Efficiency of Suction Sampling for *Rhinocyllus conicus*[1] and a Comparison of Suction and Visual Sampling Techniques[2]

J. T. TRUMBLE[3], B. CARTWRIGHT, AND L. T. KOK

Department of Entomology, Virginia Polytechnic Institute and State University, Blacksburg, Virginia 24061

ABSTRACT

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Efficiency and reliability of a suction device for assessing *Rhinocyllus conicus* populations were determined and compared with current visual research techniques. A suction machine collected a greater proportion of weevils from thistles ranging in height from 6 cm to 1 m but was less efficient than visual searches on rosettes or plants in excess of 1 m. A single, 2-sec suction sample was as efficient as multiple samples with durations up to 6 sec. Horizontal approaches were superior to up-sweep or vertically oriented suction samples and collected 98.6 ± 1.3% of adult weevils in recapture tests. *R. conicus* population density increased with plant height; correlation coefficients were highest (r = 0.95) when plant height variability was greatest and all thistles except rosettes were sampled. Although ca. 15% of the potentially viable eggs per primary bloom may be dislodged during suction sampling, removal of old, dried-out egg casings resulted in counts of eggs remaining on thistle blooms which were generally more indicative of actual weevil populations.

Rhinocyllus conicus Froelich has been widely introduced into North America as a biological control agent for thistles in the genera *Carduus, Cirsium*, and *Silybum* (Harris and Zwölfer 1971, Surles et al. 1974, Goeden and Ricker 1978, Puttler et al. 1978). Establishment and dispersal of this weevil have led to significant reductions in thistle infestations in at least two geographically diverse areas, including Virginia (Kok and Surles 1975) and Montana (Rees 1977). Interest in determining population levels and dispersal patterns of *R. conicus* has increased with each successful establishment, but no statistically comprehensive sampling plans have been reported. Currently, either destructive removal of thistle blooms (Hodgson and Rees 1976, Trumble and Kok 1979), or tedious visual counts of eggs or adults or both (Hawkes et al. 1972, Goeden 1978) are used to monitor populations. Both techniques are frequently unsatisfactory, since small or newly dispersed populations can be seriously reduced by destructive sampling and thorough, statistically adequate visual searches are extremely time consuming. The study reported here was conducted to determine if a suction machine could be a useful alternative to present sampling techniques for adult *R. conicus*.

Materials and Methods

Suction Sampling Technique

Experiments comparing the efficiency and reliability of suction sampling were conducted in Pulaski and Giles Counties, Va. from 1976 to 1979. In all experiments, the suction machine (D-Vac® Model 1A) was operated with the throttle fully open and using the standard 33-cm-diameter intake aperture unless otherwise specified. Air intake was ca. 2.5 m^3/min.

Vertical and horizontal approaches with the suction device were evaluated for capture efficiency under laboratory conditions by placing known numbers of *R. conicus* adults (range = 5–10) on *Carduus nutans* L.[4] (musk thistle), allowing them to acclimate for 10 min, and recording the capture rates for 25 replications. Horizontal and vertical approach techniques were similar to those described by Richmond and Graham (1969), but the horizontal approach was modified by sampling plants individually and gently shaking each thistle while sampling. Similar tests were conducted in the field, using naturally occurring weevil populations on 100 thistles.

An additional release-capture study was conducted on thistle with *R. conicus* adults by using an "up-sweep" method of D-Vac® suction sampling described by Gonzales et al. (1977). Sampling by the "up-sweep" method was done by contacting the plant with a 20-cm-diameter cone at the plant base, then drawing the cone upward so that all plant foliage comes in contact with the effective radius of the suction cone. Ten insects were released on each plant, and ca. 10 min was allowed for the insect to become adjusted before testing. Forty plants were selected randomly, and height was recorded for each. Of the total plants, half were selected to be greater than 1 m tall and half less than 1 m. Height of plants ranged from 48–185 cm.

Field trials were designed to determine the sampling interval (2-, 4-, or 6-sec samples) and number of successive suction samples (one to three) necessary for maximum capture from individual plants. These tests were repeated 100 times and analyzed by using a population estimation method described by Carle and Strub (1978).

Field Comparisons of Visual and Suction Sampling

Tests comparing the efficiency of suction vs. visual sampling for *R. conicus* adults were carried out in a 2.5-ha pasture in Giles County, Va. (elevation 850 m) in 1979. *R. conicus* adults (400 ♂♂, 400 ♀♀)

[1] Coleoptera: Curculionidae.
[2] Received for publication 14 November 1980.
[3] Present address: Dept. of Entomology, Univ. Calif., Riverside, CA 92521.
[4] Resembles *C. theormeri* Weinmann.

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were collected from an established site in Pulaski County, Va., using the suction device, and introduced into the study area on 17 May, 1977. Comparisons of the two techniques were based on data from line-transect samples selected using a stratified random method. An area 25 by 25 m of pasture densely infested with musk thistle was divided into five sections which were 5 m wide by 25 m long. Weekly visual and suction samples were taken from separate, randomly chosen 25-m line-transects in each section for both visual and suction techniques. A measuring tape was stretched along each transect, and plants were included if leaves or stalks intersected the vertical plane of the tape as seen from directly above. Plants included in each transect were measured for height, number of blooms, number of *R. conicus* eggs per primary bloom, and number of adult weevils. Samples were collected in such a way that shadows of suction machine operators and air vented from the suction device did not influence the insects on plants to be sampled. All weevils were returned to the plants they were taken from immediately after collection and counting.

Impact of Suction Sampling on R. conicus Eggs

Effects of the suction device on *R. conicus* egg populations were determined by assessing egg removal from 50 musk thistle plants of various heights. The suction machine was used as if sampling for adult weevils, and egg casings shaken loose were examined along with associated thistle blooms to assess: (1) total number of egg casings removed, (2) number of eggs already hatched, and (3) number of egg casings remaining on the thistle blooms.

Statistical Analyses

Data were analyzed for normality, using the KSL and Univariate tests of SAS 79 (Blair et al. 1979). Correlation coefficients were subsequently generated with the CORR procedure, using the Spearman rank-order correlation for untransformed data and the Pearson product-moment correlation on data transformed by $\log_{10}(\times + 1)$ and square-root procedures. The Spearman rank-order correlation coefficients are presented because the data were only ca. 85% normalized by transformations and the correlation coefficients were more conservative with the nonparametric test.

Linear regressions of the total number of egg casings per terminal bloom vs. the number of egg casings removed by suction sampling, and for the number of eggs eclosed vs. the number of egg casings removed by suction sampling were calculated by using the R-square procedure of SAS 79. The number of egg casings removed by suction sampling and the number of eggs eclosed were used as dependent variables, respectively.

Results and Discussion

Suction Sampling Technique

Thistles ranging from ca. 6 cm to 1 m in height were rapidly and efficiently sampled for *R. conicus* adults by using a suction machine. Thanatosis (death feigning) by adult weevils facilitated capture from plants which could be approached horizontally, tilted into the collecting bag, and gently shaken. Suction samples using the horizontal approach recaptured 98.6 ± 1.3% (mean [$\bar{x}$] ± SD) of adults released on thistles in laboratory tests. Vertical suction samples were less efficient: fewer than 2% of the weevils released on plants up to 1.5 m in height were recaptured in laboratory tests. Additionally, vertical samples accounted for less than 1% of total captures in field studies using naturally occurring populations.

The up-sweep method was ineffective for extracting newly emerged *R. conicus* adults; only 21.0% were recaptured with this technique. Little correlation ($r^2 = 0.13$) was found in the number of *R. conicus* removed vs. plant height. However, the mean removal rate from plants less than 1 m tall (27.5 ± 4.7% ($\bar{x}$ ± SD) was significantly greater ($P \geq 0.05$; F test) than from plants larger than 1 m (14.5 ± 2.9%). Thus, the efficiency of the up-sweep method in removing *R. conicus* from the plant is intermediate to that of the horizontal method and vertical method.

Observations on the response of *R. conicus* adults to the noise, air turbulence, and shadows produced during suction machine operation demonstrated that abruptly occurring shadows were responsible for the greatest reduction in field collections. Direct exposure to air exiting from the machine also caused some weevils to initiate thanatosis, but beyond 2.5 m the effect was negligible.

Field tests evaluating sampling interval deter-

Table 1.—Sample sizes and mean heights of musk thistles contrasted by sampling plans and dates[a]

Date	All plants analyzed				Selected plants analyzed[b]			
	With rosettes		Without rosettes		With rosettes		Without rosettes	
	Sample size	Plant ht	Sample size	Plant ht	Sample size	Plant ht	Sample size	Plant ht
9 May	169	3.7 ± 5.8	82	7.7 ± 6.3	45	10.5 ± 7.1	44	10.8 ± 6.9
17 May	150	19.9 ± 12.7	136	22.0 ± 11.5	74	26.6 ± 12.2	73	26.9 ± 12.0
24 May	159	26.8 ± 20.9	125	34.1 ± 17.4	69	43.9 ± 15.1	69	43.9 ± 15.1
31 May	141	45.4 ± 24.1	132	48.6 ± 21.6	58	60.4 ± 17.3	58	60.4 ± 17.3

[a] Plant heights measured in cm ± SD.
[b] Includes only thistles infested with *R. conicus*.

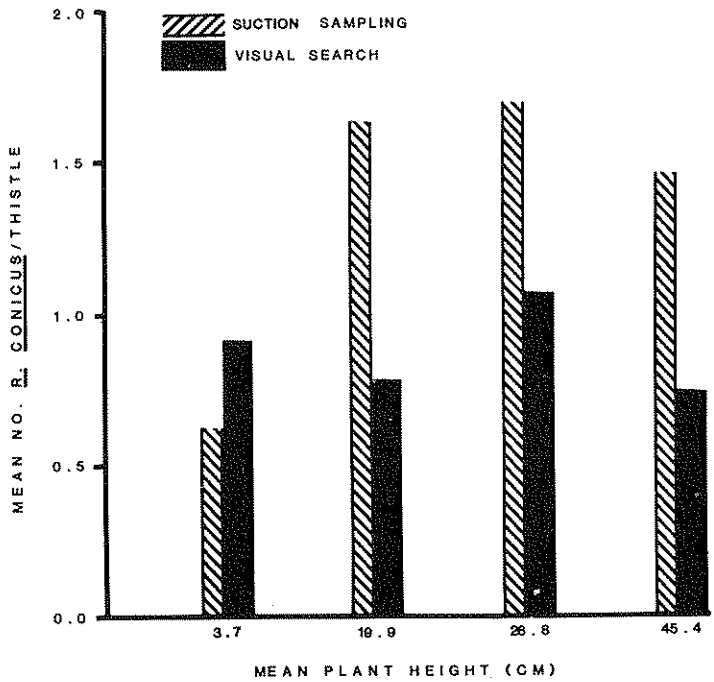

FIG. 1.—Mean number of *R. conicus* adults per musk thistle collected from five 25-m transects by suction sampling and visual searches at various mean plant heights.

mined that a single 2-sec suction was as effective as samples lasting 6 sec. Repeated collections from the same plant proved unnecessary since 99.6 ± 3% of the weevils which could be captured were collected on the first sample. Although sampling interval and repetition were not affected by plant heights from 5 cm to 1 m, more adults were collected from taller thistles throughout this study on each date.

Field Comparisons of Visual and Suction Sampling

Visual sampling for *R. conicus* adults on musk thistle was effective while musk thistles were short (<6 cm) but became less efficient and accurate when compared with suction sampling as plant height increased (Fig. 1). Visual surveys required additional time in the dense foliage of larger plants and proved less reliable due to difficulty in locating weevils and losses caused by sampling disturbance.

The mean heights and sample sizes of *C. nutans* have been contrasted by sampling plans and dates in Table 1. Mean plant heights increased between dates and among sampling plans as rosettes and plants not infested with *R. conicus* were excluded from the analysis. Larger weevil populations were associated with the taller thistles, suggesting that *R. conicus* prefers taller plants. Statistical variation in mean plant heights (coefficients of variation) decreased by consecutive sampling dates and as uninfested plants were excluded.

Four analyses of the transect data were undertaken to determine if the variability in plant height and apparent preference of *R. conicus* for taller thistles could be utilized in a population sampling program. The analyses included: all plants sampled including rosettes, all plants excluding rosettes, infested plants including rosettes, and infested plants excluding rosettes. Correlation coefficients (r) comparing visual and suction techniques for all four sampling plans demonstrated that the vacuum procedure explained more of the relationship between variables than visual samples for nearly all sampling plans and dates (Table 2).

The most useful predictive correlation (r = 0.95 for plant height × number of *R. conicus*) occurred when all plants excepting rosettes were sampled at an average plant height of 3.7 cm. Plant height variation (coefficient of variation = 156%) was greatest at this time, resulting in a distinct distribution pattern of weevils; taller plants attracted more adults. By not sampling rosettes, sampling error due to inefficiency of the suction device was reduced. As plant size increased with consecutive sample dates, height variation was reduced, and distribution of weevils on the basis of plant height became less pronounced. Additionally, smaller plants appeared to become more attractive to some weevils as oviposition sites became scarce on the taller thistles.

Impact of Suction Sampling on R. conicus Eggs

Suction sampling increased correlations between eggs and adults by improving sampling accuracy for both stages. *R. conicus* females cement eggs to the calyx of thistle blooms and on nearby stalks with a protective covering of moist fecal material. Air turbulence during vacuum sampling removed the old, dried-out egg casings. Subsequent egg counts from

Table 2.—Correlation coefficients[a] (r) contrasted between suction sampling and visual search techniques from various sampling plans for *R. conicus* on musk thistle

Analysis	Sampling method	All plants analyzed								Selected plants analyzed[b]							
		With rosettes				Without rosettes				With rosettes				Without rosettes			
		A[c]	B	C	D	A	B	C	D	A	B	C	D	A	B	C	D
Plant ht (cm) × no. of *R. conicus* adults	Vacuum	0.89	0.67	0.85	0.50	0.95	0.63	0.84	0.49	0.87	0.53	0.58	0.18[d]	0.87	0.55	0.58	0.18[d]
	Visual	0.71	0.46	0.66	0.55	0.67	0.36	0.56	0.51	0.57	0.42	0.36	0.32[d]	0.56	0.42	0.36	0.32[d]
Plant ht (cm) × no. of *R. conicus* eggs	Vacuum	—	0.71	0.87	0.81	—	0.69	0.85	0.80	—	0.59	0.79	0.87	—	0.57	0.79	0.87
	Visual	0.67	0.67	0.83	0.83	0.47	0.59	0.76	0.78	0.03[d]	0.68	0.53	0.55	0.12[d]	0.68	0.53	0.55
No of *R. conicus* adults × no. of *R. conicus* eggs	Vacuum	—	0.77	0.81	0.60	—	0.76	0.77	0.59	—	0.62	0.70	0.15[d]	—	0.63	0.70	0.16[d]
	Visual	0.57	0.59	0.70	0.63	0.53	0.53	0.61	0.61	0.31[d]	0.67	0.54	0.29[d]	0.31[d]	0.67	0.54	0.29[d]
No. of *R. conicus* adults × no. of plant blooms	Vacuum	0.78	0.58	0.80	0.59	—[e]	0.55	0.77	0.59	—[f]	0.66	0.63	0.45	—[e]	0.69	0.63	0.45
	Visual	0.51	0.45	0.59	0.62	0.10[d]	0.36	0.50	0.62	0.05[d]	0.48	0.50	0.28[d]	0.04[d]	0.48	0.50	0.28[d]

[a] Sample sizes listed in Table 1; correlations based on Spearman's ranking test (Sokal and Rohlf 1969).
[b] Only thistles infested with *R. conicus* included in analysis.
[c] A, B, C, and D refer to sample dates at 9, 17, 24, and 31 May, respectively; eggs not counted for suction samples on 9 May.
[d] "F" statistic not significant at 0.05 level.
[e] No plants with more than one flower, by removing rosettes all plants had one bloom and no correlations possible.
[f] No adults found on rosettes, all remaining plants with one bloom, no correlation possible.

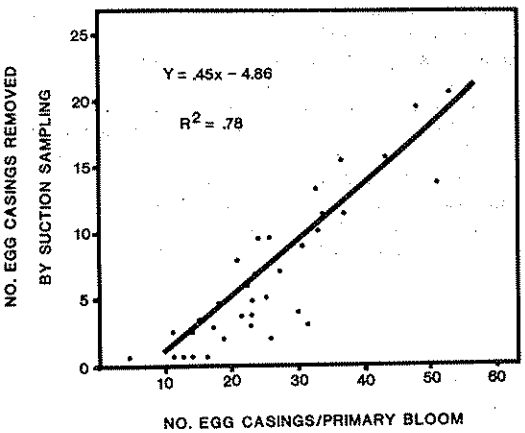

FIG. 2.—Linear regression of the number of *R. conicus* egg casings removed by suction sampling vs. the total number of egg casings per primary bloom.

primary blooms were more indicative of the current adult populations present, since overwintered populations decline toward midsummer, yet eggs frequently remain on the plants for 1 month or more.

Linear regression analysis of the number of egg casings removed during suction sampling vs. the total number of egg casings per terminal bloom (Fig. 2) indicated that as the number of egg casings per terminal bloom increases, the number of egg casings removed by vacuum sampling also rises. A mean of 23.8% of the total number of egg casings per terminal bloom were removed. Examination of the egg casings revealed that 63.8% of the removed eggs had already eclosed. An increase in the number of empty casings per sample was associated linearly with an increase in the total number egg casings removed during suction sampling (Fig. 3). Potentially viable eggs constituted ca. 15% of the eggs collected in field tests. However, these eggs were in casings which were not moist; thus, they may have been infertile or subjected to adverse factors (extreme environmental conditions, unsuitable oviposition sites) which may have prevented larval eclosion.

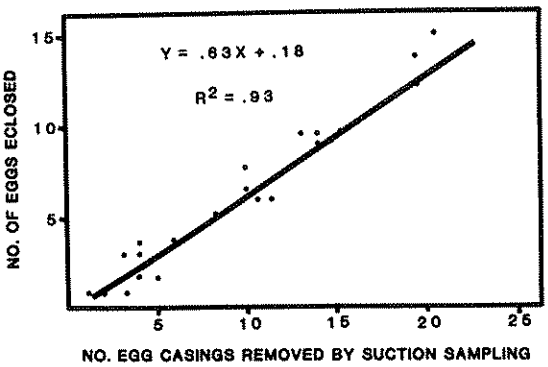

FIG. 3.—Linear regression of the number of *R. conicus* egg casings dislodged by suction sampling vs. the number of egg casings containing eclosed eggs.

Although up to 15% of the potentially viable eggs per primary bloom are removed during suction sampling, this technique is more reliable, accurate, and efficient than visual searches for *R. conicus*. The speed of sampling and knowledge of the attraction of tall thistles for adult weevils can be used effectively in a sampling program when plant height variation is greatest; less time is required and fewer plants need to be sampled to estimate relative densities of adults. Suction sampling may be most suitable for establishing relative population fluctuations on an annual basis. However, since suction samples can be influenced by the extent of plant development, yearly population surveys should coincide with selected plant heights, and not with time of year.

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