FACTORS AFFECTING BLUEBERRY MAGGOT, RHAGOLETIS MENDAX CURRAN (DIPTERA: TEPHRITIDAE), POPULATIONS IN ATLANTIC CANADA LOWBUSH BLUEBERRY FIELDS

by

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ABSTRACT

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FACTORS AFFECTING BLUEBERRY MAGGOT, *RHAGOLETIS MENDAX* CURRAN (DIPTERA:TEPHRITIDAE), POPULATIONS IN ATLANTIC CANADA LOWBUSH BLUEBERRY FIELDS

An investigation was conducted in Nova Scotia and New Brunswick to identify some regulatory factors that influence *R. mendax* populations in lowbush blueberry fields. In order to assess these factors it was necessary to evaluate the Pherocon® AM trap as a means of estimating adult fly populations.

The effectiveness of the fly traps was influenced by the position and orientation of their installation whether they were located above or between blueberry bushes. Traps impregnated with a proteinaceous attractant captured more *R. mendax* adults than unbaited traps, and more females than males, but the baited traps also captured some other fly species with similar wing patterns.

There was a positive correlation between weed growth, and the number of blueberry maggots (adults and larvae) detected. There was no correlation between soil pH and the incidence of *R. mendax*.

RESUME

M.Sc. Paul S. Geddes Entomologie

FACTEURS AFFECTANT LES POPULATIONS DE LA MOUCHE DE L'AIRELLE, RHAGOLETIS MENDAX CURRAN (DIPTERA: TEPHRITIDAE), DANS LES BLEUETIERES DE L'ATLANTIQUE

Un programme de recherche a été mis de l'avant en Nouvelle-Ecosse et au Nouveau-Brunswick afin d'isoler certains facteurs régulatoires qui influencent les populations de R. mendax dans les champs de bleuets sauvages. Afin de quantifier ces facteurs, il a été préalablement nécessaire d'évaluer l'efficacité du piège Pherocon ® AM comme méthode d'estimation des populations d'adultes.

L'efficacité de ces pièges à mouches est influencée par la position et l'orientation de leur installation, qu'ils soient localisés au-dessus ou entre les bosquets de bleuets. Les pièges imprégnés d'un appât protéinique captèrent plus d'adultes de R. mendax que ceux non appâtés, ainsi que plus de femelles que de mâles; cependant, les pièges appâtés ont capturé d'autres espèces de mouches ayant des nervures d'aile similaires.

Une corrélation positive a été détectée entre la croissance des mauvaises herbes, et les mouches de l'airelle (adultes et larves) dénombrées. Aucune corrélation entre le pH du sol et l'incidence de R. mendax n'a été mise en évidence.

Short title:

FACTORS AFFECTING BLUEBERRY MAGGOT POPULATIONS

Paul S. Geddes

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CONTRIBUTIONS TO KNOWLEDGE

1. An improved method of installing Pherocon AM traps for monitoring blueberry maggot adults, Rhagoletis mendax Curran, in lowbush blueberry fields was developed.

2. Pherocon AM traps baited with a proteinaceous attractant were found to capture more R. mendax flies than smaller unbaited traps, and more female than male flies.

3. It was determined that there is no relationship between soil pH and the incidence of R. mendax in Atlantic Canada.

4. A relationship was found between the extent of weed growth, blueberry growth, and the number of R. mendax (adults and larvae) detected within individual blueberry fields.

5. R. mendax flies were shown to migrate from the burned sections of blueberry fields into adjacent production sections.

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I. INTRODUCTION

The blueberry maggot, Rhagoletis méndax Curran (1932) (Diptera: Tephritidae), is generally known to be the most economically important insect pest of commercially grown blueberries in North America. In Maine, for example, an increase in blueberry maggot incidence early in this century nearly resulted in the collapse of the industry (Lathrop and Nickels 1932).

Blueberries were not an economically important crop in eastern Canada prior to 1940. One result of this earlier low market status is that the blueberry maggot was not reported in Nova Scotia until 1930, although it was believed to have occurred sporadically in the region before that time (Brittain and Pickett 1933). Since the Second World War, however, Canadian blueberry production has steadily increased (Eaton 1949; Barker et al. 1964) and blueberries have become a major agricultural export (Anon. 1976). In 1981, blueberries ranked fourth among Canada's fruit crops with a production of 18,000 tonnes and a farm value of over $20 million (Vandenberg 1982). Furthermore, 80% of this production came from managed stands of wild lowbush blueberries in eastern Canada (Fig. 1).

As a result of the increase economic importance of this crop, Maritime producers have expressed concern over possible losses caused by the blueberry maggot. The rapid

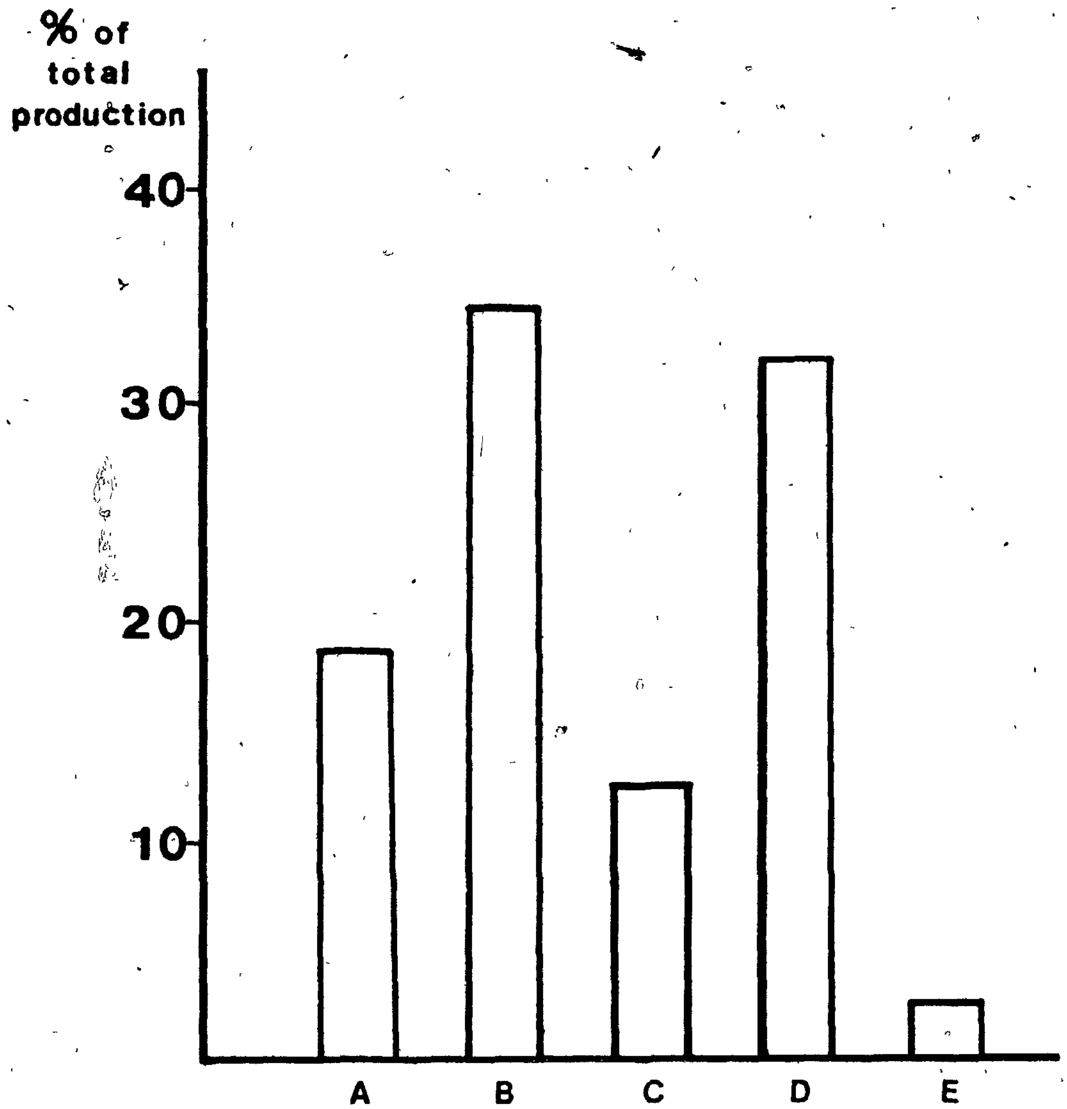

Figure 1. Canadian blueberry production for 1981.
(a) British Columbia (b) Quebec (c) New Brunswick
(d) Nova Scotia (e) Prince Edward Island and
Newfoundland
(from Vandenberg 1982)

growth of the industry emphasized the lack of published scientific information on *R. mendax*, a problem that may have been compounded by the confusion of this insect with the apple maggot, *R. pomonella* (Walsh). It is now apparent that additional research on the bionomics of *R. mendax* is required if efficient and economical management techniques are to be developed.

My study was undertaken to determine if a relationship exists between specific biotic and abiotic factors and the incidence of *R. mendax* in Atlantic Canada. In order to meet this objective, however, an attempt was also made to improve and standardize trapping techniques for monitoring blueberry maggot adults. Although the results of this latter study are reported separately here, these were required as an integral part of my investigation.

II. LITERATURE REVIEW

The literature on Rhagoletis mendax Curran is limited and has generally been published on an irregular basis since the insect was first reported in 1914. The threatened collapse of the blueberry industry in Maine during the mid-1920's resulted in numerous publications on its biology and control between 1928 and 1932. Since 1970, the rapid growth of the blueberry industry in eastern Canada has generated a renewed interest in this pest and several reports have been published, particularly dealing with monitoring techniques. Also, there has been in the past, considerable interest paid to the proper taxonomic classification of R. mendax.

The present literature review is a synopsis of the available literature on R. mendax, and includes discussions on taxonomy, life history and habits, occurrence and damage, control practices, and monitoring techniques.

A. Taxonomy

The blueberry maggot was first reported by Woods (1914) and O'Kane (1914). Based on the physical characteristics of flies reared from larvae and puparia collected from blueberry fields, these workers identified this insect as the apple maggot, Rhagoletis pomonella (Walsh). Blueberry maggot flies were described as being smaller than apple maggot flies, however, and were more elusive and agile. Furthermore, these flies could not be induced to oviposit on apples, and it was surmised that the apple and blueberry forms represented two distinct strains or races of R. pomonella, each co-existing independently (Woods 1915; Patch and Woods 1922). This finding was supported in subsequent reports (Phillips 1923; Porter 1928; Cresson 1929; Greene 1929; Thorpe 1930; Lathrop and McAlister 1931; Lathrop and Nickels 1931, 1932; Brittain and Pickett 1933).

Curran (1932) classified the blueberry maggot as the species Rhagoletis mendax based on the shape of the ejaculatory apodeme of the male genitalia. Benjamin (1934) and Pickett (1936, 1937), however, disagreed with Curran's classification, and claimed the shape of the male genitalia is variable in Rhagoletis species. In an attempt to resolve this debate over classification, crossbreeding and host selection studies were carried out (Lathrop and Nickels 1931; McAlister and Anderson 1935; Pickett 1936, 1937; Pickett and Neary 1940). Although these studies were difficult to interpret because of poor rearing results (Pickett 1936, 1937), the taxon R. pomonella was constantly used in several subsequent reports (Beckwith and Doehlert 1937; Maxwell and Pickett 1949; Lathrop 1952; Christenson and Foote 1960; Rohdendorf 1961).

In a major revision of the North American genus Rhagoletis, Bush (1966) accepted the classification of Curran (1932), and placed R. mendax in a pomonella species group;

also, R. mendax and R. pomonella were proposed as sibling species based on the following criteria: (1) crossbreeding experiments, (2) host plants, (3) slight but consistent morphological differences, and (4) distribution (Bush 1969a,b; Prokopy and Bush (1973). In addition, Bush (1966) reported the existence, in Florida, of a second population of R. mendax, morphologically distinct from the northern one, on the basis of characteristics of the male genitalia. Divergence of the Florida population from the northern one probably occurred sometime during the Pleistocene period when peninsular Florida was isolated from the mainland as a chain of islands. Because both populations utilize the same host plants, the Florida form should not be considered a distinct species without additional crossbreeding, life cycle, and distribution studies.

An electrophoretic analysis of the genus Rhagoletis by Berlocher and Bush (1982) supports the evidence that Rhagoletis spp. evolved independently of their host plants (Bush 1966, 1969a,b). Simon (1969) found that populations feeding on apple and hawthorn could be differentiated from those feeding on blueberry. This author used quantitative and qualitative serological techniques to compare protein extracts and stated: "It is unlikely that serological differences of such magnitude could be maintained by these species if free gene exchange occurred between them."

The present classification of the blueberry maggot is as follows (Stone et al. 1965):

Order: Diptera

Suborder: Cyclorrhapha

Division: Schizophora

Section: Acalyptratae

Superfamily: Tephritoidea

Family: Tephritidae

Subfamily: Trypetinae

Tribe: Trypetini

Genus: Rhagoletis

Species Group: pomonella (Bush 1966)

Species: mendax

A morphological key for North American Rhagoletis spp. (Bush 1966) distinguishes R. mendax from R. pomonella by the following adult characteristics: (1) absence of black shading on the posterior surface of femur I, (2) shorter ovipositor length, (3) difference in wing band ratios, and (4) host plants. Using the larval key designed by Phillips (1946), one can differentiate between R. mendax and R. pomonella on the basis of their host plants; however, this key does not include morphological differences other than size. Berlocher (1980) developed a more accurate electrophoretic key for this genus based on the mobility of six enzymes separated by gel electrophoresis. It allows distinction between larvae, pupae, and adults of nine Rhagoletis spp., including the pomonella group.

B. Life History and Habits of R. mendax

R. mendax adults generally begin to emerge as the first blueberries ripen; emergence time, however, varies with geographical location (Table 1) and other factors. For example, Lathrop and Nickels (1932) found the later the larvae enter the soil in the fall, the earlier the flies emerge the following summer. Lathrop (1952), however, noted that emergence dates varied with the type of blueberry land; flies generally emerged earlier from warm, well-drained land than from cool and comparatively low land. Emergence time is also reported from laboratory-reared R. mendax as being related to length of diapause and incubation temperatures (Neilson 1982). There is a single generation per year and ca. 98% emergence is usually complete within thirty days of the flies first appearing. Emergence continues at a declining rate until the first frost occurs (Woods 1915; Patch and Woods 1922; Lathrop and McAlister 1931; Lathrop and Nickels 1932; Beckwith 1943; Lathrop 1952; Neunzig and Sorensen 1976).

R. mendax adults forage on the leaves of the various types of vegetation commonly found in blueberry fields, for a period of 7 to 15 days after emergence (Lathrop and McAlister 1931; Lathrop and Nickels 1932; Beckwith 1943; Lathrop 1952; Wood 1962, 1979b; Neunzig and Sorensen 1976). This varied dietary requirement is common with other species of the Tephritidae family. Plant secretions such as nectar

Table 1. General emergence times of *R. mendax*.

Location	Time	Reference
Eastern Canada	Early July	Pickett and Spicer 1931 Wood 1962, 1979b
Maine	Late June	Lathrop and McAlister 1931 Lathrop and Nickels 1932 Lathrop 1950, 1952
New Jersey	Mid-June	Beckwith 1943
North Carolina	Late May	Neunzig and Sorensen 1976

(or secretions caused by insects, disease or mechanical damage), rotting fruit, bird dung, decaying insects, and honeydew secreted by homopterous insects, have been identified as food sources used by tephritid adults (Christenson and Foote 1960; Boller and Prokopy 1976). Lathrop and Nickels (1932) reported that blueberry maggot flies have even been induced to feed on a finger moistened with saliva or the juice of a crushed blueberry.

Sexual maturation is accompanied by the movement of flies from foliage to blueberry fruit and has been found to be related to changes in ambient temperature, incident light intensity, and female receptivity (Smith and Prokopy 1981, 1982). During copulation, the male grasps the female with the prothoracic and mesothoracic legs and remains coupled 15 to 20 minutes (Woods 1915; Patch and Woods 1922). I have also observed this process in the laboratory and noted that mating pairs tend to be less alert than foraging individuals. During oviposition, the female inserts its ovipositor into the fruit at an angle of about 45° and deposits a single egg, attaching it to the inner surface of the blueberry skin (Lathrop and McAlister 1931; Lathrop and Nickels 1932; Lathrop 1952). Females produce from 25 to 100 eggs over a period of 15 to 25 days. Because the average life span of a fly may reach 30 days, and emergence can occur over a period of thirty days also, oviposition will continue late into the season (Lathrop and Nickels 1932; Lathrop 1952).

Factors contributing to host plant detection and ovipositional response by R. mendax are largely unknown, however, several investigations on R. pomonella have been reported. For example, Prokopy and Owens (1978, 1983) characterize the latter species as a "visual specialist". Apple maggot flies initially detect host trees by foliage color (reflective hue), tree shape, tree size, and fruit odor. Upon arrival at the tree, however, the fruit is detected solely by its size, shape, and color in contrast with background lighting (Prokopy et al. 1973; Moericke et al. 1975; Boller and Prokopy 1976; Prokopy 1977, 1982). There is also evidence that apple maggot flies may accept or reject a host fruit based on previous ovipositional experience (Prokopy et al. 1982). The stimuli eleciting oviposition are not necessarily specific to host plants suitable for larval development (Boller and Prokopy 1976). R. mendax has been shown to oviposit on fruit in which the larvae cannot survive (Pickett 1936, 1937; Pickett and Neary 1940; Neilson and Knowlton 1983), as well as in artificial oviposition devices lacking host fruit material (Prokopy and Bush 1973). Oviposition deterring pheromones (ODP's) also influence egg laying in Rhagoletis species. These are secreted on the surface of a host fruit by females following oviposition, and deter other females from ovipositing on the same fruit (Prokopy 1982). The behavior of dragging the ovipositor across fruit after egg laying suggests ODP secretion by R. mendax (Prokopy et al. 1976),

R. pomonella (Prokopy 1972, 1981a), and several other Rhagoletis spp. (Prokopy 1981b).

The eggs of R. mendax require an incubation period of three to ten days in the field (Lathrop and McAlister 1931; Lathrop 1952; Neunzig and Sorensen 1976). There are three larval instars and second instar larvae usually appear eight to nine days after egg-hatching. Third instar larvae appear about three or four days later, and larval populations generally peak about blueberry harvest time (Lathrop and Nickels 1932). The whitish, torpedo-shaped third instar larvae require six to nine days to mature and are then ca. 0.75 cm. in length (Lathrop and Nickels 1932; Beckwith 1943; Lathrop 1952; Neunzig and Sorensen 1976). If an infested blueberry remains undisturbed on the plant, the maggot will remain in the fruit until the pulp is completely devoured and will either exit from the berry while it is still on the plant, or after it has dropped to the ground. If, however, the fruit dries due to unusually warm weather, or is battered by heavy rains, the larvae may be forced to leave the fruit earlier (Lathrop and Nickels 1932). On at least one occasion, a larva was observed to pass from one blueberry into another (McAlister 1932).

Most postfeeding larvae enter into the surface organic soil layer to a depth of 5 cm. after exiting from the blueberry fruit (Pickett and Spicer 1931; Lathrop and Nickels 1932; Beckwith 1943; Lathrop 1952). Early reports claimed the puparium is formed one to two days after the postfeeding larvae enters the soil and pupation occurs seven to ten days later (Woods 1915; Patch and Woods 1922). Although specific studies have not been made of the process of pupariation and pupation for R. mendax, it is likely similar to that of R. pomonella and other cyclorrhaphous Diptera as described by Dean and Chapman (1973) and Fraenkel and Bhaskaran (1973).

The majority of puparia will remain in the soil for only one season; however, as many as 20% may remain for two seasons and up to 6% for as long as five seasons (Pickett and Spicer 1931; Lathrop and Nickels 1932; Beckwith 1943; Wood 1962, 1979b; Boller and Prokopy 1976; Neunzig and Sorensen 1976). Flies from puparia that carried over more than one season generally emerge several days later than flies from single-season puparia (Lathrop and Nickels 1932).

C. Occurrence and Damage

The distribution of R. mendax in North America is not extensively documented. In the United States it is primarily restricted to the northeastern region (Fig. 2), including Maine (Woods 1914), New Hampshire (O'Kane 1914), New Jersey (Beckwith and Doehlert 1937), Michigan (Bush 1966), and North Carolina (Neunzig and Sorensen 1976). The morphologically distinct Florida R. mendax is believed to be coextensive with the northern population, however, its range has not been established with certainty (Bush 1966). In eastern Canada, R. mendax is restricted to the Atlantic

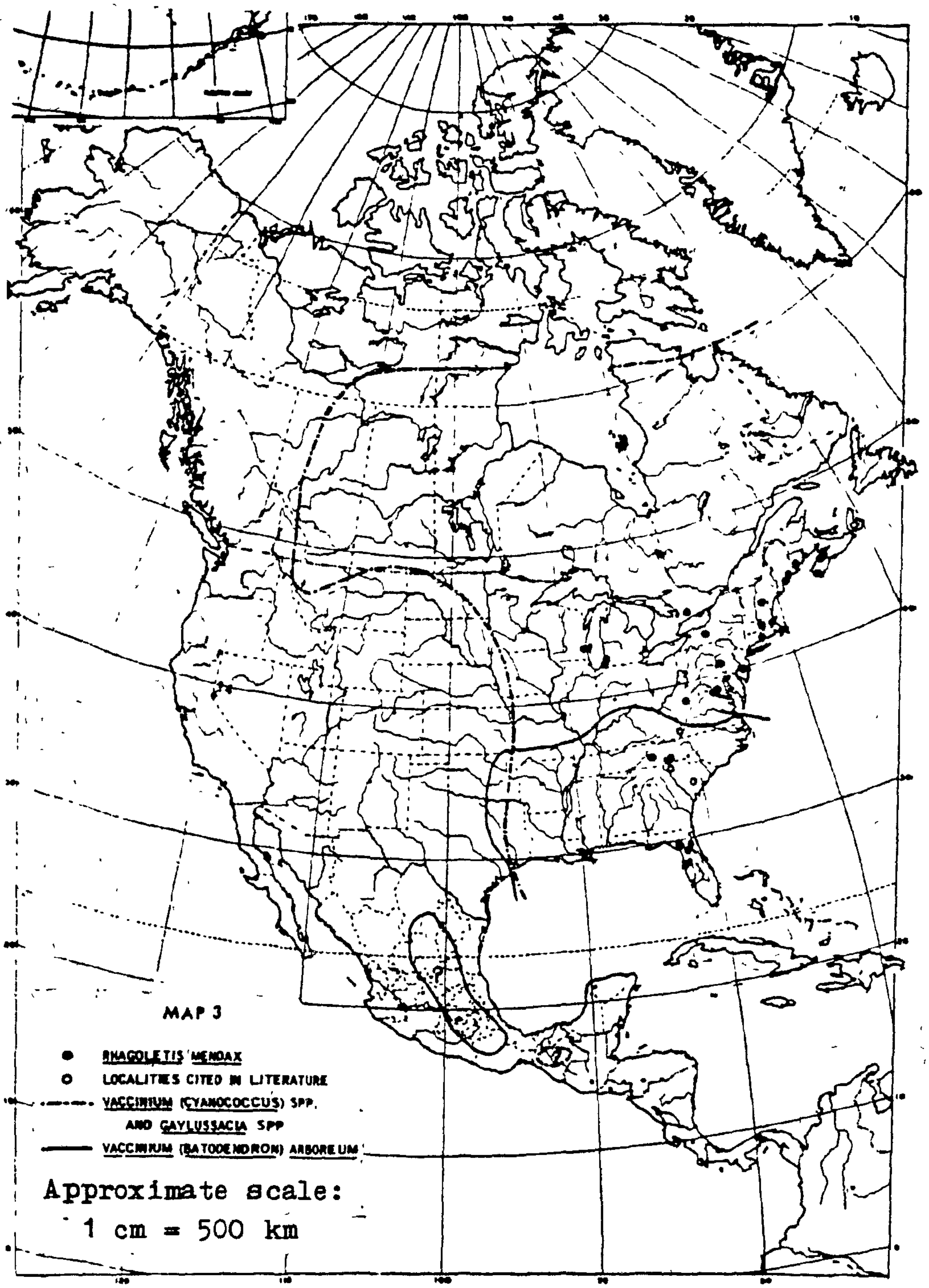

Figure 2. Distribution of R. mendax and host plants in North America.
(from Bush 1966, with permission)

provinces, with the exception of Newfoundland (Wood 1962, 1979b; Barker et al. 1964). Localities where the blueberry maggot is most prevalent include the counties of Colchester, Cumberland, Hants, and Yarmouth in Nova Scotia and Charlotte, Kent, and Westmorland in New Brunswick (Fig. 3). All blueberry growing areas except the New Brunswick counties of Restigouche, Madawaska, Victoria, and Carleton are considered to be infested for quarantine purposes.[1]

The blueberry maggot was first reported infesting three species of blueberry[2] in Maine (Woods (1914). These are the low sweet blueberry, Vaccinium angustifolium (= pennsylvanicum) Ait., the sour-top blueberry, V. myrtilloides (= canadense) Michx. (Kalm), and the early sweet blueberry, V. vaccilans Torr. The blueberry maggot was also reported on highbush blueberry, V. corymbosum L. in New Hampshire (O'Kane 1914). Both larvae and adults have been obtained from the above blueberry species (Lathrop and Nickels 1931, 1932). A small form of R. pomonella that resembled the

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[1]Quarantine Directive No. 82-03. Agriculture Canada, Food Production and Inspection Branch, Plant Health Division, Ottawa. September 27, 1982.

[2]Gray's Manual of Botany (Fernald 1950) places the blueberry in the Ericacae or Heath family and among the Vaccinoidae or Whortleberry subfamily, which includes the gerera Chiogenes (snowberry), Gaylessacia (huckleberry), and Vaccinium (cranberry, deerberry, and blueberry). An extensive key and description of the species and related groups of North American Vacciniacae is provided by Camp (1945).

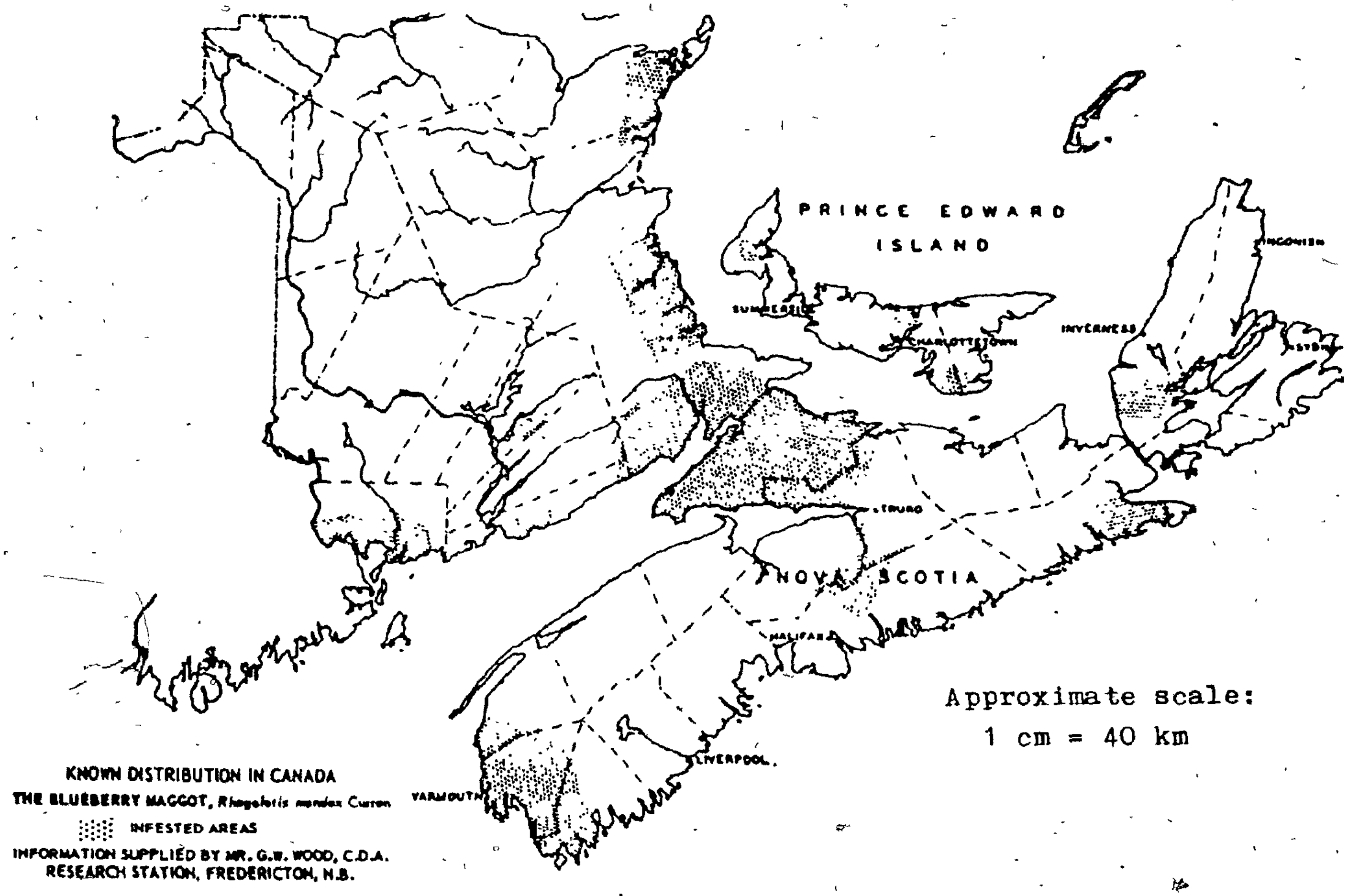

Figure 3. Distribution of R. mendax in Atlantic Canada (Insect Distribution Maps, CANADA, Vol 4, 1955-1965, Entomology Division, Agriculture Canada, Ottawa)

blueberry maggot (Woods 1915; Patch and Woods 1922), was reported on huckleberry, Gaylessacia baccata (Wange), in Connecticut (Britton 1906) and New Jersey (Smith 1910). Later studies carried out in Maine revealed that G. baccata was indeed a host of R. mendax, as both larvae and adults of the species were observed (Lathrop and McAlister 1931; Lathrop and Nickels 1931, 1932; Lathrop 1952). The blueberry maggot has also been associated with the following plants: mountain cranberry, V. vistis-ideae minus Lodd., chokeberry, Pyrus (= Aronia) melanocarpa Willd. (Michx.), bunchberry, Cornus canadensis L., sugar pear or dwarf serviceberry, Amelanchier bartramiana Roem., and wintergreen, Gaultheria procumbens L. (Lathrop and McAlister 1931; Lathrop and Nickels 1931, 1932; Lathrop 1952). Larvae and adults were also obtained from bunchberry, but only larval stages were retrieved from the other species (Lathrop and Nickels 1931, 1932). Neilson and Knowlton (1983) were able to rear one generation of R. mendax on Indared apples in the laboratory although larval mortality reached 83%. This disputed earlier claims that R. mendax larvae are unable to survive on apples (Pickett 1936, 1937).

As with all other Rhagoletis spp., only the larvae of R. mendax are completely phytophagous, feeding solely on the fruit of host plants (Boller and Prokopy 1976). Damage is generally difficult to detect when the larvae are in the early stages of development, but as they mature the berry pulp breaks down, eventually causing the fruit to collapse (Woods 1915; Patch and Woods 1922; Neunzig and Sorensen 1976).

The blueberry maggot is generally considered a "cosmetic" pest. The presence of larvae in mature berries makes them less attractive to fresh market consumers. Infestation by maggots also reduces the export of fresh and processed fruit to foreign markets (Lathrop and McAlister 1931; Pickett and Spicer 1931; Lathrop and Nickels 1932; Wood 1962, 1979b). Damage is usually most apparent after the fruit is harvested (Neunzig and Sorensen 1976); damaged fruit are difficult to process and thus often reach the market in poor condition (Lathrop and McAlister 1931; Lathrop and Nickels 1932). In the case of cultivated highbush blueberries, a one percent larval infestation can render a crop useless as fresh or processed fruit (Beckwith 1943). Currently in eastern Canada, when standard monitoring yields four or more larvae per litre of freshly harvested fruit, the crop may be rejected for export.

D. Control Practices

Although burning and weed control have a positive effect in reducing R. mendax population levels (see section IV), chemical control is generally recommended when blueberry maggot infestations are detected. For many years, calcium arsenate dust applied at a rate of six to seven pounds per acre (6.7 to 7.8 kg per ha) was used to control

R. mendax (Lathrop and Nickels 1930, 1932; Lathrop and McAlister 1931; Pickett and Spicer 1931; Brittain and Pickett 1933; McAlister 1933). Calcium arsenate was also combined with copper sulfate and calcium hydroxide and applied at rates of six to twenty pounds per acre (6.7 to 22.5 kg per ha), depending on the severity of blueberry maggot infestation (Maxwell and Pickett 1949; Lathrop 1950, 1952; Hawboldt 1954; Wood 1962). Insecticides such as azinphos-methyl and carbaryl have been recommended in recent years (Wood 1979a) and in 1984, azinphos-methyl 80% EC (0.5 L per ha), dimethoate 40% EC (1.4 L per ha) or 50% WP (0.6 kg per ha), and phosmet 50% WP (2.0 kg per ha) are registered for R. mendax control.[1]

The strategy used in the chemical control of R. mendax has been to kill the flies before they begin to oviposit because there is no effective way of controlling the larval stage. Insecticide applications are usually made about one week after blueberry fruit begin to ripen. A second application is generally recommended in cases where there is a known history of blueberry maggot infestation.

E. Monitoring Techniques

The earliest monitoring technique devised for R. mendax involved detecting and counting larvae. This was

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[1] 1984 Lowbush Blueberry Production Guide, Advisory Committee on Berry Crops, Atlantic Provinces Agricultural Services Co-ordinating Committee. 3p.

done by boiling and straining samples of fresh blueberry fruit and recording the number of maggots retrieved (Pickett and Spicer 1931; Brittain and Pickett 1933; Hawboldt 1954; Wood 1962). One shortcoming of this method, however, is that the insect is detected after damage occurs, with chemical controls being applied the following season. It is obvious that attempts to detect adults would be more useful for management programs to be carried out the same season.

Several types of sticky yellow board traps, including the commercially available Pherocon® AM trap[1] and Rebel® trap[2] (developed to monitor apple maggot flies), were tested for their ability to capture blueberry maggot flies with positive results (Prokopy and Coli 1978; Neilson and Fuller 1981, 1982; Wood et al. 1983; Neilson et al. 1984). The attraction of adult *Rhagoletis* spp. to these yellow traps is actually explained by a foraging response (Prokopy 1968a). The reflective-transmittance hue of green leaves lies between 500 and 580 nm and peaks at 560 nm in the yellow band of the spectrum (Prokopy and Owens 1983). This feature could make the Pherocon AM trap a potentially valuable pest management tool for *R. mendax* as outbreaks could be detected and action taken before females begin to oviposit. Prokopy and Coli (1978) have suggested the Pherocon AM trap could also be used to reduce *R. mendax* populations in small highbush blueberry fields of one hectare or less. A knowledge of

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[1] Zoëcon Corp., Palo Alto, California, 94304.

[2] Swiss Federal Research Station, Wädenswil, Switzerland.

how to obtain maximum trap captures would, however, be essential for such applications.

Another type of trap which has been shown to be attractive to R. mendax flies is the sticky red sphere. An example is the commercially available tartar dark red spheres[1] (Prokopy and Coli 1978; Neilson and Fuller 1981, 1982; Neilson et al. 1984). As with the Pherocon AM traps, these spheres were initially developed to monitor apple maggot flies (Prokopy 1968b, 1975, 1976). The attraction of Rhagoletis spp. to these traps, however, is based on an ovipositional response to the fruit, i.e., the contrast of a dark silhouette against a light background (Prokopy 1968a). These spheres, which are less expensive than the Pherocon AM traps, are more attractive and selective to apple maggot flies (Prokopy and Hauschild 1979). I consider the sphere would be less useful than the Pherocon AM trap for monitoring R. mendax populations, however, because flies would not be detected until mating and oviposition begin. At this point it may be impossible to prevent infestation of the already mature fruit. The sphere traps are also difficult to install and inspect because of their design and construction and would likely be inconvenient for grower use (Neilson and Fuller 1982; Neilson et al. 1984).

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[1] New England Insect Traps, Amherst, Massachusetts, 01003.

III. ADULT MONITORING TECHNIQUES: EVALUATION OF THE PHEROCON AM TRAP

A. Introduction

Attempts to establish an economic threshold for R. mendax in lowbush blueberry fields using Pherocon AM traps have not been successful to date. Conflicting results were obtained from trials in Maine (Brown and Ismail 1981) and in eastern Canada (Wood et al. 1983; Neilson et al. 1984). These attempts demonstrated that a standard monitoring program cannot be developed without further research into the effect of trap position and location. Furthermore, when relative estimates of an insect population are made, the relationship between the sex ratio of captures and the one of the population from which the samples were taken should be considered (Southwood 1978). Therefore, any economic threshold that is established for R. mendax based on Pherocon AM trap results may have to be adjusted if the sex ratio of flies captured differs from that of the field populations.

The objectives of my experiments were to evaluate the Pherocon AM trap as a monitoring tool for R. mendax in the following manner: 1) the effect of position, location, and orientation on the number of R. mendax flies captured; 2) comparison of traps baited with a proteinaceous attractant with unbaited traps in terms of the total number of flies captured; 3) the sex ratios of the fly population captured; and, 4) the specificity of the baited traps for R. mendax.

B. Materials and Methods

a) Trap placement

Two experiments were conducted to determine how the placement of Pherocon AM traps might influence the number of R. mendax flies captured. In the first experiment which was carried out during early July and August 1982, effects of trap position and location were tested. Three lowbush blueberry fields were selected because of their infestation history and lack of insecticide use. The fields were located in Glenholme, Nova Scotia; Richibucto, New Brunswick; and Jonesboro, Maine. Results from the Richibucto field were provided by Dr. G.W. Wood[1] and G. Chaisson;[2] the data from the Jonesboro field was supplied by K. Flanders.[3]

Baited Pherocon AM traps (23 x 28 cm) were folded to form a 90° angle with the apex either pointed upward

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[1]Agriculture Canada Research Station, Fredericton, New Brunswick.

[2]New Brunswick Department of Agriculture and Rural Development, Bathurst, New Brunswick.

[3]Department of Entomology, University of Maine at Orono, Orono, Maine.

to form a "roof" (Λ position), or downward to form a "V" (V position); the sticky yellow surface was oriented toward the ground in each case. These traps could be located between or above blueberry bushes. Those traps set between bushes (Λ between, V between) were positioned with the lower edge 30 cm above the ground. Traps located above (Λ above, V above) were placed to allow a 10 cm clearance between plants and traps (see Table 2 and Fig. 4).

Numbers of blueberry maggot flies captured were recorded by weekly inspection, and the data from each field was submitted to a two-way analysis of variance at the 5% level (Sokal and Rohlf 1981).

A second experiment on the effect of trap orientation was carried out during July and August 1983, in the following lowbush blueberry fields: Reedpath, Stonehouse, Debert Airport, Weatherhead, Burges, Dodsworth, Harrington, Sargent, Mildrum, and Beaumont. Information pertaining to the location of each of these fields is provided in Appendix I.

In each field, sixteen baited Pherocon AM traps were uniformly distributed within a 4 ha test plot. A second plot was established in the Harrington and Sargent fields in sections that had been burned, (a standard cultural practice, Section IV-A). Each trap was installed in the previously tested V position (see Fig. 5) to achieve optimum fly capture. The outer surface of eight of the traps was lined up in a north-south direction (magnetic north), and the other eight in an east-west direction.

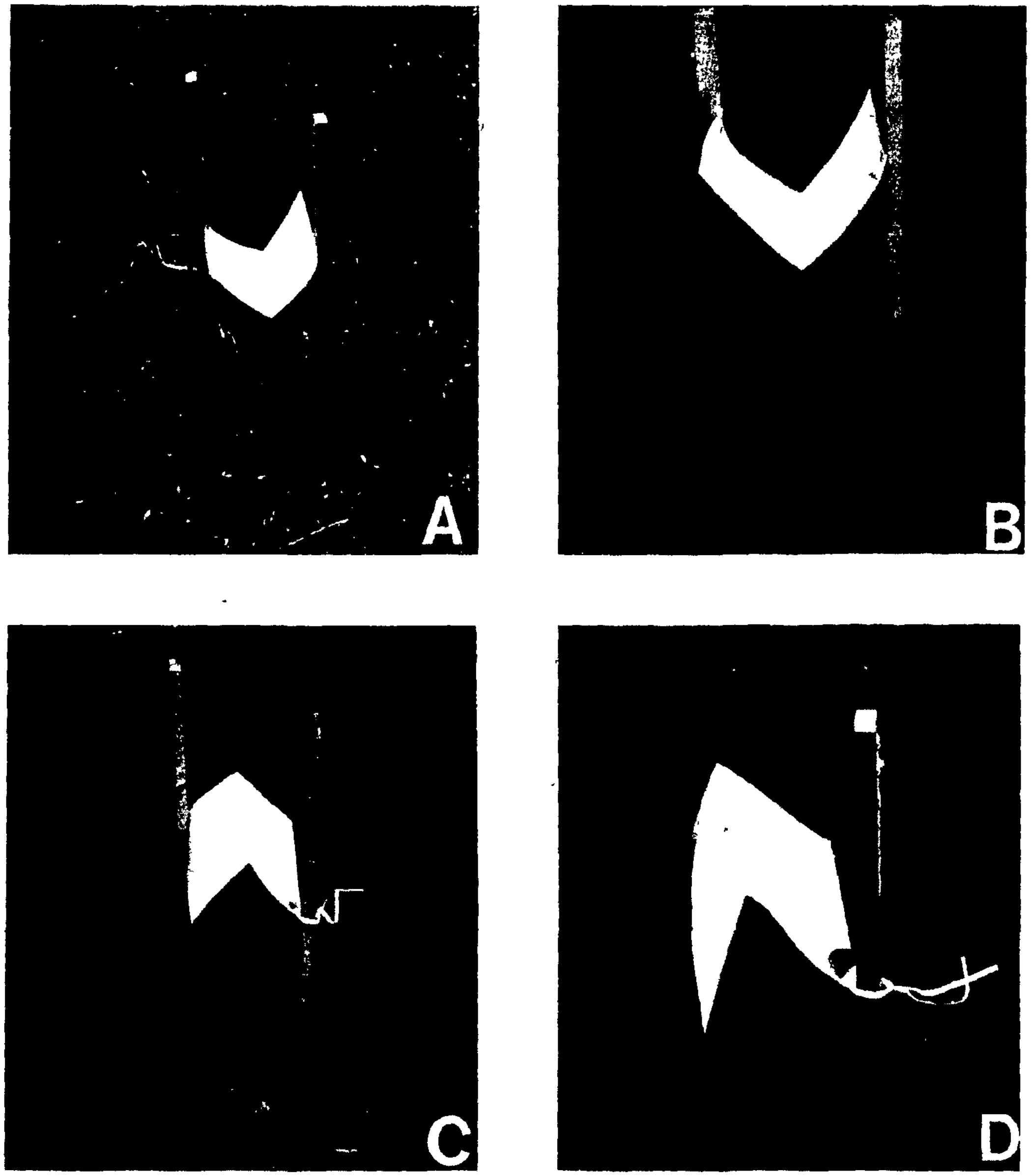

Figure 4. Combinations of Pherocon AM trap positions and locations to determine optimum trap placement for capturing *R. mendax* adults. (a) V between bushes (b) V above bushes. (c) Λ between bushes; (d) Λ above bushes.

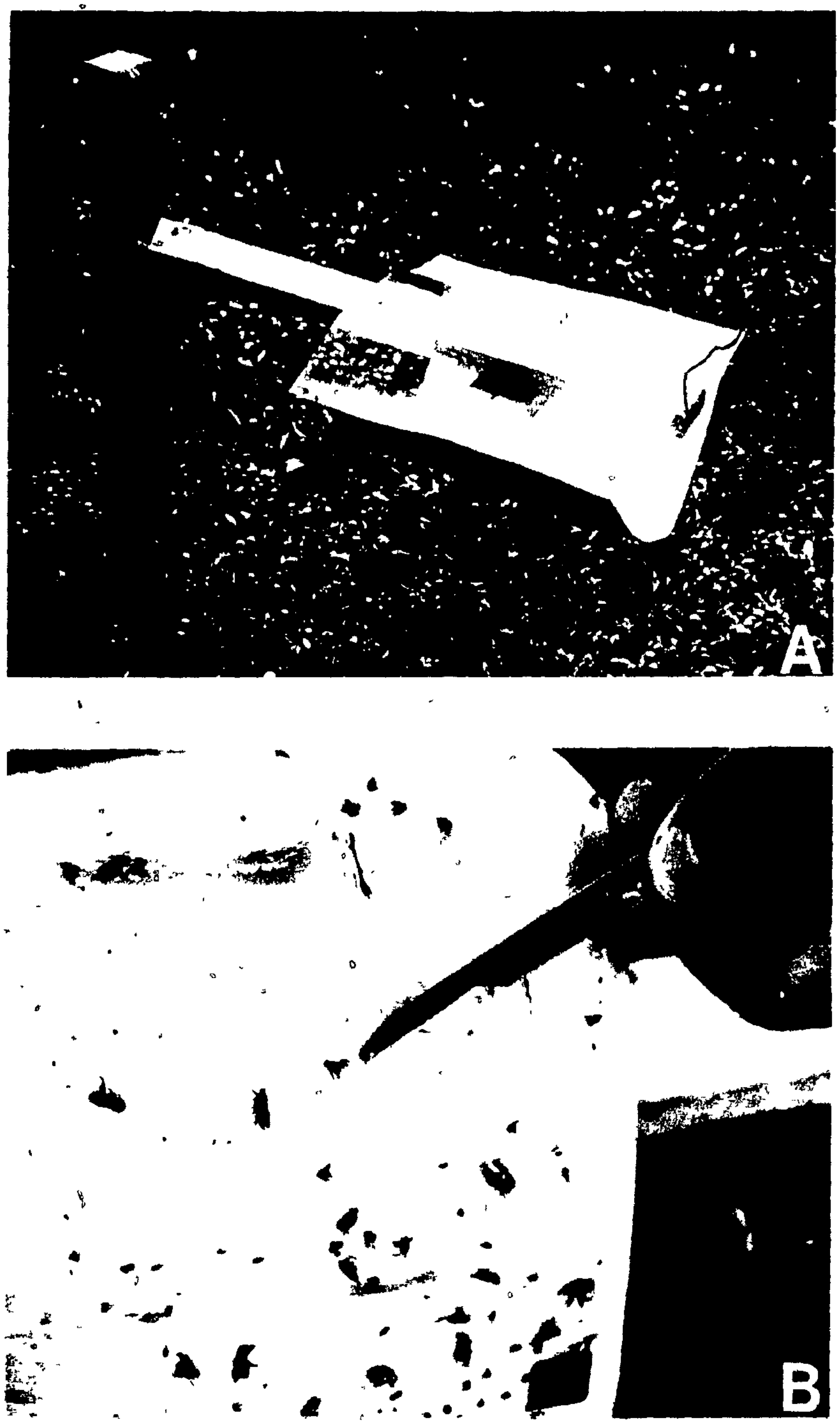

Figure 5. improved method of installing Pherocon AM traps. (a) trap mounted in V position (b) close examination of trap captures.

All traps were renewed after a three week period.

Blueberry maggot fly captures were recorded once a week and data from all fields was evaluated using a Chi-square test, adjusted with Yates' correction for continuity when trap captures differed significantly at the 5% level (Steel and Torrie 1960).

b) Trap attractants

This experiment was conducted during 1983 in the Reedpath and Harrington fields in association with Dr. L.P.S. Kuenen.[1] Six Pherocon AM traps, impregnated with an attractant bait, ammonium acetate and Hycase protein hydrolysate (Prokopy and Coli 1978) incorporated into Tanglefoot® on the yellow surface, were compared with six unbaited traps, i.e., covered with adhesive only. The twelve randomly chosen traps were placed ca. 45 m apart in the V position, 10 cm above blueberry plants.

Blueberry maggot fly captures were recorded every two to four days, and the data from both fields was analysed using a Chi-square test adjusted with Yates' correction for continuity when appropriate (Steel and Torrie 1960).

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[1] Research and Productivity Council, Fredericton, New Brunswick.

c) Examination of trap captures

Data for this experiment were obtained from the Pherocon AM trap captures reported in the above section (b). All flies captured on these traps were collected once a week and sexed in the laboratory. Sexing is easily done when the ovipositor is readily located. When the ovipositor is not extended or visible, sexing is achieved by distinguishing one or more of the following morphological characteristics: 1) size, the female is larger than the male; 2) abdominal shape, the female abdomen is more pointed at the posterior end; 3) abdominal markings, there are three white stripes on the dorsal surface of the male abdomen while the female abdomen has a fourth or partial fourth stripe; 4) abdominal segments, the male abdomen has five tergites and five sternites while the female abdomen has six of each (Bush 1966). This latter characteristic is the most reliable one.

In addition, all trap captures were also examined for the presence of Diptera species with similar wing patterns, particularly other <u>Rhagoletis</u> spp. such as <u>R. pomonella</u>, that could be mistaken for the blueberry maggot fly.

The sex ratio of all trap captures was calculated and analysed using a Chi-square test adjusted with Yates' correction for continuity when the ratio of males to females differed significantly from 1:1 at the 5% level (Steel and Torrie 1960).

C. Results and Discussion

a) Trap position and location

The number of *R. mendax* adults captured with the two Pherocon AM trap positions tested, differed significantly at the 5% level (Table 2), the **V** position having more captures than the **Λ** position in all fields. The location of traps either between or above blueberry plants had no significant effect on the results.

These results are in general agreement with those from highbush blueberry fields (Prokopy and Coli 1978). An explanation for these results may be that the yellow surface of traps in the **Λ** position was shaded from sunlight, thereby reducing the reflective yellow hue perceived by foraging adults. Trap visibility has also been shown to be an important criterion for monitoring *R. pomonella* flies (Drummond *et al.* 1984).

The similarity of captures from traps located between and above bushes may be explained by the nature of the lowbush blueberry plant, which in most fields, reach a height of 10 to 15 cm (Hall and Aalders 1979). Our results indicate that *R. mendax* flies are equally capable of flying over or between lowbush blueberry plants.

Table 2. Effect of Pherocon AM trap position and location within lowbush blueberry fields on the capture of *R. mendax* adults.

Locality (No. traps)	Date (1982)	Treatment	Captures	Captures as % of those captures on the V between treatment
Nova Scotia (16 traps)	July 20- Aug. 13	V Between	568	100.00[a] [1]
		V Above	495	87.15[a]
		Λ Between	168	29.58[b] (1393) [2]
		Λ Above	162	28.52[b]
New Brunswick (20 traps)	July 7- Aug. 11	V Between	1518	100.00[a]
		V Above	1331	87.68[a]
		Λ Between	861	56.72[b] (4737)
		Λ Above	827	54.48[b]
Maine (20 traps)	June 24- Aug. 18	V Between	308	100.00[a]
		V Above	270	87.66[a]
		Λ Between	169	54.87[b] (902)
		Λ Above	162	52.60[b]

[1] Those percentages followed by the same letter in the same field are not significantly different at the 5% level, two-way ANOVA.

[2] Total captures per field.

b) Trap orientation

The total number of R. mendax flies captured during the 1983 season on Pherocon AM traps positioned either in a north-south or east-west direction varied among fields (Table 3). Although in most fields the weekly trap captures also varied, they usually did not differ significantly at the 5% level. In the Beaumont field, however, more flies were captured on east-west traps during five of the six weeks the test lasted, and the results were significant at the 5% level.

Previous reports in the literature have suggested that blueberry maggot flies use weedy areas within fields as protection against wind (Wood 1962, 1979b). This is further supported by the results presented in section IV-C(b). The data given in Table 3 indicate that, in most fields, the number of fly captures will vary less if Pherocon AM traps are installed facing several directions. The Beaumont field is an exception to this theory, however, and suggests that additional research is required to determine to what extent and under what conditions wind may affect R. mendax adult movement and captures on Pherocon AM traps within lowbush blueberry fields.

c) Baited and unbaited traps

Baited Pherocon AM traps captured significantly larger numbers (1% level) of R. mendax adults than unbaited traps in the Reedpath and Harrington fields (Table 4). This is in

Table 3. Effect of Pherocon AM trap orientation on the capture of R. mendax adults.

Field[a]	Ratio of trap captures (north-south:east-west)	Total captures	χ^2 value
Reedpath	1:0.97	6,535	1.32
Stonehouse	1:1.83	99	7.92[b]
Debert Airport	1:0.78	335	4.78[b]
Weatherhead	1:1.21	31	0.29
Burges	1:0.56	28	2.29
Dodsworth	1:0.73	251	5.75[b]
Harrington			
-burn	1:1.55	4,209	197.60[b]
-production	1:0.90	6,240	17.33[b]
Sargent			
-burn	1:1.17	913	5.37[b]
-production	1:1.05	555	0.30
Mildrum	1:0.85	2,316	16.08[b]
Beaumont	1:2.13	454	58.52[b]

[a]See Appendix I for field locations.

[b]Significant at the 5% level ($\chi^2_{[0.05,1]} = 3.84$).

general agreement with trapping results from highbush blueberry fields (Prokopy and Coli 1978). The range of these traps may also be extended by windy conditions, based on studies of the oriental fruit fly, Dacus dorsalis Hendel. In this case, males will fly against low to moderate wind velocities to locate methyl eugenol traps (Christenson and Foote 1960).

As with the yellow surface of the Pherocon AM traps, the ammonium acetate Hycase protein hydrolysate bait incorporated into the Tanglefoot also elicits a foraging response by Rhagoletis species. This bait represents the odor given off as a result of hydrolytic, oxidative, and microbial breakdown of adult food sources (Prokopy 1977). The use of baited Pherocon AM traps could result in the establishment of a more accurate economic threshold for R. mendax.

d) Sex ratios of trap captures

The sex ratios (♂ : ♀) of R. mendax flies captured on baited Pherocon AM traps varied approximately from 1:2 to 1:8 (Table 5), with an average ratio of ca. 1:4 and a standard deviation of 1.67. On a weekly basis, the average sex ratio was also ca. 1:4 but with a standard deviation of only 0.55. The sex ratio of all baited trap captures differed significantly from unity at the 1% level (Tables 5 and 6), while the sex ratio of flies captured on unbaited traps did not differ significantly from 1:1.

Table 4. Relative effectiveness of baited vs. unbaited Pherocon AM traps as indicated by the capture of R. mendax adults.

Field[a]	Ratio trap captures (baited:unbaited)	Total captures	χ^2 value[b]
Reedpath	1:0.28	533	46.84
Harrington	1:0.45	208	28.50

[a]See Appendix I for field locations.

[b]Significant at the 1% level ($\chi^2_{[0.01,1]} = 5.99$).

These sex ratio results are consistent with trapping results obtained from highbush blueberry fields. In these experiments, baited yellow traps captured more females than unbaited traps (Prokopy and Coli 1978). Studies on R. pomonella flies have shown that newly emerged females consume larger amounts of sucrose and protein than males. This intake is essential for the maturation of the female reproductive system (Webster and Stoffolano 1978; Webster et al. 1979). This could explain why newly emerged male blueberry maggot flies have been observed spending less time foraging than females (Smith and Prokopy 1979). Results from lowbush blueberry fields revealed that larger numbers of sexually immature females were captured on baited Pherocon AM traps (Neilson et al. 1984). It seems, therefore, that the attraction of female blueberry maggot flies to Pherocon AM traps is enhanced when the Tanglefoot contains a proteinaceous bait. The relative attractancy of these traps may, however, be determined by the availability of natural food sources. This might explain why the approximate sex ratio of trap capture data from the more weedy Beaumont field was 1:8 as opposed to 1:2 for the Dodsworth field and the average of 1:4 for all the fields (Table 5).

Only one R. pomonella female was recovered from the ca. 22,000 fly captures examined. This fly was captured on a baited trap in a field where no R. mendax flies had been detected. Seven specimens of black cherry fruit flies, R. fausta (Osten Sacken), were also recovered from baited traps, but no more than one fly was ever captured in a single field.

Table 5. Sex ratios of *R. mendax* adults captured on baited Pherocon AM traps.

Field[a]	Sex ratio (♂ : ♀)	Total captures	χ^2 value[b]
Reedpath	1:6.11	6,395	3300.00
Stonehouse	1:4.50	99	38.80
Debert Airport	1:2.56	335	62.65
Weatherhead	1:3.43	31	8.26
Burges	1:4.60	28	10.32
Dodsworth	1:2.18	251	33.72
Harrington			
-burn	1:4.51	4,209	1706.00
-production	1:4.11	6,244	2311.00
Sargent			
-burn	1:3.29	913	258.70
-production	1:3.83	555	189.10
Mildrum	1:5.13	2,316	1049.00
Beaumont	1:8.27	454	277.60

[a]See Appendix I for field locations.

[b]Significant at the 1% level ($\chi^2_{[0.01,1]} = 6.63$)

Table 6. Sex ratios of R. mendax adult captures on baited and unbaited Pherocon AM traps.

Trap type	Sex ratio (♂ : ♀)	Total captures	χ^2 value
Baited	1:2.18	143	18.91[a]
Unbaited	1:1.60	65	3.46

[a]Significant at the 1% level ($\chi^2_{[0.01,1]}$=6.63.

In addition, five Urophoria jaceana (Hering) flies were collected. There are no reports in the literature of R. pomonella, R. fausta or U. jaceana parasitizing Vaccinium spp. in the field.

Apple maggot flies have been induced to oviposit on blueberries in the laboratory, but because the larvae are larger than those of R. mendax, they often require more than one blueberry in which to complete their development (Lathrop and Nickels 1931, 1932; Pickett 1936, 1937). One possible explanation for these results may be that wild host trees were located in the vicinity of the fields where these captures occurred, and these females were lured by the attractant bait of the Pherocon AM traps. Although an entomologist familiar with Rhagoletis spp. should normally be able to differentiate in situ between R. mendax, R. fausta, and U. jaceana flies captured on these traps by comparing wing patterns, microscopic examination is usually required to distinguish between R. mendax and R. pomonella. The capture of large numbers of these tephritid flies could present a problem to blueberry growers using baited Pherocon AM traps because they may be more inclined to confuse the wing patterns with those of R. mendax.

IV. ENVIRONMENTAL FACTORS AFFECTING R. MENDAX FIELD POPULATIONS

A. Introduction

The distribution of *R. mendax* in eastern Canada is generally restricted within commercial blueberry growing regions (see section II-C). This may be a result of certain limiting environmental factors such as regional weather patterns, soils, and the occurrence of natural enemies.

There is evidence to suggest that soil pH may play a part in regulating the distribution of some tephritid fruit fly species. For example, Darby and Kapp (1934) proposed that the distribution of the Mexican fruit fly, *Anastrepha ludens* (Loew), was influenced by the sensitivity of larvae to acidic soil conditions, although Baker *et al.* (1944) cited evidence to counter this claim. Pryor (1940) and Wigglesworth (1972) noted that instead of normal sclerotization, tephritid puparia, *i.e.*, the European cherry fruit fly, *Rhagoletis cerasi* (L.), (Wiessman 1938, cited by Wigglesworth 1972), are impregnated with large amounts of calcium carbonate, which gives them a characteristic whitish color. The lime in these puparia was shown to be soluble in acid.

In eastern Canada, blueberries are generally found growing in soil with a pH of 4.0 to 5.5 (Hall and Aalders 1979). If *R. mendax* larvae and puparia are sensitive to pH values at the more acid end of this range, then this abiotic factor could influence local variations in the population density of R. mendax. Furthermore, the soil pH of blueberry fields could be managed by the grower in order to create less favorable conditions for R. mendax without interfering with the commercial production of the crop.

While collecting field data during 1982, I noticed that well managed blueberry fields (i.e., those with little weed growth) usually had lower populations of R. mendax. Although thorough weed control was probably largely responsible for this trend, the common cultural practice of burning may also be a contributing factor.

Burning is employed as a means of pruning blueberry plants, and is normally conducted on a two-year rotation. Although this practice results in larger crop yields, blueberry plants will produce only foliage during the first growing season following a burn; therefore, the fruit is actually harvested every second year (Mason 1950; Hawboldt 1954; Hall and Aalders 1979). Initially it was believed that burning actually killed R. mendax puparia within the soil (Woods 1915; Patch and Woods 1922). Additional studies revealed, however, that the soil temperature does not increase enough during the burn to kill the pupae (Lathrop and McAlister 1931; Lathrop and Nickels 1932; Lathrop 1952). This is because most growers burn their fields in the early spring while the soil is still frozen in order to protect the roots of blueberry plants as well as the organic matter content. It was later realized that burning actually deprives the females of oviposition sites. This results in a reduction in population levels, especially when the field is thoroughly burned and alternative host plants such as bunchberry are routinely removed (Lathrop and McAlister 1931; Pickett and Spicer 1931; Maxwell and Pickett 1949; Lathrop 1952; Black 1963; Miller 1979). It is recommended to divide larger fields into two sections and burn each area in alternate years (Hall and Aalders 1979). Although this technique permits growers to harvest blueberries every year, it has been suggested that the burn section would actually act as a reservoir for R. mendax infestations, as flies might migrate into the production section to mate and oviposit (Lathrop and Nickels 1931; Wood 1980).

The objective of these experiments was to identify some of the factors which affect R. mendax populations in lowbush blueberry fields. For this purpose, two investigations were carried out. The first was to determine if a relationship exists between soil pH and the incidence of R. mendax in eastern Canada. The second was to determine if there is a relationship between common cultural practices and blueberry maggot infestation levels. In the latter investigation, the effect of weed control and burning was considered.

B. Materials and Methods

a) Soil pH

In order to achieve the objective of this experiment, an attempt was made to select lowbush blueberry fields from several geographical regions (soil types) and with varying degrees of blueberry maggot infestation. In 1982, the following six fields were chosen: Reedpath, Portier, Slack, Sargent, MacDonald, and Dalrymple. In 1983, thirteen fields were selected: Reedpath, Dupris, Knockwood, Barnhill, Stonehouse, Debert Airport, Weatherhead, Burges, Dodsworth, Harrington, Sargent, Mildrum, and Beaumont. The locations of these fields in New Brunswick and Nova Scotia are listed in Appendix I.

A four hectare test plot was established within each field. Each plot was subdivided into blocks of equal size for the installation of Pherocon AM traps and for the collection of soil and blueberry samples. In 1982, each plot consisted of fourteen blocks, in 1983, there were sixteen blocks per plot.

Blueberry maggot population levels were measured within each plot by sampling both adult and larval stages. Adult numbers were determined by placing one baited Pherocon AM trap within each block of the test plots and recording the number of flies captured each week. In 1982, all traps were installed in a Λ position (see section III-C), and beginning with the week of July 20, trap captures were recorded for a three week period. As a result of the findings reported in section III-C, however, all traps were installed in a V position during the 1983 field work to ensure more efficient fly captures. These traps were set out during the week of July 4, and fly captures were recorded once a week for six weeks. All traps were renewed during the week of July 25.

Larval counts were made using the standard boiling technique (see Section II-E). In 1982 and 1983, during the week of August 10, one litre samples of blueberries were randomly collected within each block of each test plot, then each sample was placed in boiling water for ten minutes in the laboratory. The boiled fruit and sauce was then poured over a wire grid (four mesh per cm). The sauce was collected in a black pan and the number of larvae found was recorded. The pulp left on the grid was pressed and rinsed three times and carefully checked to ensure that all larvae had dropped into the pan.

An estimate of the soil pH of each field was made by collecting soil samples from the test plots so that each sample was a composite of twelve cores measuring five centimeters in length and two centimeters in diameter. These were collected randomly within each block using a soil auger. All samples were placed in plastic bags and stored at 5° ± 1°C until laboratory analysis. In 1982, all samples were collected during the week of July 20. In 1983, however, three series of soil samples were collected to determine if the soil pH varied during the growing season. The first series was collected during the week of July 4, the second during the week of July 25, and the third during the week of August 8. Only results from the third sample series, as well as the 1982 samples, were used in the correlation analysis of this experiment because they were collected when the post-feeding larvae were entering the soil to pupate.

The pH measurements were made with a research grade digital pH meter using a two-point electrode standardization that provided an accuracy of ± 0.003 pH units. To compensate for the effect of soluble soil salts, all samples were measured in a 0.01M solution of calcium chloride at a ratio of one part soil to two parts $CaCl_2$ (Peech 1965). All final measurements were rounded off to the nearest 0.01 pH value.

All data collected during 1982 and 1983 were analysed using the Spearman rank correlation coefficient (Daniel 1978) to determine the following: 1- relationship between soil pH and the number of *R. mendax* flies detected, 2- relationship between soil pH and *R. mendax* larval counts, and 3- relationship between *R. mendax* larval counts and the number of flies detected. In addition, the results from the three series of soil samples collected in 1983 were submitted to a Kruskal-Wallis one-way analysis of variance (Sokal and Rohlf 1981).

b) Weed control and burning

The investigation to determine if a relationship exists between the control of weeds in lowbush blueberry fields and R. mendax population levels was conducted in the thirteen fields selected in 1983 for the soil pH investigation. The adult trap captures and larval count data from these fields was retained. Then, an assessment of the weed and blueberry growth within each block of the test plots was achieved using the following rating system. Blocks with sparse or no growth (0-35%) received a score of one, blocks with moderate growth (36-70%) a score of two, and blocks with dense growth (71-100%) a score of three. The average score of each test plot was then calculated and all scores were ranked along with the adult trap capture and larval count data.

All data was analysed using a Spearman rank correlation and the calculated values were adjusted for ties (Daniel 1978). The process was carried out for the following five sets of variables: 1- adult trap captures and blueberry growth, 2- adult trap captures and weed growth, 3- larval counts and blueberry growth, 4- larval counts and weed growth, and 5- blueberry growth and weed growth.

A second investigation to determine if R. mendax flies migrate from the burn sections of lowbush blueberry fields into the crop sections was carried out during 1983 in the Harrington and Sargent fields. Test plots were established and baited Pherocon AM traps installed in the burn and production sections of these fields using the techniques described in sections III-B(b). The traps were arranged in four rows (4 traps per row) perpendicular to the direction the flies would migrate from the burn section to the production section.

The number of flies captured on each trap were recorded weekly during a six week period, beginning with the week of July 4.

The numbers of adults captured in each field were submitted to a nested analysis of variance (Sokal and Rohlf 1981). This procedure allows one to determine if the number of flies captured differed amongst: 1- the traps within each row, 2- the rows within each section, and, 3- the burn and production sections.

C. Results and Discussion

a) Relationship between soil pH and the incidence of *R. mendax*

The value of the rank correlation coefficients for soil pH and the number of *R. mendax* larvae or adults recorded during the 1982 and 1983 field work was not significant (Table 7). The value of this coefficient for numbers of flies trapped and larval counts was, however, significant at the 1% level. The pH values of the three series of soil samples collected in 1983 did not differ significantly. Although this indicates that the soil pH was relatively stable in the fields tested, it should be pointed out that these measurements only represent the potential pH of the soil. Such values may vary during any one growing season, depending on the amount of precipitation received (Brady 1974). The

Table 7. Spearman rank correlation coefficient values for soil pH and R. mendax adult trap captures or larval counts.

Variables	Year 1982	Year 1983
Soil pH - number of adults	-0.49	-0.32
Soil pH - larval counts	-0.36	-0.19
Number of adults - larval counts	0.99[a]	0.84[b]

[a]Significant at the 1% level ($r_{s\,[0.01,6]}=0.89$)

[b]Significant at the 1% level ($r_{s[0.01,13]}=0.64$)

pH values of the soil samples collected ranged from 3.68 to 4.24 in 1982 and 3.38 to 4.54 in 1983.

A study of the chemical and physical properties of blueberry fruit (Ismail and Kender 1974) revealed that the pH of ripe blueberries generally averages about 3.67, although the pH increases at an accelerated rate as ripening proceeds.

This value is below the soil pH range of 4.5 to 5.0 that is recommended for optimal commercial blueberry production (Trevett *et al.* 1972); it is, however, within the pH range of the soil samples collected in 1982 and 1983. This would seem to indicate that *R. mendax* larvae are able to tolerate the acidic conditions of most blueberry fields.

Despite the fact that there is no correlation between soil pH and the incidence of *R. mendax*, soil acidity may still be a mortality factor. In studies of *R. pomonella*, for example, it was shown that there was no significant correlation between fruit pH and the time required for larval development (Dean and Chapman 1973). Prokopy (1967), however, found that optimal larval development was obtained on artificial diet media with a pH of 4.05. It seems likely, therefore, within the soil pH range that is tolerable for blueberry plant growth, that other mortality factors may play a larger role in affecting the distribution of this insect.

b) Relationship between cultural practices and the incidence of R. mendax.

An analysis of the data from the weed control investigation revealed a significant correlation (1% level) between all pairs of variables, except trap captures and weed growth which were significant at the 5% level (Table 8). The negative correlation between blueberry growth and weed growth indicated that blueberry yield increases as density of weed growth decreases. This is expected because the weeds are competing against the blueberry plant for space, light, moisture, and soil nutrients (Jackson and Hall 1979). The positive correlations between weed growth and numbers of adults and maggots, and the negative correlations between blueberry growth and the numbers of adults and maggots, suggest that controlling weed growth reduces the level of blueberry maggot populations as well as improving the yield.

These results agree with the observations of other investigators (Patch and Woods 1922; Lathrop and McAlister 1931; Lathrop and Nickels 1932; Brittain and Pickett 1933; Maxwell and Pickett 1949; Wood 1962, 1979b). None of these results, however, were quantitative. Based on the results of this investigation together with those for the experiment reported in section III-C(b) and the observations reported above, it seems likely that weed growth within a blueberry field enhances R. mendax populations by providing flies with shelter against adverse weather conditions.

The number of R. mendax adults captured on baited Pherocon AM traps in the Harrington and Sargent fields are

Table 8. Spearman rank correlation coefficient values for the number of *R. mendax* adults and larvae and the extent of blueberry and weed growth.

Variables	r_s
Adults captured and blueberry growth	-0.792[a]
Adults captured and weed growth	0.536[b]
Larval counts and blueberry growth	-0.951[a]
Larval counts and weed growth	0.731[a]
Blueberry growth and weed growth	-0.906[a]

[a]Significant at the 1% level ($r_s\,[0.01, 13] = 0.643$)

[b]Significant at the 5% level ($r_s\,[0.05, 13] = 0.478$)

shown in Tables 9 and 10 respectively. The trap captures in the burned and cropped sections differed significantly (5% level) for both fields (Table 11). Although the number of flies captured also differed significantly (1% level) between the traps within each row as well as between the rows within each section in the Harrington field, these variables did not differ significantly in the Sargent field. This was probably because the production section of the Sargent field had been treated with carbaryl 25% **wp** (4.5 kg per ha) during the week of July 15. This action coincided with a dramatic drop in the number of R. mendax flies captured at a time when adult emergence should have been reaching its peak. The effectiveness of this insecticide application was demonstrated when larval extraction produced only one maggot from the 16 L of blueberries that were sampled. Apparently the field owner had realized the value of the Pherocon AM trap for detecting the presence of blueberry maggots and for timing control measures, at the cost of the non completion of this experiment.

The difference in trap captures between rows in the Harrington field and between the burn and production sections of both the Harrington and Sargent fields would seem to indicate that flies were moving from the burn sections to the production sections. The difference in captures for traps within each row of the Harrington field, however, shows that flies were moving in all directions. This discrepancy may have been due to the baited Pherocon AM traps

Table 9. Total numbers of R. mendax flies per baited Pherocon AM traps, Harrington field, 1983.

Field section	Row series	Trap	Captures per trap	Captures per row	
		a	204		
	I	b	92	510	
		c	191		
		d	23		
		a	65		
		b	186		
Burn	II	c	64	1,193	
		d	358		
		e	225		
		f	295		
		a	346		
		b	44		
	III	c	49	2,506	
		d	655		
		e	932		
		f	480		Total: 4,209
		a	176		
		b	375		
		c	502		
	IV	d	223	2,820	
		e	55		
		f	307		
		g	503		
		h	679		
Production					
		a	804		
		b	1009		
		c	651		
	V	d	78	3,424	
		e	333		
		f	66		
		g	263		
		h	220		Total: 6,244
					TOTAL:10,453

Table 10. Total numbers of R. mendax flies per baited Pherocon AM traps, Sargent field, 1983.

Field section	Row series	Trap	Captures per trap	Captures per row	
		a	74		
	I	b	41	183	
		c	29		
		d	39		
		a	38		
	II	b	63	252	
		c	60		
		d	91		
Burn		a	68		
	III	b	70	274	
		c	21		
		d	115		
		a	70		
	IV	b	34	204	
		c	59		
		d	41		Total: 913
		a	59		
	V	b	39	199	
		c	44		
		d	57		
		a	41		
	VI	b	69	133	
		c	16		
		d	17		
Production		a	6		
	VII	b	35	89	
		c	41		
		d	7		
		a	27		
	VIII	b	25	134	
		c	49		
		d	33		Total: 555
					TOTAL: 1,468

Table 11. Calculated F values for total R. mendax adults captured during 1983 on baited Pherocon AM traps in the burn and production sections of the Harrington and Sargent fields.

Source of Variation	Field	
	Harrington	Sargent
Among sections	6.125[a]	6.243[a]
Among rows within sections	4.172[b]	0.744
Among traps within rows	3.245[c]	0.765

[a]Significant at the 5% level ($F_{0.05[1,160]}=3.92$)

[b]Significant at the 1% level ($F_{0.01[3,160]}=3.95$)

[c]Significant at the 1% level ($F_{0.01[27,160]}=1.91$)

being highly attractive to immature female R. mendax flies foraging for food (Prokopy and Coli 1978; Neilson et al. 1984). It is also likely that newly emerged flies would normally move out in several directions in a burn section because the vegetative blueberry plants would provide foraging sites. If blueberry maggot flies follow visual and olfactory cues similar to R. pomonella (Boller and Prokopy 1976; Prokopy 1977, 1982; Prokopy and Owens 1978, 1983), they would then be directed to ripe blueberry fruit within the production section for oviposition. Lathrop (1952) has suggested that flies would not be likely to reach a production section that was more than 30.5 m away from the margin of a burn section. In the case of this experiment, however, the burn and production sections of the Harrington field were separated by an access road 2.5 m wide, while the sections of the Sargent field were continuous so that the production sections were not beyond the range of the flies.

V. CONCLUSIONS

During 1982 and 1983, an attempt was made to identify some environmental factors that are responsible for the regulation of R. mendax populations in Atlantic Canada. Based on a rank correlation analysis of data collected from seventeen commercial lowbush blueberry fields in Nova Scotia and New Brusnwick, it was determined that there is no relationship between soil pH and the incidence of R. mendax (larvae and adults). Within thirteen fields sampled during 1983, however, there was a positive correlation between weed growth and the number of blueberry maggot flies and larvae detected. There was also a negative correlation between blueberry growth and R. mendax population levels. This evidence suggests that the weedy areas within lowbush blueberry fields provide R. mendax flies with protection against adverse weather conditions (Wood 1962, 1979b). By practicing thorough weed control, therefore, blueberry producers should be able to reduce the level of R. mendax infestations by removing these shelter sites, as well as to improve their crop yields.

In blueberry fields that were divided into burn and production sections (each section being burned in alternate years), R. mendax flies were detected moving from the burn sections into the production sections. Although this problem could be eliminated if the fields were entirely burned over every other year, such a practice would not likely be economically feasible in most of the larger production sites of eastern Canada because of the revenue loss incurred during burn years. One ecologically sound alternative, however, may be to develop some sort of physical barrier (*e.g.*, a screen) that could be placed on a border separating burn and production sections, thereby blocking the migration of flies within isolated fields.

The Pherocon AM trap was evaluated to determine how efficiently and accurately it can measure *R. mendax* adult populations. Traps baited with a proteinaceous attractant captured more flies than unbaited traps, and more female than male flies. This was attributed to a foraging response of sexually immature flies, particularly females, to the odor of the attractant bait. These baited traps also captured a small number of *R. pomonella*, *R. fausta* and *U. jaceana* flies. If the action threshold for *R. mendax* were set at one fly per trap (Wood *et al*. 1983), the similarity of wing patterns among these species could result in the misidentification and misinterpretation of trap captures by growers.

Traps installed in a **V** position - folded to form a 90° angle with the apex and sticky yellow surface facing downward - captured more blueberry maggot flies than traps placed in a **Λ** position (apex up, yellow surface down). This could have been a result of the **V** position traps being more visible to the flies. There was no significant difference in fly captures when, in either position, the traps were located above or between blueberry plants. This result may be due to the flies being equally capable of flying over or between plants. Trap orientation (north-south or east-west) also had an effect on trap captures, although it also was a variable among the fields selected. This variation was considered to be caused by changeable wind conditions.

As a result of this investigation, it was determined that R. mendax populations are influenced to some extent by the cultural practices employed in lowbush blueberry fields. An improved method of installing Pherocon AM traps was also demonstrated. I feel, however, that additional research is required to identify other regulatory factors that affect blueberry maggot populations, e.g., predators, parasites, and pathogens.

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Appendix I. Location of commercial lowbush blueberry fields selected for research

Field No.	Field Owner	Location		
		Town or Community	County	Province
1	Reedpath	Richibucto	Kent	New Brunswick
2	Portier	Shediac	Westmorland	New Brunswick
3	Dupris	West Memramcook	Westmorland	New Brunswick
4	Knockwood	Dorchester	Westmorland	New Brunswick
5	Barnhill	Dorchester	Westmorland	New Brunswick
6	Beaumont	Oxford	Cumberland	Nova Scotia
7	Mildrum	New Canaan Mountain	Cumberland	Nova Scotia
8	Sargent[a]	Parrsboro	Cumberland	Nova Scotia
9	Harrington	Glenholme	Colchester	Nova Scotia
10	Slack	Folly Lake	Colchester	Nova Scotia
11	Debert Airport	Debert	Colchester	Nova Scotia
12	Stonehouse	Central North River	Colchester	Nova Scotia
13	MacDonald	Glencoe	Pictou	Nova Scotia
14	Burges	Middle Musquodoboit	Halifax	Nova Scotia
15	Dodsworth	Wittenberg	Colchester	Nova Scotia
16	Dalrymple	East Gore	Hants	Nova Scotia
17	Weatherhead	Rawdon	Hants	Nova Scotia

[a]Sprayed with insecticide during the 1982 and 1983 growing seasons.

N.B.: A map of these locations appears as Figure 6, page 72.

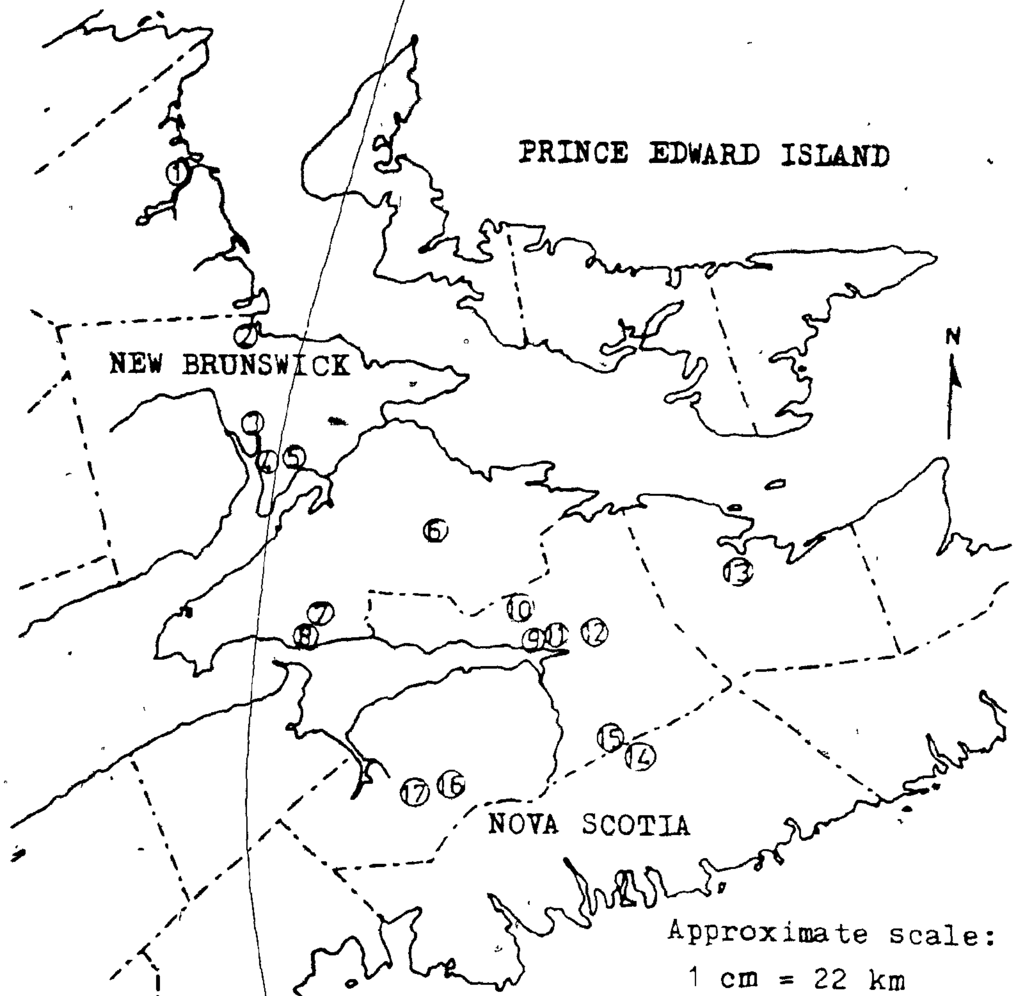

Figure 6. Location of commercial lowbush blueberry fields selected for this research.