, these weevils have barely managed to survive and success is questionable if selection fails to produce a better synchronized, hardy strain. Although selection is an optimistic possibility it is improbable at the Devil's Backbone due to the present small population and limited gene pool.

Possibilities for improving success of establishment would be:

1/ to match localized environments with the weevil's native habitat.

2/ to release the weevil only where adequate forest cover and diversity of habitats are available.

3/ to selectively collect weevils from plumeless thistles in their native habitats for release on plumeless thistles in Virginia. We have gotten good establishment at Turner Gilmer's farm in Russell Co. on plumeless in an environ not drastically different from Highland, except that thistles are more extensive. Perhaps we have the right gene pool at Russell Co. and this should be used in further releases on plumeless.

4/ to discontinue late summer releases and begin releasing the insect in early spring so that the possibility of extensive winter mortality can be eliminated.

Biological control of musk and plumeless thistles can only occur following successful establishment of R. conicus; therefore, more emphasis should be placed on improving the release possibilities with each site being considered individually.

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APPENDIX

Table 1: Fecundity and mortality of <u>Rhinocyllus conicus</u> under controlled environmental conditions

Dates	Eggs laid by weevil pair number: 1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
5-12	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
5-15	1	1	3	1	0	0	5	2	0	2	1	2	0	15	3	0	0	1	2	0	0	0	0	17	0
5-17	0	0	5	0	0	0	0	25	0	0	0	0	0	20	1	1	0	0	5	0	3	0	15	19	0
5-22	18	0	11	1	18	0	5	2	0	1	5	3[a]	0	21	0	0	14	0	19	0	13	0	4	20	0
5-24	8	0	17	5	13	0	3	4	0	1	13	0	0	16	0	0	0	0	18	0	0	0	0	20	0
5-26	11	5	16	18	9	1	12	9	1	2	13	13	16	13	5	0	1	3	25	0	7	0	0	11	0
5-29	2	28	22	16	6	0	31	16	0	16	19	33	13	19	14	0	13	0	24	8	8	0	17[a]	14	1
5-31	15	15	13	18[a]	20	0	15	35	14	0	18	27	16	25	20	0	12	1	17	4	9	1	3	11	0
6-2	14	13	10	12	39	0	14	18	25	0	20	33	10	9	13	0	0	0	0	5	4[a]	0	6	1	0
6-6	16	16	15	0	0[b]	0	20	4	22	0	15	11	9	10	7	0	4	0	12	3	3	0	19	10	0
6-7	11	3	7		2	0	4	3	11	0	17	10	4	9	1	0	3	0	6	0	1	0	11	1	0
6-9	6	6	9		0	0	2	1	11[a]	5	8	9	3	10	4	0	7	0	8	1	7	0[b]	6	4	0
6-12	8	16	0			0	5	0		9	5	16	0	5	8	0	0	0	1	0	14		0	4	0
6-14	9	11	8			0	4	0	2	9	2	11	0	7	7	0	0	1	0	0	6	0	0	2	0
6-16	8	5	11			0	0	0	0	2	0	8	0	3	5	0	3	0	0	9	9	0	b	0	0
6-19	10	7	21			0	13	0	3	6	0	7	0	0	5	0	0	0	0	0	0	0		0	0
6-21	4	4	7			3	0	0	0	2	0	5	0	2	a	3	0	15[a]	3	11	0	0		3	0
6-24	5	0	18			0	0	0	0	4	0	1	0	b	0	20	4[a]	0	7	2	0	0		0	0
6-26	0	0	10			1	0	0	0	2	0	6	b	0	b	3[a]	0	7	3	3	b	0		b	a
6-28	0	0	12			0	b	0	0	10	0	10		0		4	0	4	b	5					0
6-30	0	0	3			b		0	0	0	0	0		0		6	0	0	0	0				a	b
7-3	b	b	8[a]			0		0	0	3	0	13		0		0	1	0	0	0					
7-5			5			0		b	0	1	0	5		0		0	0	0	0	0					
7-7			0			0		0	0	0	0	3		0		0	0	b	a	0					
7-9			8		a	a		0	0	0	0	2		0		7	0			b					
7-12			2					0	0	0	0	b		a		4	0			0					
7-14			0				a	0	b	0	a		a			8	0			0					
7-17			1	b				0		b	b					0	0			0					
7-19	a		0					0								20	0			0					

Table 1: Fecundity of R. conicus under controlled environmental conditions (Cont'd.)

	Eggs laid by weevil pair number:																								
Date	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
7-21			0					0								2	0			0		a			
7-24			0					0								5	0			0					
7-26			b					0								2	b			0					
7-28								0								0				0					
7-31								0								2				a					
8-3								0		a						3									
8-4								0								2									
8-7								0								b									
8-14								a																	
8-28		a																							

[a] Male died

[b] Female died

Table 2: *Carduus nutans* density data for Pulaski study area in July, 1972.

Sub-plots[b]	plots[a]									
	I	II	III	IV	V	VI	VII	VIII	IX	X
1	81	6	60	12	29	12	6	6	3	7
2	7	3	0	33	47	7	2	7	4	11
3	27	12	81	13	20	3	7	3	3	0
4	38	21	56	62	20	0	6	8	23	44
5	20	1	36	25	12	1	34	21	1	22
6	3	5	46	3	19	1	1	21	1	11
7	124	5	81	28	28	0	2	9	12	10
8	1	0	11	14	0	14	12	3	6	3
9	153	44	32	12	0	12	15	7	8	33
10	49	2	3	0	3	2	9	4	2	11
Totals	503	99	406	202	178	52	94	89	63	152
Dimensions (in feet)	200 X 60	100^2	100^2	100^2	100^2	100^2	100^2	100^2	100^2	200 X 40
Plants per square ft.	.500	.099	.406	.202	.178	.052	.094	.089	.063	.152

[a] Plot designations coincide with sites of fig. 17.

[b] Each subplot is a square 10 feet X 10 feet. All bolted plants were counted (rosettes are not included).

Table 3. Comparison among heights for total plants.

Part i. Percent infested terminal blooms.

ANOVA.

source	df	ss	ms	F
between	3	491535.72	122883.93	65.62**
within	1994	3734252.65	1872.74	
Total	1997	4225788.37		

Part ii. Percent infested lateral blooms.

ANOVA.

source	df	ss	ms	F
between	3	11455.81	2863.95	0.50 ns
within	1784	10137087.26	5682.22	
Total	1787	10148543.07		

Table 4. Data for destruction of the achenes of

Carduus nutans by the action of Rhinocyllus conicus larvae.

X_1 = Head diameter; X_2 = Emergent weevils; Y = Mature seeds produced.

Head	X_1	X_2	Y	Head	X_1	X_2	Y	Head	X_1	X_2	Y	Head	X_1	X_2	Y
1	27	2	478	26	25	2	162	51	25	1	484	76	32	2	617
2	30	8	310	27	30	5	575	52	32	1	589	77	33	1	822
3	29	1	71	28	32	1	572	53	24	0	230	78	33	2	670
4	27	1	393	29	30	4	572	54	25	4	65	79	40	7	605
5	33	3	655	30	30	2	508	55	27	5	696	80	35	2	787
6	24	3	312	31	29	2	339	56	33	3	697	81	29	3	429
7	27	4	396	32	30	5	390	57	30	12	117	82	27	1	337
8	25	3	196	33	32	1	651	58	26	1	417	83	32	3	557
9	32	1	284	34	29	1	508	59	22	3	344	84	27	2	433
10	33	6	555	35	37	2	867	60	29	1	576	85	32	3	525
11	33	3	569	36	27	5	370	61	25	1	383	86	29	1	523
12	32	1	770	37	30	2	659	62	25	2	324	87	33	4	550
13	29	1	391	38	29	2	419	63	29	3	509	88	35	6	530
14	27	0	327	39	30	7	428	64	30	1	534	89	33	6	581
15	21	3	55	40	33	1	640	65	35	1	810	90	33	3	524
16	37	17	308	41	33	0	501	66	32	2	609	91	30	2	508
17	29	2	650	42	32	2	628	67	21	2	257	92	32	5	451
18	24	1	242	43	35	1	748	68	35	0	635	93	30	2	487
19	30	3	442	44	37	1	830	69	25	1	678	94	30	8	393
20	33	3	560	45	33	3	645	70	24	1	375	95	27	1	503
21	32	2	15	46	32	3	645	71	32	1	933	96	30	6	558
22	27	1	381	47	29	6	170	72	32	2	610	97	32	6	439
23	29	2	428	48	35	3	673	73	30	2	583	98	27	1	447
24	32	1	489	49	30	1	528	74	30	1	564	99	32	2	452
25	30	3	557	50	27	2	266	75	29	1	673	100	30	1	459

Table 4. Data for destruction of the achenes of *Carduus nutans* by the action of *Rhinocyllus conicus* larvae (cont'd.)

Head	X_1	X_2	Y	Head	X_1	X_2	Y	Head	X_1	X_2	Y	Head	X_1	X_2	Y
101	35	5	630	126	32	6	475	151	32	2	546	176	27	0	518
102	33	0	553	127	29	5	265	152	38	7	923	177	25	0	47
103	30	6	510	128	29	2	583	153	37	2	879	178	30	0	605
104	29	4	482	129	30	3	459	154	30	6	254	179	29	0	501
105	27	1	470	130	32	4	637	155	32	9	392	180	27	0	72
106	21	2	115	131	29	4	507	156	30	4	674	181	27	0	488
107	35	1	429	132	25	2	387	157	32	2	455	182	25	0	472
108	24	3	306	133	33	7	901	158	33	0	485	183	30	0	632
109	25	2	373	134	29	3	451	159	35	0	698	184	32	0	571
110	27	2	392	135	29	1	538	160	33	0	552	185	32	0	481
111	33	4	590	136	29	1	425	161	27	0	417	186	30	0	675
112	24	2	444	137	30	1	427	162	41	0	836	187	33	0	449
113	24	1	336	138	25	1	127	163	33	0	696	188	30	0	503
114	40	5	780	139	25	1	175	164	30	0	452	189	25	0	463
115	24	4	298	140	30	5	437	165	33	0	733	190	24	0	66
116	29	4	551	141	32	7	423	166	33	0	563	191	27	0	377
117	24	3	344	142	27	1	303	167	30	0	398	192	32	0	662
118	30	8	403	143	25	1	359	168	29	0	485	193	30	0	745
119	29	6	460	144	32	4	418	169	32	0	664	194	32	0	533
120	29	1	593	145	27	2	432	170	27	0	410	195	22	0	108
121	24	2	412	146	32	7	263	171	30	0	660	196	35	0	680
122	37	0	633	147	32	8	686	172	33	0	866	197	20	0	572
123	29	2	527	148	29	0	200	173	29	0	601	198	27	0	457
124	29	1	555	149	30	2	503	174	34	0	654	199	32	0	811
125	35	1	607	150	35	8	394	175	25	0	280	200	32	0	711

Table 4. Data for destruction of the achenes of

<u>Carduus nutans</u> by the action of <u>Rhinocyllus conicus</u> larvae (cont'd.)

Head	X_1	X_2	Y	Head	X_1	X_2	Y	Head	X_1	X_2	Y
201	29	0	550	226	28	0	216	251	27	0	209
202	29	0	427	227	24	0	311	252	22	0	139
203	29	0	567	228	25	0	206	253	24	0	141
204	32	0	634	229	26	0	248	254	31	0	300
205	27	0	334	230	28	0	231	255	29	0	383
206	30	0	335	231	28	0	347	256	31	0	360
207	30	0	460	232	22	0	192	257	33	0	497
208	25	0	111	233	28	0	321	258	27	0	344
209	24	0	184	234	27	0	377	259	35	0	620
210	24	0	190	235	29	0	250	260	31	0	444
211	32	0	380	236	24	0	192	261	26	0	271
212	29	0	395	237	27	0	310				
213	27	0	299	238	28	0	247				
214	35	0	446	239	24	0	307				
215	25	0	226	240	25	0	344				
216	24	0	88	241	26	0	167				
217	24	0	266	242	24	0	200				
218	25	0	302	243	27	0	194				
219	31	0	358	244	18	0	118				
220	21	0	190	245	25	0	313				
221	29	0	400	246	29	0	286				
222	32	0	485	247	22	0	227				
223	24	0	190	248	28	0	309				
224	26	0	345	249	29	0	192				
225	24	0	151	250	26	0	208				

Table 5.
Polynomial regression analysis between normal uninfested florets and mature seeds produced.

ANOVA for 1st degree polynomial.

Source	df	ss	ms	F
Due to regression	1	1024857.13	1024857.13	60.32**
Deviation about regression	54	917507.88	16990.88	
Total	55	1942365.00		

Tabulated $F_{.05}$ with 1 and 54 df = 4.02

Tabulated $F_{.01}$ with 1 and 54 df = 7.15

Coefficient of determination r^2 = 0.53

Correlation coefficient r = 0.72

ANOVA for 2nd degree polynomial

Source	df	ss	ms	F
Due to regression	2	1097098.00	548549.00	34.40**
Deviation about regression	53	845267.00	15948.43	
Total	55	1942365.00		

Tabulated $F_{.05}$ with 2 and 53 df = 3.17

Tabulated $F_{.01}$ with 2 and 53 df = 5.04

Coefficient of determination r^2 = 0.56

Correlation coefficient r = 0.74

Table 6. Destruction of the achenes of *Carduus nutans* by the action of *Rhinocyllus conicus* larvae.

Part 1: ANOVA for the multiple linear regression.

Source of Variation	df	Sum of Squares	Mean Squares	F Values
Due to regression	2	4812741.00	2406370.00	138.29**
Deviation about regression	258	4489467.00	17401.03	
Total	260	9302208.00		

$F_{.05}$ with 2 and 258 df = 3.00

$F_{.01}$ with 2 and 258 df = 4.61

Variable	Mean	Std. Deviation	Reg. Coeff.	Std. Error of Reg. Coe.
Head diameter	29.24	3.81	36.95	2.23
Emergent weevils	1.84	2.63	-9.67	3.23
Seeds	447.05	189.15		

Variance of Estimate 17401.03125
Std. Error of estimate 131.91296

Coefficient of Determination: $r^2 = 0.5174$
Multiple Corr. Coefficient: $r = 0.7193$

Table 6. Destruction of the achenes of _Carduus nutans_ by the action of _Rhinocyllus conicus_ larvae (Cont'd.).

Part 2: Statistical Relationships

Y = Mature seeds

X_1 = Head diameter

X_2 = Emergent weevils

Variable	Mean	Std. Deviation	Reg. Coeff.	Std. error of Reg. coeff.
X_1	29.24	3.81	36.95	2.23
X_2	1.85	2.63	-9.67	3.24
Y	447.05	189.15		

Variance of estimate = 17401.03
Std. error of estimate = 131.91
Correlation coefficients between:

X_1 and X_2 $r = 0.28$

X_1 and Y $r = 0.1$

X_2 and Y $r = 0.73 - 01$

Table 7. Mortality factors of pre-adult <u>Rhinocyllus</u> <u>conicus</u> at Pulaski, Virginia.

Rep #I	Head Number 1	2	3	4	5	6	7	8	9	10	11	Totals
Eggs												
Original	14	5	25	8	3	4	6	4	7	4	10	90
Present upon collection	12	3	22	7	1	4	5	3	7	4	9	77
Dead larvae recovered												
Early instars	1	0	1	0	0	0	0	0	1	0	1	4
Late instars	0	0	0	0	0	0	0	0	0	0	0	0
Total	1	0	1	0	0	0	0	0	1	0	1	4
Dead pupae recovered	0	0	2	1	0	0	0	0	0	0	0	3
Parasites	0	0	0	0	0	0	0	0	0	0	0	0
<u>Aliolus curculionis</u>	0	0	0	0	0	0	0	0	0	0	0	0
Others												
Total	0	0	0	0	0	0	0	0	0	0	0	0
Adults	8	5	4	0	0	1	1	1	5	2	1	28
Probable egg mortality	5	0	18	7	3	3	5	3	1	2	8	55
% mortality (# Adults/#Orig. eggs)	43	0	84	100	100	75	83	75	29	50	30	

Table 7. Mortality factors of pre-adult *Rhinocyllus conicus* at Pulaski, Virginia (cont'd.).

Rep # II

	Head Number 1	2	3	4	5	6	7	8	9	10	11	Totals
Eggs												
Original	11	4	7	18	6	15	16	13	18	10	14	132
Present upon collection	4	3	5	0	3	4	6	5	7	6	8	51
Dead larvae recovered												
Early instars	1	0	0	3	0	0	3	0	2	0	1	10
Late instars	0	0	0	0	0	6	0	0	0	0	0	6
Total	1	0	0	3	0	6	3	0	2	0	1	16
Dead pupae recovered	0	0	3	0	0	0	0	0	0	0	0	3
Parasites												
Aliolus curculionis	0	0	0	0	0	0	0	1	1	2	0	4
Others	0	0	0	0	0	0	0	0	1	0	0	1
Total	0	0	0	0	0	0	0	1	2	2	0	5
Adults	4	2	1	1	1	1	0	3	9	2	7	31
Probable egg Mortality	6	2	3	14	5	8	13	9	5	6	6	77
% mortality (# Adults/# orig. eggs)	64	50	86	94	83	93	100	77	50	8	50	

Table 7. Mortality factors of pre-adult

Rhinocyllus conicus at Pulaski, Virginia (cont'd.).

Rep. # III

	Head Number												
	1	2	3	4	5	6	7	8	9	10	11	12	Totals
Eggs													
Original	8	5	4	9	5	10	4	6	4	4	10	7	76
Present upon collection	8	4	4	8	0	7	4	5	4	3	8	0	55
Dead larvae recovered													
Early instars	0	0	0	0	0	0	0	0	0	0	0	0	0
Late instars	0	0	1	0	1	0	0	0	0	0	0	0	2
Total	0	0	1	0	1	0	0	0	0	0	0	0	2
Dead pupae recovered	0	0	0	0	0	0	0	0	0	0	0	0	0
Parasites													
Aliolus curculionis	0	0	0	0	0	0	0	0	0	0	2	4	6
Others	0	0	0	0	2	0	0	0	0	0	0	0	2
Total	0	0	0	0	2	0	0	0	0	0	2	4	8
Adults	0	1	1	2	1	3	0	1	3	1	6	1	20
Probable egg mortality	8	4	2	7	1	7	4	5	1	3	2	2	46
% mortality (# Adults/# Orig. eggs)	100	80	75	78	80	70	100	83	25	75	40	86	

Table 7. Mortality factors of pre-adult

Rhinocyllus conicus at Pulaski, Virginia (cont'd.).

Rep. # IV	Head Number												
	1	2	3	4	5	6	7	8	9	10	11	12	Totals
Eggs													
Original	4	4	8	8	7	14	4	5	6	10	4	8	82
Present upon collection	4	0	8	6	4	8	1	2	5	3	3	4	48
Dead larvae recovered													
Early instars	0	0	0	0	0	0	0	0	0	1	0	0	1
Late instars	0	0	0	0	0	0	0	0	0	0	0	0	0
Total	0	0	0	0	0	0	0	0	0	1	0	0	1
Dead pupae recovered	0	0	0	0	0	1	0	0	0	0	0	0	1
Parasites													
Aliolus curculionis	0	0	0	0	0	0	0	0	0	0	0	0	0
Other	0	0	0	0	0	0	0	0	0	0	0	0	0
Total	0	0	0	0	0	0	0	0	0	0	0	0	0
Adults	0	4	4	5	1	9	2	0	4	3	2	1	35
Probable egg mortality	4	0	4	3	6	4	2	5	2	6	2	7	45
% mortality (# Adults/# Orig. eggs)	100	0	50	37	86	36	50	100	33	70	50	87	

Table 7. Mortality factors of pre-adult

Rhinocyllus conicus at Pulaski, Virginia (cont'd.).

Rep. # V

	Head Number											
	1	2	3	4	5	6	7	8	9	10	11	Totals
Eggs												
Original	11	8	9	14	5	6	7	5	8	7	6	86
Present upon collection	8	2	4	9	5	4	4	3	6	5	2	52
Dead larvae recovered												
Early instars	0	1	1	0	0	1	0	0	0	1	1	5
Late instars	0	0	0	0	0	0	0	0	0	0	0	0
Total	0	1	1	0	0	1	0	0	0	1	1	5
Dead pupae recovered	0	1	0	2	0	0	0	0	0	0	0	3
Parasites												
Aliolus curculionis	0	0	0	0	0	0	0	0	0	0	0	0
Others	0	0	0	0	0	0	0	0	0	0	0	0
Total	0	0	0	0	0	0	0	0	0	0	0	0
Adults	2	1	0	0	0	0	4	0	0	1	3	11
Probable egg mortality	9	5	8	12	5	5	3	5	8	5	2	67
% mortality (# Adults / # orig. eggs)	82	87	100	100	100	100	43	100	100	86	50	

Table 7. Mortality factors of pre-adult

<u>Rhinocyllus</u> <u>conicus</u> at Pulaski, Virginia (cont'd.).

Rep. # VI

	Head Number								
	1	2	3	4	5	6	7	8	Totals
Eggs									
Original	32	30	15	28	38	11	11	7	172
Present upon collection	30	28	13	20	30	9	10	7	147
Dead larvae recovered									
Early instars	0	0	2	0	0	0	0	0	2
Late instars	0	1	0	0	0	0	0	0	1
Total	0	1	2	0	0	0	0	0	3
Dead pupae recovered	0	0	0	0	2	0	0	0	2
Parasites									
<u>Aliolus</u> <u>curculionis</u>	0	0	0	0	0	0	0	0	0
Others	0	0	0	2	0	0	2	0	4
Total	0	0	0	2	0	0	2	0	4
Adults	17	20	8	9	30	11	3	0	98
Probable egg mortality	15	9	5	17	6	0	6	7	65
% mortality (# Adults/# Orig. eggs)	47	33	47	68	21	0	73	100	

Table 7. Mortality factors of pre-adult

<u>Rhinocyllus</u> <u>conicus</u> at Pulaski, Virginia (cont'd.).

Rep. # VII

	Head Number										
	1	2	3	4	5	6	7	8	9	10	Totals
Eggs											
Original	7	4	6	15	5	8	4	6	5	6	66
Present upon collection	2	2	6	3	5	1	4	1	3	0	27
Dead larvae recovered											
Early instars	0	0	0	0	1	0	0	0	0	0	1
Late instars	0	0	0	0	0	0	0	0	0	0	0
Total	0	0	0	0	1	0	0	0	0	0	1
Dead pupae recovered	0	0	0	0	0	0	0	0	0	0	0
Parasites											
<u>Aliolus curculionis</u>	0	0	0	1	0	1	2	0	0	0	4
Others	0	0	0	0	0	0	0	0	0	0	0
Total	0	0	0	1	0	1	2	0	0	0	4
Adults	3	3	1	9	2	3	2	3	3	1	30
Probable egg mortality	4	1	5	5	2	4	0	3	2	5	31
% mortality (# Adults/# Orig. eggs)	57	25	83	40	60	62	50	50	40	83	

Table 7. Mortality factors of pre-adult

Rhinocyllus conicus at Pulaski, Virginia (cont'd.).

Rep. # VIII

	Head Number 1	2	3	4	5	6	7	8	9	10	11	Totals
Eggs												
Original	6	10	13	10	8	9	6	4	14	12	5	97
Present upon collection	6	7	11	9	5	8	6	4	12	9	4	81
Dead larvae recovered												
Early instars	0	0	1	0	0	0	0	0	0	0	0	1
Late instars	0	0	0	1	0	0	0	0	0	0	0	1
Total	0	0	1	1	0	0	0	0	0	0	0	2
Dead pupae recovered	0	1	0	0	0	0	0	0	1	2	0	4
Parasites												
Aliolus curculionis	0	0	0	3	0	0	0	0	3	0	0	6
Others	0	0	0	0	0	1	0	0	0	0	0	1
Total	0	0	0	3	0	1	0	0	3	0	0	7
Adults	0	0	1	3	1	2	0	0	1	6	1	15
Probable egg mortality	6	9	11	3	7	6	6	4	9	4	4	69
% mortality (# Adults/# Orig. eggs)	100	100	92	70	87	78	100	100	93	50	80	

Table 7. Mortality factors of pre-adult

<u>Rhinocyllus</u> <u>conicus</u> at Pulaski, Virginia (cont'd.).

Rep. # IX	Head Number					
	1	2	3	4	5	
Eggs						
Original	14	12	23	20	28	97
Present upon collection	1	5	11	7	15	39
Dead larvae recovered						
Early instars	0	0	2	0	1	3
Late instars	0	0	0	0	0	0
Total	0	0	2	0	1	3
Dead pupae recovered	0	0	0	0	0	0
Parasites						
<u>Aliolus</u> <u>curculionis</u>	0	0	0	4	1	5
Others	1	0	0	0	0	1
Total	1	0	0	4	1	6
Adults	4	9	8	9	23	53
Probable egg mortality	9	3	13	7	3	35
% mortality (# Adults/# Orig. eggs)	71	25	65	55	18	

Table 7. Mortality factors of pre-adult

Rhinocyllus conicus at Pulaski, Virginia (cont'd.).

Rep. # X

	Head Number												
	1	2	3	4	5	6	7	8	9	10	11	12	Totals
Eggs													
Original	8	9	8	6	6	6	7	12	25	10	12	8	117
Present upon collection	2	7	7	2	3	5	7	5	25	7	6	8	84
Dead larvae recovered													
Early instars	1	0	1	0	0	0	0	0	0	0	0	1	3
Late instars	0	0	0	0	0	0	0	0	0	0	0	0	0
Total	1	0	1	0	0	0	0	0	0	0	0	1	3
Dead pupae recovered	0	0	0	0	0	0	0	0	0	0	0	1	1
Parasites													
Aliolus curculionis	0	0	0	0	0	0	0	0	0	0	1	0	1
Other;	2	0	0	0	0	0	0	0	0	0	0	0	2
Total	2	0	0	0	0	0	0	0	0	0	1	0	3
Adults	2	2	0	0	0	0	1	0	0	0	0	0	5
Probable egg mortality	3	7	7	6	6	6	6	12	25	10	11	6	105
% mortality (# Adults/# Orig. eggs)	75	78	100	100	100	100	86	100	100	100	100	100	

Table 7. Mortality factors of pre-adult

<u>Rhinocyllus</u> <u>conicus</u> at Pulaski, Virginia (cont'd.).

Rep. # XI	Head Number												
	1	2	3	4	5	6	7	8	9	10	11	12	Totals
Eggs													
Original	5	7	5	6	10	12	8	6	13	14	11	16	113
Present upon collection	4	4	5	5	3	12	2	5	8	7	9	6	70
Dead larvae recovered													
Early instars	0	0	1	1	1	1	2	1	0	0	0	2	9
Late instars	0	0	0	0	0	2	0	0	0	0	0	0	2
Total	0	0	1	1	1	3	2	1	0	0	0	2	11
Dead pupae recovered	0	0	0	0	0	0	1	0	0	0	0	0	1
Parasites													
<u>Aliolus</u> <u>curculionis</u>	0	0	0	0	0	2	0	0	1	0	0	1	4
Others	0	0	0	0	0	0	0	0	0	0	0	0	0
Total	0	0	0	0	0	2	0	0	1	0	0	1	4
Adults	2	0	1	3	7	1	5	2	7	3	1	2	34
Probable egg mortality	3	7	3	2	2	6	0	3	5	11	10	11	63
% mortality (# Adults/# Orig. eggs)	60	100	80	50	30	92	37	67	46	79	91	87	

Table 8. A comparison between egg removal (due to wind, rain and mechanical dislodgement), X, and emergent adults, Y, of *Rhinocyllus conicus* taken from *Carduus nutans* blooms in Pulaski, Va. (July, 1972).

Head No.	X	Y	Head No.	X	Y	Head No.	X	Y	Head No.	X	Y
1	2	8	31	0	3	61	8	9	91	1	23
2	2	4	32	1	1	62	8	30	92	6	2
3	3	5	33	2	6	63	2	11	93	2	2
4	1	0	34	7	1	64	1	3	94	1	0
5	2	0	35	0	0	65	0	0	95	4	0
6	0	1	36	4	4	66	13	3	96	3	0
7	1	1	37	0	4	67	7	3	97	1	0
8	1	1	38	2	5	68	12	1	98	0	1
9	0	5	39	3	1	69	13	9	99	7	0
10	0	2	40	6	9	70	13	2	100	0	0
11	1	1	41	3	2	71	5	3	101	3	0
12	7	4	42	3	0	72	2	2	102	6	0
13	1	2	43	1	4	73	0	3	103	0	0
14	2	1	44	7	3	74	12	3	104	1	2
15	18	1	45	1	2	75	0	1	105	3	0
16	3	1	46	4	1	76	7	0	106	0	1
17	11	1	47	3	2	77	0	0	107	1	3
18	10	0	48	6	1	78	5	1	108	7	7
19	8	3	49	5	0	79	2	3	109	0	1
20	11	9	50	5	0	80	6	1	110	6	5
21	4	2	51	0	0	81	0	2	111	1	2
22	6	7	52	2	0	82	3	0	112	5	7
23	0	0	53	3	4	83	2	0	113	7	3
24	1	1	54	2	0	84	1	1	114	2	1
25	0	1	55	2	0	85	3	6	115	10	2
26	1	2	57	2	1	86	1	1			
27	5	1	57	4	3	87	0	4			
28	3	3	58	2	17	88	0	9			
29	0	0	59	2	20	89	2	8			
30	1	1	60	2	8	90	3	9			

Table 9. Mortality of *Rhinocyllus conicus* larvae and pupae within infested thistle blooms (Y) compared to number of eggs laid on the blooms (X) as a measure of crowding effects (Pulaski, Va., July, 1972).

Head No.	X	Y	Head No.	X	Y	Head No.	X	Y	Head No.	X	Y
1	9	1	31	3	0	61	32	2	91	5	1
2	5	0	32	1	0	62	11	0	92	2	0
3	7	3	33	8	0	63	5	0	93	1	1
4	1	1	34	5	0	64	0	0	94	0	0
5	0	0	35	0	0	65	3	0	95	0	0
6	1	0	36	4	0	66	3	0	96	0	0
7	1	0	37	4	0	67	1	0	97	1	0
8	1	0	38	5	0	68	10	1	98	0	0
9	6	1	39	1	0	69	3	0	99	0	0
10	2	0	40	10	1	70	4	0	100	0	0
11	2	1	41	2	0	71	4	0	101	1	0
12	5	1	42	0	0	72	3	0	102	2	2
13	2	0	43	4	0	73	3	0	103	2	0
14	4	3	44	4	1	74	1	0	104	0	0
15	4	3	45	2	0	75	0	0	105	2	1
16	1	0	46	2	0	76	1	1	106	4	1
17	7	6	47	3	2	77	2	1	107	8	1
18	3	3	48	1	1	78	7	1	108	6	3
19	0	0	49	2	2	79	1	0	109	8	3
20	9	2	50	0	0	80	3	0	110	3	1
21	5	0	51	1	1	81	0	0	111	8	0
22	8	1	52	4	0	82	0	0	112	3	0
23	0	0	53	0	0	83	5	1	113	1	0
24	1	0	54	0	0	84	8	2	114	5	2
25	2	1	55	2	1	85	1	0	115	0	0
26	2	0	56	4	1	86	5	0			
27	4	1	57	17	0	87	9	0			
28	3	0	58	21	1	88	10	2			
29	0	0	59	10	2	89	13	0			
30	1	0	60	11	0	90	25	1			

Table 10. Mortality of *Rhinocyllus conicus* immatures at eleven sites within the Pulaski release area in 1972.

ANOVA of % mortality among sites

source	df	ss	ms	F
Treatments	10	24,976.1	2,497.6	4.64**
Error	104	55,964.0	538.1	
Total	114	80,940.1		

Tabulated $F_{.05}$ with 10 and 104 df = 1.96

Tabulated $F_{.01}$ with 10 and 104 df = 2.57

Variance of the mean = 48.86
Standard error of the mean = 6.99

Table 11

A comparison between egg removal (due to wind, rain, and mechanical dislodgement), X, and emergent adults, Y, of *Rhinocyllus conicus* taken from *Carduus nutans* blooms in Pulaski Co., Va. (July, 1972).

ANOVA of regression

Source	df	ss	ms	F
Regression	1	34.93	34.93	1.64 ns
Residual	113	2400.10	21.24	
Total	114	2435.03		

Tabulated $F_{.05}$ with 1 and 114 df = 3.97

Correlation coefficient: r = .0145

Coefficient of determination: r^2 = .0002

Table 12. A comparison between eggs present upon collection and emergent adults of *Rhinocyllus conicus* taken from *Carduus nutans* blooms in Pulaski, Va. (July, 1972).

ANOVA of regression

source	df	ss	ms	F
Regression	1	980.9	980.9	70.61**
Residual	113	1454.1	12.9	
Total	114	2435.0		

Tabulated $F_{.05}$ with 1 and 114 df = 3.97

Tabulated $F_{.01}$ with 1 and 114 df = 7.02

Correlation coefficient: $r = .64$
Coefficient of determination: $r^2 = .41$

Table 13. A comparison between eggs present upon collection (X) and emergent adults (Y) of *Rhinocyllus conicus* taken from *Carduus nutans* blooms in Pulaski, Va. (July, 1972.

Head No.	X	Y	Head No.	X	Y	Head No.	X	Y	Head No.	X	Y
1	12	8	31	4	3	61	20	9	91	15	23
2	3	4	32	3	1	62	30	30	92	2	2
3	22	5	33	8	6	63	9	11	93	7	2
4	7	0	34	0	1	64	10	3	94	7	0
5	1	0	35	4	0	65	7	0	95	2	0
6	4	1	36	0	4	66	2	3	96	3	0
7	5	1	37	8	4	67	2	3	97	5	0
8	3	1	38	6	5	68	6	1	98	7	1
9	7	5	39	4	1	69	3	9	99	5	0
10	4	2	40	8	9	70	5	2	100	25	0
11	9	1	41	1	2	71	1	3	101	7	0
12	4	4	42	2	0	72	4	2	102	6	0
13	3	2	43	5	4	73	1	3	103	8	0
14	5	1	44	3	3	74	3	3	104	4	2
15	0	1	45	3	2	75	0	1	105	4	0
16	3	1	46	4	1	76	6	0	106	5	1
17	4	1	47	8	2	77	7	0	107	5	3
18	6	0	48	2	1	78	11	1	108	3	7
19	5	3	49	4	0	79	9	3	109	12	1
20	7	9	50	9	0	80	5	1	110	2	5
21	6	2	51	5	0	81	8	2	111	5	2
22	8	7	52	4	0	82	6	0	112	8	7
23	8	0	53	4	4	83	4	0	113	7	3
24	4	1	54	3	0	84	12	1	114	9	1
25	4	1	55	6	0	85	9	6	115	6	2
26	8	2	56	5	1	86	4	1			
27	0	1	57	2	3	87	1	4			
28	7	3	58	30	17	88	5	9			
29	4	0	59	28	20	89	11	8			
30	5	1	60	13	8	90	7	9			

Table 14. Mortality of *Rhinocyllus conicus* larvae and pupae within infested thistle blooms compared to number of eggs laid in the blooms as a measure of crowding effects (Pulaski, Va., July, 1972).

ANOVA of Regression

source	df	ss	ms	F
Regression	1	11.0	11.0	12.36**
Residual	113	100.6	.89	
Total	114	111.6		

Tabulated $F_{.05}$ with 1 and 114 df = 3.97

Tabulated $F_{.01}$ with 1 and 114 df = 7.02

Correlation coefficient: $r = .31$
Coefficient of determination: $r^2 = .096$

Table 15. Survey data on the establishment and dispersal of <u>Rhinocyllus conicus</u> at White Hall (Frederick Co., Va. 1971-72)

PI = Plants infested; HI = Heads infested; TP = Total plants counted (up to 10)

	South						North					
Integrals	1971			1972			1971			1972		
of 10 ft.	PI	HI	TP	PI	HI	TP	PI	HI	TP	PI	HI	TP
0	1	1	10(2p)*	0	0	0	-	-	-	-	-	-
1	2	3	10	0	0	1	2	2	10(1p)	7	74	10
2	2	4	10	0	0	2	0	0	10	7	100	10
3	4	4	10(1p)	0	0	0	1	2	10(1p)	0	0	0
4	2	3	10	0	0	0	1	3	10	0	0	0
5	3	4	10(1p)	0	0	0	0	0	10	1	8	1
6	2	2	10	0	0	0	0	0	10(2p)	0	0	0
7	0	0	10	0	0	0	0	0	10	1	12	2
8	2	2	10(1p)	0	0	0	2	3	10	2	26	4
9	0	0	10	0	0	0	1	1	10	2	7	2
10	3	3	10	0	0	0	0	0	10	0	0	0
Integrals of 20 ft.												
1	0	0	10	1	2	1	0	0	10	0	0	0
2	0	0	10	0	0	0	0	0	10	0	0	2
3	0	0	0	0	0	0	1	2	10	0	0	0
4	0	0	1	0	0	1(1p)	0	0	10	2	10	2
5	0	0	0	0	0	10	0	0	10	0	0	0
6	0	0	0	2	6	8(1p)	0	0	0	0	0	0
7	0	0	0	0	0	0	0	0	10	0	0	0
8	0	0	0	0	0	0	0	0	10	0	0	0
9	0	0	0	0	0	0	0	0	0	0	0	0
10	0	0	3	1	3	5	0	0	10	3	15	4

*Unless otherwise specified all plants are musk (<u>Carduus nutans</u>). (2p) indicates that of the 10 plants examined 2 were plumeless thistles (<u>C. acanthoides</u>) which were not infested.

Table 15. Survey data on the establishment and dispersal of *Rhinocyllus conicus* at White Hall (Frederick Co., Va. 1971-72) (Cont'd.)

	South						North					
Integrals	1971			1972			1971			1972		
of 50 ft.	PI	HI	TP	PI	HI	TP	PI	HI	TP	PI	HI	TP
1	0	0	1	4	6	10(2p)	0	0	10	0	0	0
2	0	0	2	0	0	0	0	0	10	3	34	10
3	0	0	0	0	0	6	0	0	10	2	24	10
4	--- Woods------			-----Woods------								

PI = Plants Infested
HI = Heads Infested
TP = Total Plants
*(2p) = 2 plumeless thistles present which were not infested.

Table 15. Survey data on the establishment and dispersal of *Rhinocyllus conicus* at White Hall (Cont'd.)

	East						West					
Integrals	1971			1972			1971			1972		
of 10 ft.	PI	HI	TP	PI	HI	TP	PI	HI	TP	PI	HI	TP
1	4	9	10	0	0	0	5	27	10	0	0	0
2	1	1	10	0	0	10	5	28	10	0	0	0
3	0	0	2	0	0	10	2	5	10	0	0	0
4	0	0	0	0	0	10	1	3	10	0	0	0
5	1	1	3	0	0	2	4	10	10	1	1	2
6	0	0	0	0	0	0	3	5	10	1	1	1
7	0	0	0	0	0	0	1	8	10	0	0	1
8	0	0	0	0	0	0	1	1	10	0	0	2
9	0	0	4	0	0	0	2	2	10	0	0	1
10	0	0	0	0	0	0	2	2	10	1	5	5
Integrals of 20 ft.												
1	1	1	10	0	0	0	2	10	10	1	2	2
2	0	0	10	0	0	0	1	2	10	1	7	7
3	0	0	10	0	0	0	0	0	10	1	9	1
4	1	1	10	0	0	0	0	0	10	1	0	1
5	0	0	10	0	0	0	0	0	10	0	0	10
6	0	0	10	0	0	0	0	0	10	0	0	10
7	0	0	10	0	0	0	0	0	10	0	0	1
8	0	0	10	0	0	0	1	1	10	3	4	4
9	0	0	10	0	0	0	0	0	10	2	0	2
10	------Woods----			-----Woods------			1	1	10	1	0	1

Table 15. Survey data on the establishment and dispersal of *Rhinocyllus conicus* at White Hall (Cont'd.)

Integrals	East						West					
	1971			1972			1971			1972		
of 50 ft.	PI	HI	TP	PI	HI	TP	PI	HI	TP	PI	HI	TP
1	-----Woods-----			-----Woods------			0	0	10	1	6	6
2							0	0	10	0	0	10
3							0	0	8	0	0	1
4							--End of Plants-			0	0	10
5										0	0	10
6										0	0	2
7										1	10	10
8										1	10	10
9										0	0	10
10										0	0	1
11										0	0	1
12										0	0	1
13										1	21	10
14										0	0	1
15										0	0	1
16										0	0	1

Table 16. Survey data on the establishment and dispersal of Rhinocyllus conicus at Devil's Backbone (Highland Co., Va. 1971-1972)

	South						North					
Integrals	1971			1972			1971			1972		
of 10 ft.	PI	HI	TP	PI	HI	TP	PI	HI	TP	PI	HI	TP
0	0	0	10	0	0	10	-	-	-	-	-	-
1	1	1	10	0	0	10	0	0	10	0	0	10
2	0	0	10	0	0	10	0	0	10	0	0	10
3	1	1	10	0	0	10	2	4	10	0	0	10
4	0	0	10	0	0	3	0	0	10	0	0	10
5	0	0	10	0	0	1	1	1	10	0	0	10
6	0	0	10	0	0	4	0	0	0	0	0	10
7	0	0	8	0	0	0	0	0	10	0	0	0
8	0	0	8	0	0	1	0	0	10	0	0	0
10	0	0	4	0	0	10	0	0	10	0	0	3
Integrals of 20 ft.												
1	0	0	10	0	0	10	1	1	10	0	0	2
2	0	0	0	0	0	2	1	1	10	0	0	1
3	0	0	10	0	0	1	0	0	10	0	0	0
4	0	0	10	0	0	0	0	0	10	0	0	0
5	0	0	10	0	0	0	0	0	10	0	0	10
6	1	1	10	0	0	0	0	0	0	0	0	8
7	0	0	10	0	0	10	0	0	10	0	0	1
8	1	2	10	0	0	10	1	1	10	0	0	1
9	0	0	10	0	0	10	1	1	10	1	1	2
10	---Hay Field------------------------					10	1	1	10	0	0	3

Table 16. Survey data on the establishment and dispersal of *Rhinocyllus conicus* at Devil's Backbone (Cont'd.)

Integrals	South						North					
	1971			1972			1971			1972		
of 50 ft.	PI	HI	TP	PI	HI	TP	PI	HI	TP	PI	HI	TP
1	-----Woods-----			-----Woods------			1	1	10	0	0	10
2							0	0	10	0	0	10
3							-----Woods-----			-----Woods-------		
4												
5	0	0	10	0	0	0						

Table 16. Survey data on the establishment and dispersal of <u>Rhinocyllus conicus</u> at Devil's Backbone (Cont'd.)

	East						West					
	1971			1972			1971			1972		
Integrals of 10 ft.	PI	HI	TP	PI	HI	TP	PI	HI	TP	PI	HI	TP
0	-	-	-	-	-	-	-	-	-	-	-	-
1	0	0	10	0	0	10	1	5	10	0	0	1
2	0	0	10	0	0	10	0	0	10	0	0	1
3	0	0	0	0	0	4	0	0	0	0	0	10
4	0	0	10	0	0	1	0	0	0	1	1	10
5	0	0	10	0	0	0	0	0	10	0	0	10
6	0	0	10	0	0	5	2	5	10	1	1	10
7	0	0	0	0	0	0	2	4	10	2	3	10
8	0	0	0	0	0	1	0	0	10	0	0	3
9	2	11	10	0	0	1	1	1	10	1	2	6
10	0	0	0	0	0	0	0	0	10	1	1	10
Integrals of 20 ft.												
1	1	1	10	0	0	5	0	0	0	2	6	10
2	0	0	10	0	0	2	0	0	0	0	0	10
3	0	0	10	0	0	4	0	0	10	1	12	10
4	0	0	0	0	0	0	0	0	10	0	0	10
5	0	0	0	0	0	0	1	1	10	0	0	10
6	---no plants---			0	0	0	0	0	10	1	1	10
7				0	0	0	0	0	10	0	0	10
8				0	0	10	0	0	10	0	0	10
9				0	0	0	0	0	10	0	0	10
10				0	0	2	0	0	10	0	0	10

Table 16. Survey data on the establishment and dispersal of *Rhinocyllus conicus* at Devil's Backbone (Cont'd.)

Integrals	East						West					
	1971			1972			1971			1972		
of 50 ft.	PI	HI	TP	PI	HI	TP	PI	HI	TP	PI	HI	TP
1				0	0	10	0	0	10	0	0	10
2				0	0	3	0	0	10	0	0	10
3				0	0	1	0	0	10	0	0	10
4				0	0	0						
5				0	0	10	----Thistles terminated-----------					

Table 17. Survey data on the establishment and dispersal of *Rhinocyllus conicus* at Tippett's Farm (Loudon Co., Va., 1971-1972)

Integrals	South						North					
	1971			1972			1971			1972		
of 10 ft.	PI	HI	TP	PI	HI	TP	PI	HI	TP	PI	HI	TP
0	4	20	10	1	1	5	-	-	-	-	-	-
1	1	2	2	2	3	5	5	23	10	6	31	10
2	0	0	2	3	6	10	3	6	10	4	15	10
3	2	3	10	0	0	10	3	5	10	3	8	10
4	1	1	10	0	0	10	4	8	10	0	0	10
5	1	2	10	0	0	10	0	0	10	5	10	10
6	1	1	10	0	0	10	0	0	10	2	2	10
7	1	2	10	0	0	10	0	0	10	4(2p)	7(2p)	10(4p)*
8	1	1	10	0	0	10	0	0	10	4	5	10
9	------Corn-----			-----Corn-------			0	0	10	1	1	10
10							-----Woods-----			------Woods------		

Integrals	East						West					
	1971			1972			1971			1972		
of 10 ft.	PI	HI	TP	PI	HI	TP	PI	HI	TP	PI	HI	TP
1	5	12	10	2(1p)	9(8p)	10(7p)	3	7	10	0	0	10
2	2	3	10	4	14	10	3	5	10	0	0	10
3	4	36	10	2	12	10	0	0	10	0	0	10
4	2	30	10	3	11	10	0	0	8	0	0	10
5	5	22	10	0(1p)	0(1p)	10(1p)	0	0	0	0	0	0
6	4	26	10	1	6	10	0	0	0	0	0	0
7	0	0	10	0	0	10	------ orn-----			------ orn-------		
8	0	0	0	0	0	10						
9	0	0	0	2	11	10						
10	------Woods----			-----Woods								
							600 ft. from origin					
							0	0	10	0	0	10

*Parenthetical quantities refer to the numerical portion of the total which is composed of *C. acanthoides*, plumeless thistle.

VITA

The author was born May 8, 1946 in Fredericksburg, Virginia. Following graduation from Stafford High School in June, 1964 he entered Lynchburg College in September of the same year. In June, 1968, he was graduated with a B. S. degree and a major in Biology. Immediately thereafter he enrolled in the Graduate School of Virginia Polytechnic Institute and State University. After spending a summer working for the Entomology Department, he began attending classes in the Fall of 1968 while being employed as an Area Coordinator for the men's dormitory program. In January, 1969 he had to take a two year leave of absence to serve in the United States Army. During this interval he was married to Miss Kathryn L. Jones of LaCrosse, Virginia (August 28, 1970).

Reenrollment in the Graduate School began in October 1970 as a Fellow under the McCormic Scholarship. From September 1971 until June, 1972 the author served as a teaching assistant in the Entomology Department. He is a member of Chi Beta Phi Society, the Blue Key and The Entomological Society of America.

Walter Wayne Surles

AN ANALYSIS OF THE ESTABLISHMENT AND IMPACT OF AN EXOTIC INSECT, RHINOCYLLUS CONICUS FROELING (COLEOPTERA: CURCULIONIDAE), ON CARDUUS NUTANS L. AND CARDUUS ACANTHOIDES L. (CAMPANULATAE: COMPOSITAE) IN VIRGINIA WITH NOTES ON THEIR BIOLOGIES.

by

Walter Wayne Surles

"ABSTRACT"

Studies over a two year period were undertaken to evaluate the potential and effect of Rhinocyllus conicus as a biological control agent for Carduus nutans and C. acanthoides in Virginia. Over an 81 day range 25 females oviposited an average 100.5 eggs. Life expectancy did not differ between sexes. Examination of 1999 C. nutans plants in Pulaski Co. showed: 26.7% of all blooms were infested (46.7% terminals and 18.2% laterals); no weevil orientation relative to plant density but a preferance for terminal blooms and no bloom size preference for oviposition. Evaluation of 261 capitula revealed that an infested bloom produced 37 mature seeds/mm of diameter. Each larva destroyed 9.7 achenes.

Weevil mortality on C. nutans capitula occurred primarily during the egg stage (58.3%). Mechanical egg dislodgement was not a major mortality factor. Egg and/or adult parasitism was not observed. Aliolus curculionis, Bracon mellitor and Campoplex polychrosidis parasitized the weevil larvae and pupae. Twelve other possible parasites were collected. Crowding was not a significant mortality

factor. An egg maturation of 31.9% was noted, and 3.1 weevils emerged per infested bloom. Mortality among sites ranged from 56.1% (adjacent to trees) to 95.8% (unprotected).

Weevil adults exhibited thigmotaxis by overwintering in the cracks of the framework of a large outdoor rearing cage. They apparently preferred this site rather than soil litter and debris.

Best release establishment and dispersal occurred on *C. nutans* which was preferred to *Carduus acanthoides*.