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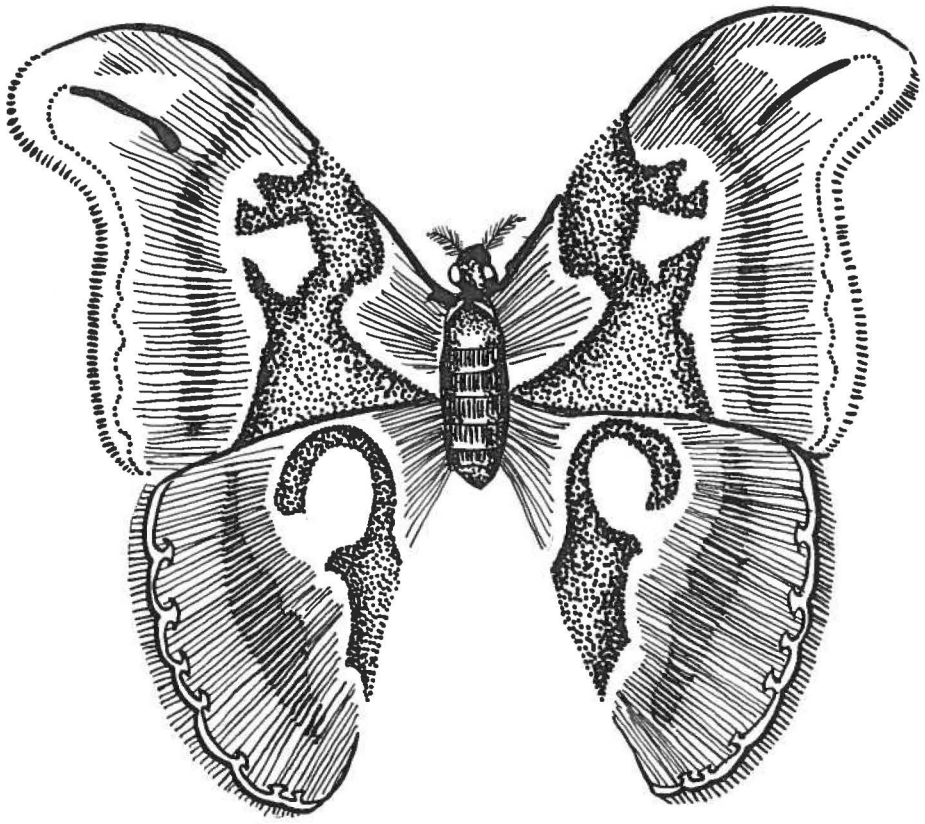

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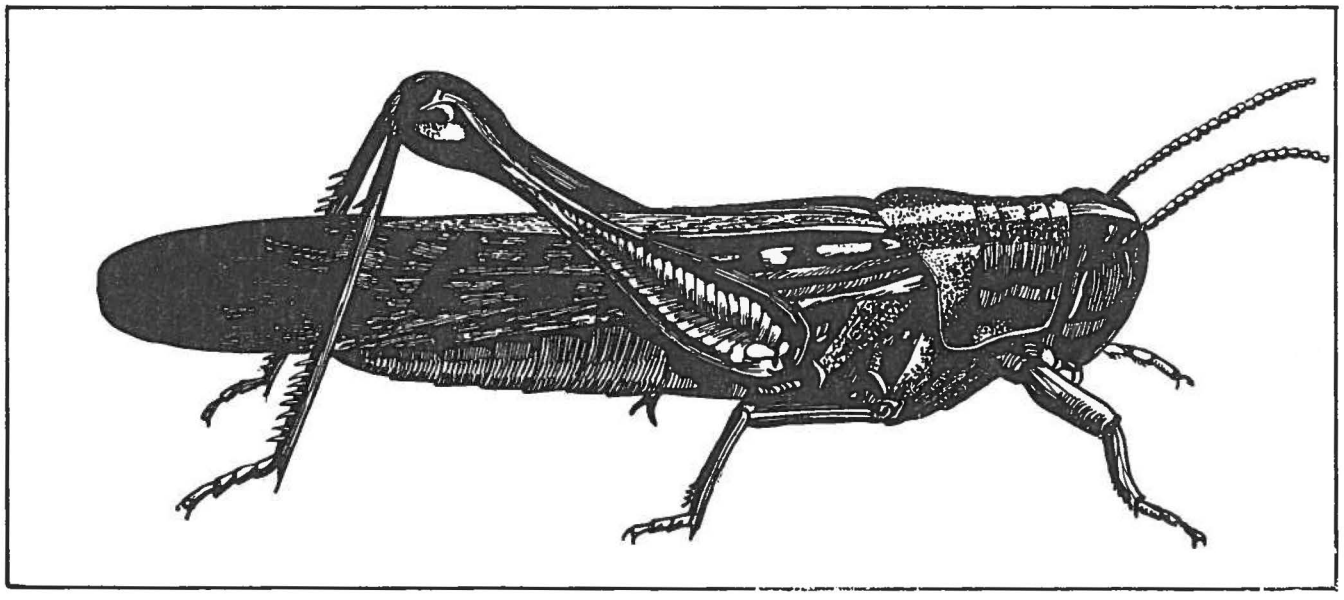

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THE MANITOBA ENTOMOLOGIST

Official publication of the Entomological Society of Manitoba, an organization to foster the advancement, exchange and dissemination of entomological knowledge

CONTENTS

LARCH SAWFLY POPULATION DYNAMICS: TECHNIQUES

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ABSTRACT

Techniques developed and currently in use for studying the population dynamics of the larch sawfly, *Pristiphora erichsonii* (Hartig), are reviewed. Methods are described for sampling or obtaining indices of abundance for each of the life stages of this forest pest and its insect parasites, invertebrate and vertebrate predators, associated fauna and host foliage production. Descriptions are given of the procedures used for evaluating and determining the causes of mortality of the sawfly throughout its life cycle and for measuring and monitoring the physical environmental factors that may have significant effects on sawfly abundance. The techniques used for measuring the impact of the insect on its host are also described.

Problems encountered in the development of these techniques are discussed together with a qualitative evaluation and critique.

INTRODUCTION

The "team" approach to the study of the population dynamics of the larch sawfly, *Pristiphora erichsonii* (Hartig), began in 1955 when four research scientists, each previously concerned with particular aspects of the larch sawfly problem, combined their resources and talents. The objectives of this group were to explain larch sawfly population fluctuations by a systematic study of the factors affecting these populations. Through this study they hoped to suggest methods of control of the larch sawfly through environmental manipulation as well as contribute to the knowledge of population dynamics and the ecology of forest communities. Although the study was "problem oriented" the approach was essentially "holistic". While the "life table" approach was selected for the organization of the larch sawfly data, it was recognized that measurements of a large number of other facets of the environment would be necessary to expose the network of relationships in the ecosystem. Major emphasis has been placed on those facets of the ecosystem affecting the larch sawfly, but we have also attempted, within our limited resources, to include other facets of the ecosystem.

Few of the necessary sampling techniques were available in 1955. Since then, new techniques have been developed and published, but are scattered throughout the literature, often incorporated into papers dealing primarily with topics other than sampling. In addition, some techniques have been further refined since publication to improve accuracy or efficiency. It is therefore difficult for anyone not familiar with the larch sawfly population dynamics study to obtain a clear and complete picture of the sampling procedures.

We decided at the outset of this study that our population estimates could be expressed more easily on an areal rather than a tree basis, because the larch sawfly inhabits two sampling universes, the tree and the forest floor, at different stages in its life cycle. For various reasons we have found it necessary to limit our areal estimates of larch sawfly populations to three stages: adults, eggs and newly formed cocoons. It has been impractical to obtain estimates of the numbers of larvae in the different stadia on an areal basis because the prolonged emergence period of the adults results in marked overlapping of stages. Larvae developing from eggs laid by the early-emerging adults have usually dropped to spin cocoons before the last of the adults have emerged. Sampling methods have therefore been developed to provide indices of the numbers of insects present at intervals throughout the season, without attempting to relate these to any unit of surface area. Similarly we have developed techniques for estimating the proportion of deaths occurring during the various stages in the life cycle of the insect.

Quantitative estimates on an areal basis are obtained for the following factors affecting larch sawfly populations: populations of small mammals, birds and insect parasites, and the amount of foliage produced by the host trees. Indices to the abundance of invertebrates associated with the larch sawfly, including predaceous species, are also prepared.

Assessments of the growth and mortality of the host tree, together with estimates of defoliation by the larch sawfly, are also made. The microtopography of each plot is measured periodically and fluctuations in the water table in relation to the microtopography recorded. Finally, since critical facets of the weather may vary locally, meteorological instruments are placed near each plot.

This paper describes the various techniques now in use but is not concerned with a statistical evaluation of their efficiency. The paper is intended to serve a dual purpose: to clarify our sampling procedures, and to aid others faced with similar sampling problems. The technical details on any of the techniques are not described. Additional information may be obtained by reading the original papers or by contacting any of the authors of this paper.

ESTIMATES PER UNIT AREA

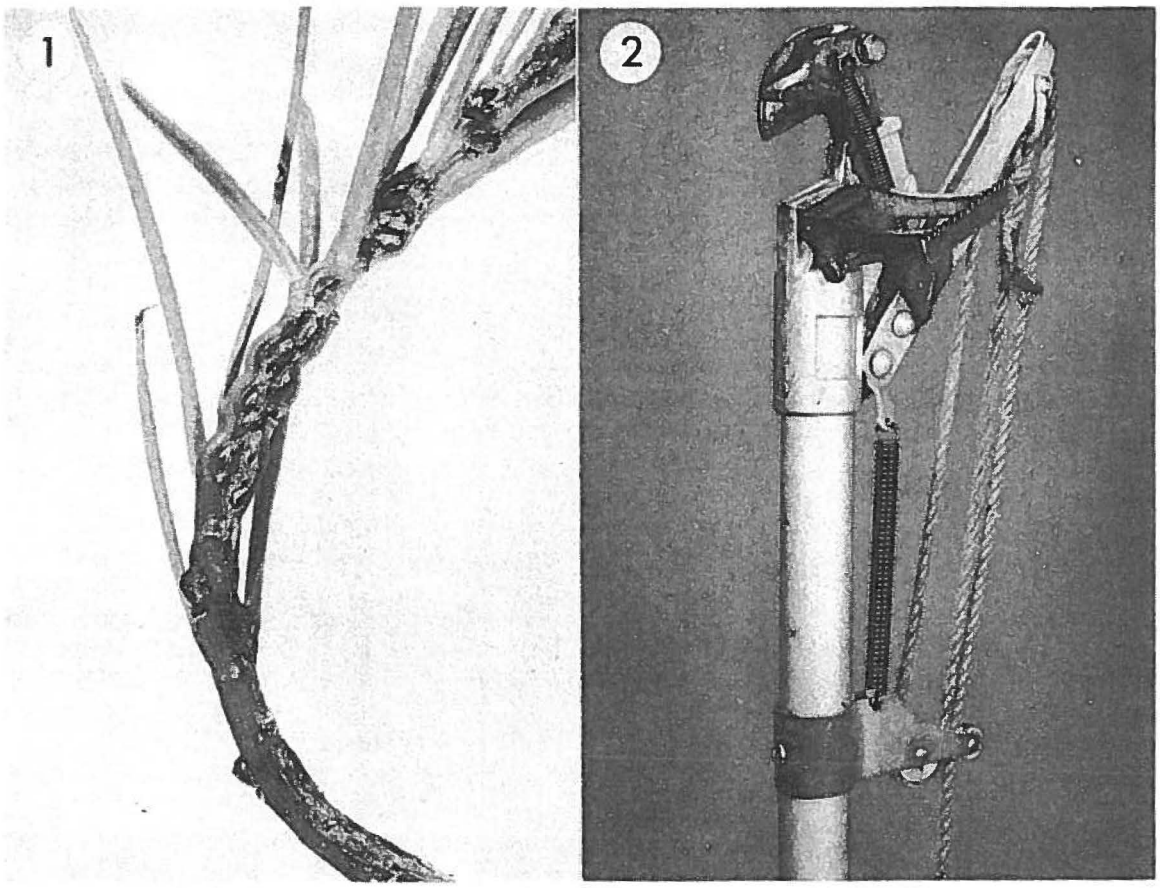
Tamarack stands in Manitoba, where this study has been undertaken, are typically small and heterogeneous. It is difficult to find stands of any size that are relatively uniform throughout. To reduce within-plot variability we have therefore made our larch sawfly plots quite small, typically 0.4 acres. This is much too small for small mammal and bird plots, so these have been extended beyond the boundaries of the larch sawfly plots. For uniformity, all areal estimates have been expressed as the numbers or amounts per acre.

The sampling units used for estimating larch sawfly cocoon and adult populations cover an area of 2 sq ft. A hexagonally shaped sampling unit was adopted because it combined the advantages in construction accruing from a circular cone with a geometric pattern which left no gaps. If circles had been used it would have been impossible to cover all of the area with a discrete number of possible locations.

Larch Sawfly Eggs

The adult female deposits her eggs lineally in slits cut into current year's shoots which causes damage and desiccation on the injured side of the shoots. If the shoots are succulent at the time of oviposition, as most are, continued growth causes a typical curling of the shoot, and the expansion of the tissues due to the swelling of the eggs causes a typical scarring of the shoot. It is therefore relatively easy to determine the numbers of eggs laid long after hatching (Fig. 1). Consequently, it is possible to estimate the amount of oviposition each year by sampling late in the summer, when oviposition is nearly complete. Occasionally, a few eggs will be laid as late as early September, but sampling can usually be done any time after mid-August.

The sampling procedure basically follows that described by Ives (1955) except that the number of eggs per branch are counted rather than the number of scarred shoots. A number of tamarack trees (usually 40) are selected at random from each plot, with the stipulation that each tree can be sampled a maximum of once in every three years. The height and crown depth of each selected tree are measured with a graduated aluminum pole. Each crown is divided into upper, middle and lower thirds; random selections are then made for the locations (height and cardinal direction) of two sample branches to be removed from each crown level. Extension pole pruners, fitted with a clamping device (Fig. 2), are used to remove the selected branches. In the lower parts of the crown, and in trees under 40 feet high, one man can usually do this sampling without assistance, but in the upper crowns of taller trees it is often necessary for an assistant with binoculars to give direction. The branches are dropped or lowered to the ground and examined. All shoots are counted. The scarred ones are placed in paper bags, one for each branch, and labelled. In the laboratory, the numbers of egg slits in each scarred shoot are counted under low magnification provided by a stereoscopic microscope. The mean number of eggs per branch in each crown level for each sample tree is then calculated.



Figs. 1-2. 1. Typical larch sawfly oviposition damage to a tamarack shoot.
2. Pole pruner head with clamp for holding branches.

To estimate the numbers of eggs per tree it is necessary to know the numbers of branches. This varies so much from tree to tree and from stand to stand that an average figure is inadequate. An estimate of the number of branches on each sample tree is obtained by counting from the ground, using binoculars. Two men count the number of branches in each crown level, working independently from opposite sides of the tree. The two counts are usually very similar, but if they differ markedly, the two men change places and count again. Branch counting on tamarack is best done just as the foliage is flushing: living branches are easily identified and the branches are easier to count because there is no dense foliage to obstruct the view.

The estimated number of eggs per tree is simply the sum, for the three crown levels, of the products of the mean number of eggs per branch and the number of branches in each crown level. Multiplication of the mean number of eggs per tree by the number of trees in the plot gives an estimate of the number of eggs per plot, which is then converted to the number per acre.

Larch Sawfly Cocoons

The larch sawfly larvae, after completing their feeding, drop to the ground and burrow into the moss to spin cocoons. These cocoons are very durable and usually persist in the soil for several years, but if the larvae die soon after cocoon formation the cocoons undergo a rapid, although partial, decomposition. Consequently, we have found it to be impossible to separate new cocoons from those formed in previous years with any degree of certainty. Estimation of current cocoon populations by direct sampling of the moss or duff on the forest floor is therefore impossible, and special traps to catch the falling larvae had to be devised so that only the current cocoon population was sampled (Ives and Turnock 1959).

Fresh sphagnum moss has proven to be the most satisfactory cocooning medium but is time consuming to examine. The variability in the number of cocoons per unit area of forest floor necessitated large samples to obtain reasonable accuracy. The problem was resolved by placing 6-inch-square traps containing moss under funnels with 2-sq-ft collecting areas. This concentration of the larvae enabled us to obtain an adequate sample size with a minimum effort and still provided a suitable cocooning medium.

The traps (Fig. 3) have a copper screen bottom (ordinary window screening) and are fitted with 4 x 4 wire mesh covers, to prevent small mammals from entering. Larvae are prevented from escaping by the incurved lips on the side of the traps. Each trap is filled about two-thirds with clean sphagnum moss. Less than this dries out during prolonged periods of drought: more prevents the larvae from entering the traps, especially if populations are high and heavy frass-production fills the trap.

The funnels that are placed over the traps to concentrate the falling larvae (Fig. 4) are made of fiberglass window screen heat-fused into cones and attached in the same manner to hexagonal metal frames constructed from 1/8 x 1/2 inch mild steel. Each funnel is supported by three aluminum stakes fitted with peg-board hooks. Installation or removal of the funnels for winter storage is therefore very simple.

Location of the randomly selected, permanent funnel positions in each plot is a relatively simple matter. Special graph paper was prepared on which all possible locations are identifiable. Tables of random numbers are used to select 100 of these locations in each plot. After marking each of the selected locations on a map their position in relation to a series of base lines is determined. The center of any funnel location is specified by forming an isosceles triangle from these base lines (Fig. 5). This information is then used to locate the positions in the field.

When the plots are first established, stakes are driven at the spacing shown in Fig. 5. Poles fitted with pins are placed on these stakes, and a hinged device fitted over the appropriate pins forms the specified isosceles triangle for each funnel position (Fig. 6). A stake is driven to temporarily mark each location. A hexagonal jig, consisting of a plywood

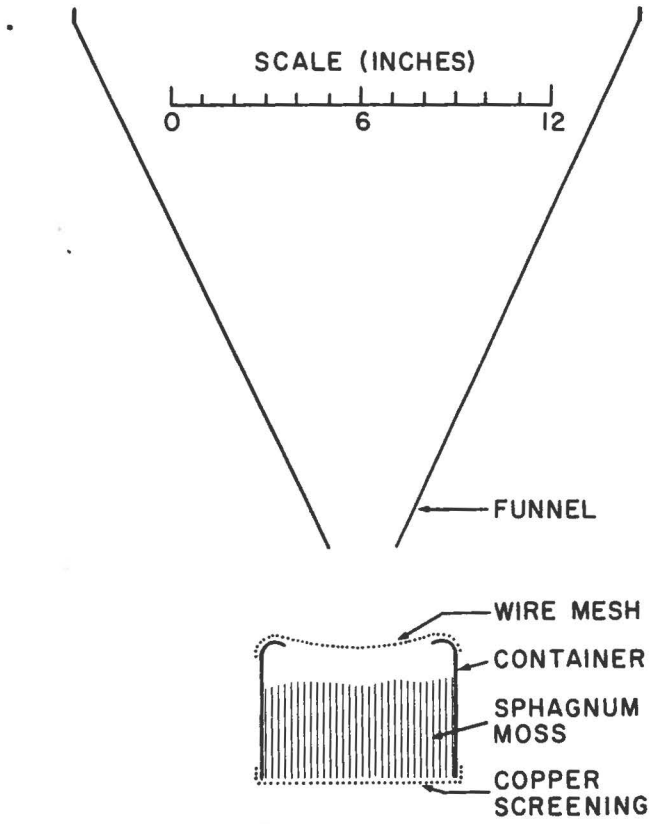


Fig. 3 Cross-sectional view of larval trap and funnel.

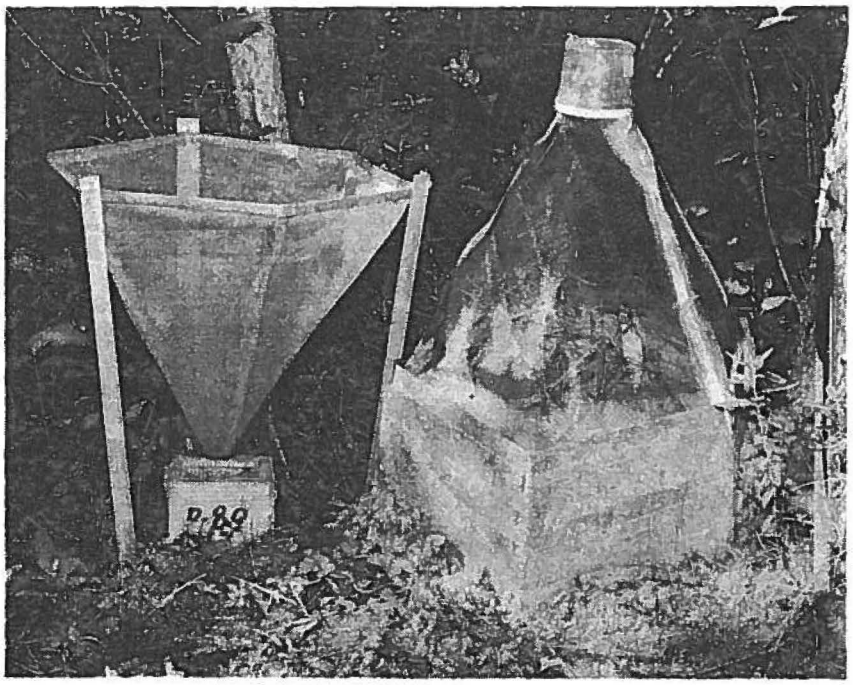


Fig. 4 Moss-filled larval trap and funnel, and adult emergence trap showing use of legs and plates used for levelling. This is an extreme situation, normally this much levelling is not required.

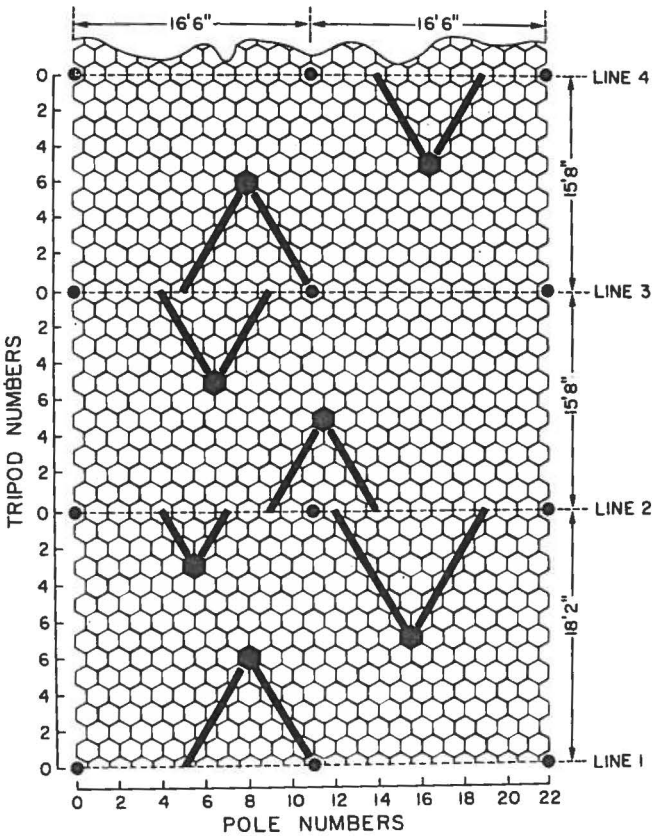


Fig. 5

Hexagonal graph paper used for locating the random positions for the moss-filled traps and adult emergence traps. The dots represent stakes driven at the indicated spacings; the black hexagons represent a possible selection of positions. The dotted and heavy lines show the pole and tripod settings for locating these positions in the field: the numbers on the X-Y-axes correspond to the pole and tripod numbers.

Fig. 6 Jig used for locating positions of moss-filled traps in the field.

hexagon, with a square hole in the center, is slipped over these temporary stakes when driving the supporting stakes at alternate points of the hexagon. The stakes are driven until the tip of the funnel is about three inches above the top of the trap. Usually, the trap is set into the moss so that the moss inside is even with that outside, but if the location is in a hollow, the trap position is built up to avoid complete flooding during wet seasons.

In early September, the moss is removed from the traps and sorted carefully to obtain counts of the numbers of larch sawfly cocoons per trap. After counting, the cocoons are used as a source of material for estimates of mortality and reproductive capacity, as described in later sections. Since the number of possible sampling positions is known, it is a simple matter to obtain estimates of the number of cocoons per plot or per acre, as desired. These estimates are considered to be of the potential rather than the actual number of cocoons, because the larvae have been protected against predation and some of the traps have been elevated. In dry years there should be close agreement between potential and actual numbers of cocoons, but in wet years the traps will over-estimate the actual cocoon populations because most of the effects of flooding have been removed by elevating the traps.

Larch Sawfly Adults

Larch sawfly adults emerge over a prolonged period. Estimating their numbers therefore requires the use of traps that can be left in place and examined periodically. The traps originally used were described by Turnock (1957). Those currently in use incorporate certain improvements in design. They consist of a screen cone attached to a hexagonal metal base which is pressed into the soil (Fig. 4). Each emergence trap is paired with a funnel and trap used for estimating cocoon populations. Two of the six possible locations around each funnel are selected at random, with the restriction that two adjacent positions cannot be used, because larvae falling onto the adult emergence traps roll down the sides and concentrate cocoons around the traps. Once the two positions have been selected they are marked with color coded stakes and the adult emergence traps are alternated between them in successive years.

Two small holes are drilled in each corner of the metal base of the cages. These are tapped for No. 4 self-threading metal screws, to provide a means for attaching levelling legs to the traps, if the ground is uneven. The legs are made of 3 x 9-inch pieces of 16-gauge metal, bent lengthwise to fit the corners of the hexagonal base, with four holes drilled at spacings to coincide with those in the base. By using different holes and orientation of the legs it is possible to vary the length that projects below the base of the cage. Before the screws holding the legs are tightened, light-gauge sheet metal plates, with a strip of heavier metal spot welded along their center line, are slipped over the edges of the legs to seal off gaps. The plates can also be placed at an angle, and no additional sealing is required to obtain a snug fit. However, the traps are usually banked with sphagnum moss from a black spruce bog to prevent accidental shifting of the plates.

The upper part of the screen cone terminates in a pencil-sized opening. The raw edges of the screen are covered with solder, to prevent impalement of the insects as they crawl through the opening. Interchangeable plastic traps are fitted over the tops of the cones to catch the insects as they emerge (Fig. 7). Spring clips hold them in place. To ensure a snug fit between screen cone and trap, a "doughnut" of 1/4 inch thick plastic foam is placed over the cone before the plastic trap is put in place.

The plastic traps are constructed from clear plastic 1-pint covered containers and 1/2-pint tinned funnels. All but the outer 1/4-inch of the lids are removed, and the tips of the funnel are cut off, to leave a hole about 1 1/4 inches in diameter. The rolled funnel edges are flattened, and the funnels placed inside the pint containers. The outer rims of the lids form locking rings to hold the funnels in place. A small piece (about 3/4 inches square)

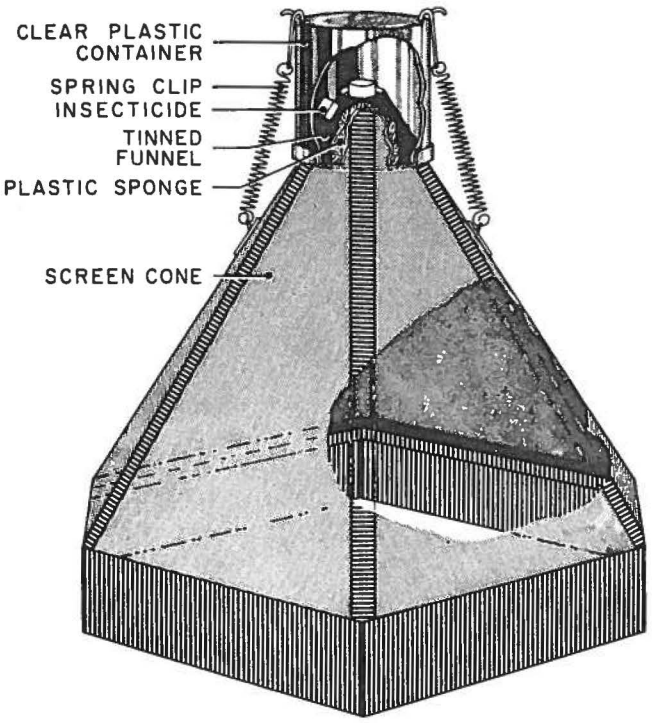


Fig. 7 Cut-away view of adult emergence trap.

Fig. 8 Adult emergence traps in wire screen carrying case.

of an insecticide impregnated plastic[1] is stapled to the outside of each funnel to provide more rapid kill of the trapped insects.

Duplicate sets of color-coded numbered plastic traps are used in each plot. Wire screen (fur fabric) carrying cases (Fig. 8) greatly facilitate the changing of the traps, and minimize the chance of placing the traps on the wrong cones. Every two weeks the traps are changed and replaced with the alternate set. The cut-out portions of the lids are snapped in place as the traps are removed from the screen cones to prevent any insects being lost during transportation to the laboratory. In the laboratory, the contents of each trap are examined and any larch sawfly adults are removed, sexed and counted. All other insects are retained for subsequent identification.

At the end of the season, the total numbers of sawfly adults for each trap are used to calculate the numbers of adults per plot or per acre, as desired.

Other Adult Insects

A large variety of insects, other than larch sawfly, are caught in the emergence traps. Many of these are of no particular interest to us, but some are sufficiently important to warrant the extra work involved in their identification. The insects of most interest are the three main parasites of the larch sawfly in this area, *Bessa harveyi* (Townsend), *Mesoleius tenthredinis* Morley and the recently introduced *Olesicampe benefactor* Hinz. We also obtained estimates of two other sawflies, *Anoplonyx canadensis* Harrington and *A. luteipes* (Cresson) and a number of species of elaterids. Various species of carabids and ants are caught in the traps, but the catches probably cannot be interpreted as population estimates.

The dried insects are stored in pill boxes. They are later relaxed and prepared for identification.

Population estimates per plot or per acre are obtained in the same manner as are those for larch sawfly adults.

Small Mammals

The populations of small mammals per acre are estimated from catches made in 64 traps placed at 1-chain intervals in an 8 x 8 grid. Plots measuring 7 x 7 chains (4.9 acres) were established, encompassing the larch sawfly plots, usually along one edge. Lines were brushed at the one chain intervals because heavy undergrowth interfered with trapping, particularly at night. These lines have to be cleared every few years, as regrowth is rapid. Two different types of traps are used, one for mice and voles, and the other for shrews.

Mice and Voles. – Mice and voles are trapped with Sherman live traps[2], modified by drilling a number of 1/2 inch holes in one end to allow the small species of shrews to escape and baited with a mixture of oatmeal and peanut butter (Buckner 1957). The traps are normally examined in the morning and again in the evening, but in cold, wet weather it is necessary to check them as many as three times during the night. Headlamps powered by a battery pack have been found to provide the most suitable illumination for nightwork, as they leave both hands free. When a catch is made, it is dumped into a plastic bag for ease in handling. The species is recorded and notes are made on its age, sex, breeding condition and external parasites. Before release, the animal is identified by numbering it serially, in order of catch, using a toe clipping code.

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[1] Vapona Insecticide Strip, Shell Canada Limited.

[2] Made by H. B. Sherman, P. O. Box 683, De Land, Florida.

Trapping is continued until all of the animals have been caught, or for 10 days, whichever comes first. Usually, in light to moderate populations, all individuals will be caught before the 10 day period has expired, but not in high populations.

The estimation of population numbers is not as straightforward for mammals as for insects. The population usually consists of a mixture of two types of individuals: residents and vagrants. If an animal is not recaptured it is assumed to be a vagrant, although at high population densities this assumption may be invalid.

Those animals that are resident in the area have well defined home ranges, with a cruising radius that is typical for each species. Animals residing outside the plot will also be caught, so a strip equal to the cruising radius for each species must be added to the plot to obtain the effective area trapped. These areas are then divided into the numbers of each species as determined by the total count, or Lincoln Index[3] if all animals were not captured. Populations of vagrants are estimated by dividing their mean daily catch by the area encompassed by the traps (4.9 acres). The total population for each species of mice and voles is simply the sum of residents and vagrants.

Shrews. – Shrews are characteristically active, high-strung animals, and some are very small. Methods suitable for catching mice or voles are unsuitable for the smaller species of shrews. Due to their small size, they do not trigger a Sherman trap too easily, and trap mortality is high because the "cage effect" of the Sherman trap causes the shrews to expend all of their energy in attempting to escape. Tumble-in traps made from clean 1-quart cans with one end removed, sunken into the ground with the top flush with the surface, have proven to be much more effective (Buckner 1966). The animals cannot escape, and trap mortality is reduced because they do not "panic" to the same extent, as the upper end of the cans are open. Also about 40 live mealworms are placed in the traps when they are set, to provide a bait and a source of food for any animals that are caught. This food helps to reduce mortality, but when shrews are being caught it is still necessary to check the traps at least twice during the night, in addition to the morning and evening visits. Trapping is continued until all animals are marked, or for 10 days, whichever comes first.

The shrews are removed from the trap by hand (the smaller species cannot bite one's finger, as their mouths are too small), identified and where possible the age, sex, breeding condition and external parasites are recorded. The toes of living specimens are clipped in a serial code and released for attempted recapture. Because of their nervous nature, the mortality rate in shrews is higher during trapping than it is for mice and voles, and consequently the recapture rate is lower. Thus the error in separating the population into residents and vagrants is somewhat higher. However, no satisfactory alternative is available, and the total population for each species of shrews is calculated as the sum of resident and vagrant populations.

Birds

The estimation of bird populations is even more difficult than for small mammals, as the populations are so highly mobile. As a consequence, the plots used must be larger, at least 10 x 10 chains, preferably 20 x 20 chains. Observation posts are established at 2-chain intervals and the lines are cleared for ease in walking. As in small mammals, there are resident and transient bird populations.

Resident male birds have strong territorial instincts, which they manifest by singing as they move about in their territories. This characteristic is used to map and measure their territories (Kendeigh 1944). With training, an experienced observer can identify all of the species without necessarily seeing the birds. As with small mammal estimates, the radius of

[3] $\text{Population} = \frac{\text{Number Caught in Last Sample} \times \text{Total Number Marked}}{\text{Number of Marked Individuals in Last Sample}}$

the territory is added as a boundary strip to give the effective area censused for each species of bird. Because only male birds are censused, it is necessary to assume that each territory represents a pair of birds with two offspring in order to estimate the total number of resident birds. This number is then divided by the effective area censused to give an estimate of the number of birds per acre for each species (Buckner and Turnock 1965).

The numbers of transients or vagrants (those without territories) are counted or estimated and the mean daily number for each species determined. These numbers are divided by the area enclosed by the lines to give the numbers of vagrants per acre.

The total bird population per acre is simply the sum of the resident and vagrant populations.

Foliage and Shoot Production

Tamarack trees are deciduous conifers and consequently there is a fresh supply of foliage each year. The trees are very responsive to adverse conditions, especially larch sawfly defoliation, so that the amount of foliage produced varies considerably from year to year during the course of a larch sawfly outbreak. In order to assess the effect of the larch sawfly on its host it is necessary to know how foliage and shoot production are affected. It is also desirable to have an estimate of the amount of foliage, so that the relative intensities of the infestations in different stands can be compared because the study plots have marked differences in tree density and size. We have found it to be impractical to estimate foliage production annually: sampling every 2 to 5 years, depending on infestation levels, provides us with the essential information. Shoot production can be estimated from the egg sampling as well; this provides quantitative information on the condition of the trees in the intervening years. Annual observations of needle and shoot growth on selected trees are also available (next section).

The technique used for estimating foliage production (Ives 1959) is very similar to the one described for estimating the numbers of eggs. Careful timing in sampling is required, however, because of the relatively brief period between the completion of foliage growth and the onset of defoliation during periods of severe larch sawfly infestations. Timing is not as critical when populations are low, although the gradual increase in foliage weight throughout the season dictates that sampling be done at approximately the same phenological time if results between plots and years are to be comparable.

The randomization, sampling and branch counting procedures are identical to those used for egg sampling. The sample branches are examined and the numbers of shoots recorded. They are then cut into pieces and placed in labelled cotton bags, which are hung in a warm place until dry.

During the winter the branches and all loose needles are removed from the bags. The larger branches and twigs are discarded, taking care that no needles are left on them. The remainder is then placed in a special separator (Kemp, Ives and Hergert 1965) (Fig. 9) to remove the smaller twigs and debris. The cleaned foliage is then placed in metal cans and oven dried at 105°C for 48 hours before weighing.

The weight of foliage and number of shoots per plot or acre is then calculated in the same manner as are the numbers of eggs.

Tree Mortality and Growth

The preceding estimates of shoot and foliage production are supplemented by making annual observations on the condition of 20 to 30% of the trees in the stand. The trees are selected at random, and the same trees are examined each year. Trees that die are replaced by selecting additional trees at random.

In June, ratings of shoot production, shoot length and needle length are made: these are classed as light (short), medium, or heavy (long) as indicated in Table I. The numbers of

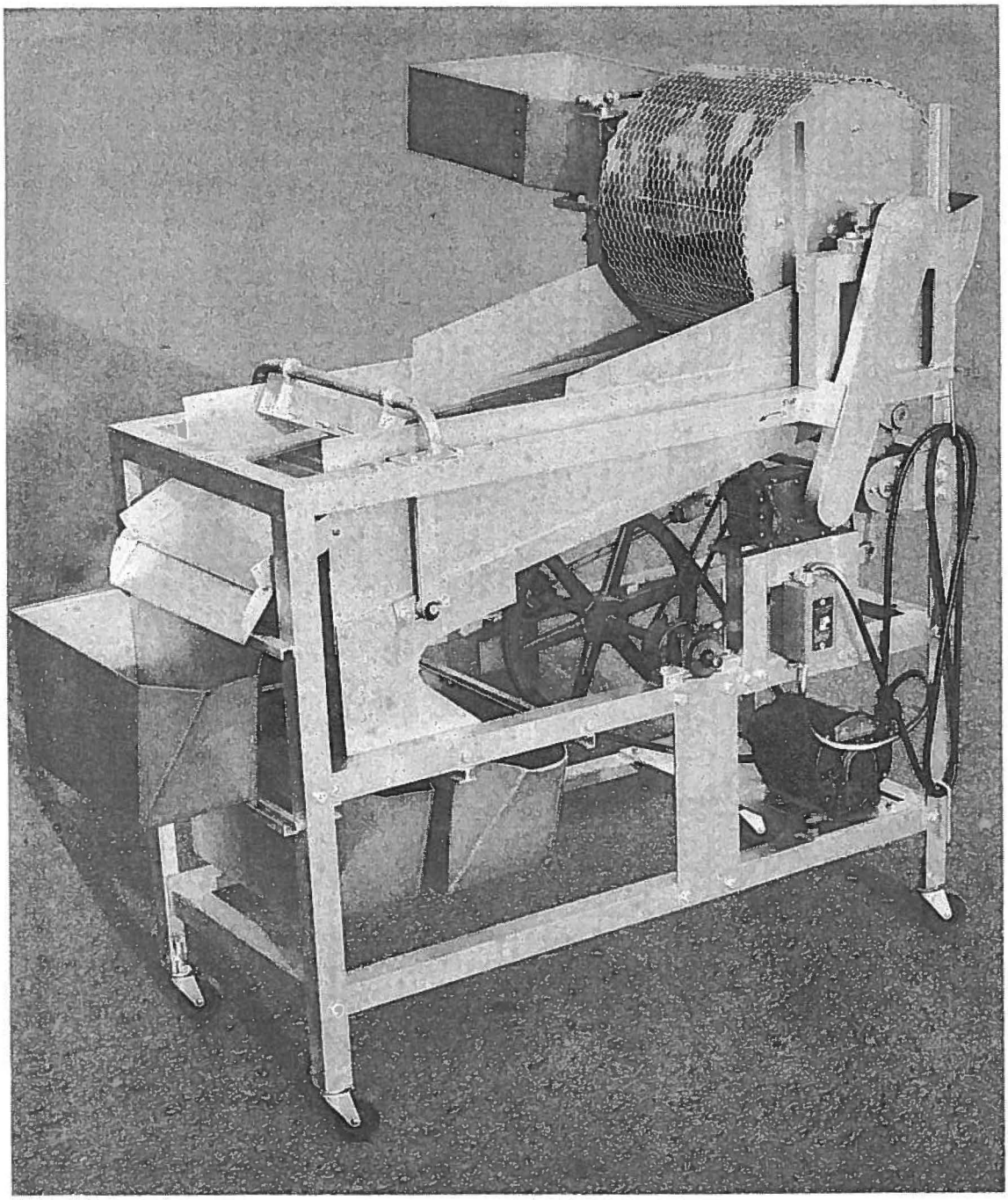

Fig. 9 Separator used for removing debris from foliage samples.

adventitious shoots (nil, few, many) in and below the crown are also noted. In the fall, cone production is rated as light, medium or heavy (Table I). Defoliation estimates (in per cent) and dead branch ratings are recorded for each crown level of the sample trees. The average defoliation for each tree is obtained by summing the products of crown level defoliation estimates and weighting ratios, in an attempt to allow for the different amounts of foliage in each crown level. These ratios are 0.17, 0.47, 0.36 for the upper, middle and lower crown levels. Dead branches in each crown level are rated into five categories: 1 - branch tips dead; 2 - 25% of the branches dead; 3 - 50% of the branches dead; 4 - 75% of the branches dead; and 5 - the whole portion of the crown dead.

Dead trees are recorded annually in each plot. The cambium is checked before these trees are classified as dead.

Table I. Class limits for rating shoot and needle length (mm) and shoot and cone production (numbers per branch)

	Rating		
	Light (Short)	Medium	Heavy (Long)
Shoot production	0-5	6-25	> 25
Cone production	0-4	5-15	> 15
Shoot length	≤ 35	36-50	> 50
Needle length	≤ 10	11-20	> 20

INDICES

For various reasons, some of our quantitative estimates cannot, by themselves, be placed on a plot or acre basis. These estimates are referred to in this paper as indices, but they are just as quantitative as our area estimates. They include: adult reproductive capacity; seasonal abundance in larval drop; and seasonal abundance of branch-inhabiting fauna.

Adult Reproductive Capacity

The reproductive capacity of larch sawfly females is quite variable. Annual assessment in each plot is therefore desirable, whenever the sawfly population is high enough to provide a source of material. The adult traps do not provide a satisfactory source of females, as they are only visited once every two weeks, and the material must be fresh and of known age when preserved. As an alternative, we have used the adults emerging from the cocoons collected in the moss-filled traps already described. These cocoons are overwintered and incubated under near-natural conditions (as described in a later section). Adult emergence is checked daily, once emergence starts, and adults to be used for reproductive capacity estimates are kept alive at 10 - 15°C for an additional 24 hours before being preserved in 10% formalin. This procedure has been adopted because there is some post-emergence maturation of eggs in larch sawfly, and estimates of reproductive capacity based on newly-emerged females tend to underestimate the true value. The preserved specimens are kept under refrigeration to prevent excessive hardening of the tissues. The numbers of adults used vary with availability: if possible we try to obtain about 75 (Heron 1966).

The reproductive capacity of each selected female is determined by dissecting and staining the ovaries and counting the oocytes. Specimens are pinned in dissecting trays, dorsal side up, and flooded with water. An incision is made along the center line of the

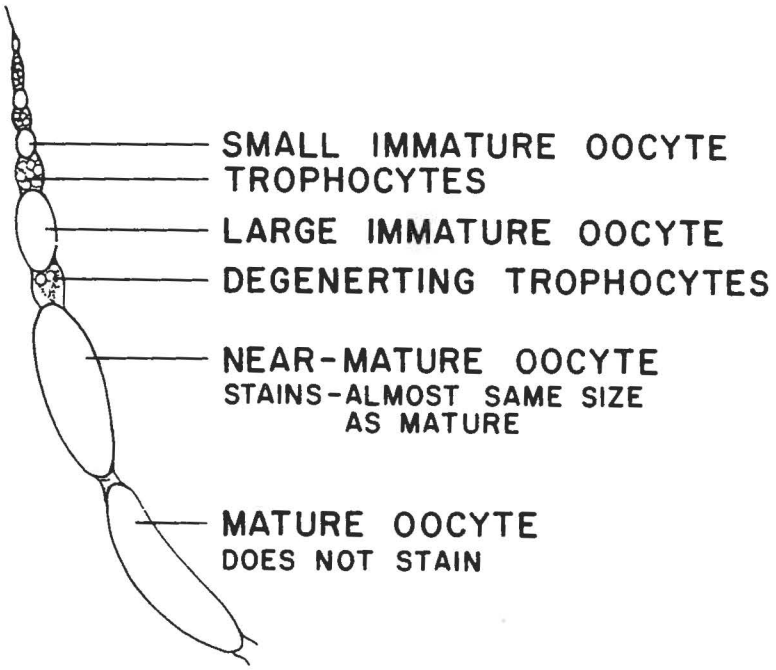

Fig. 10 Hypothetical larch sawfly ovariole.

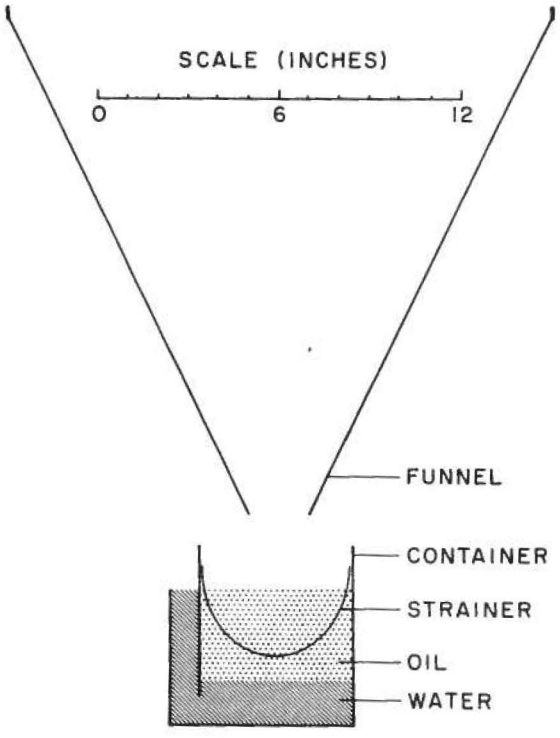

Fig. 11 Cross-sectional view of funnel and oil trap.

dorsal abdominal segments and the body wall is pinned back to expose the ovaries. The water is drained off and is replaced with a concentrated alcoholic solution of Sudan III[4] for a period of about 5 minutes.

Each ovary (and any loose mature oocytes) is removed from the specimen and placed in a drop of water on a microscope slide. The individual ovarioles (there are typically 20 per ovary) are teased out to make the counts.

The ovarioles are of the polytrophic type, with an alternating succession of oocytes and groups of nurse cells or trophocytes. As the oocytes develop they become larger and change in shape and dye-absorbing characteristics (Fig. 10). Mature oocytes have a well developed chorion and do not absorb dye, unless the chorion is broken. Near-mature oocytes are nearly as large as the mature ones, but are more elliptical in shape and take up the stain. The accompanying nurse cells have atrophied. Large-immature oocytes are also stained, and are defined as being those that are at least twice as large as their associated groups of nurse cells. These three categories are included in the counts. Experimental studies (Heron 1966) have shown that they provide reliable estimates of the reproductive capacity of the larch sawfly and take into account the post-emergence ovarian maturation that normally occurs.

Seasonal Abundance in Larval Drop

Larch sawfly larvae drop to the ground to spin cocoons upon completion of feeding. The moss-filled traps provide estimates of the numbers that successfully form cocoons, but do not give any information on the seasonal distribution of larval drop. Special traps (Fig. 11) were therefore designed to catch and preserve the larvae as they drop from the trees (Ives 1967).

The traps, 5 inches square at the top and 6 inches deep, are made of galvanized mild steel, soldered together. About 2 inches of water is poured into the traps, then a layer of light oil[5] containing a fungicide[6] which helps to prevent deterioration of the larvae. A medium-mesh kitchen strainer, about 5 inches in diameter, is suspended in the oil in each trap by wire hooks. A duplicate set of strainers is interchanged at weekly intervals. The used strainers are transported to the laboratory in 5-lb. honey pails (Fig. 12).

A considerable amount of work is required in examining the material collected from the traps, especially when larch sawfly populations are high. The number of traps has therefore been limited to 30 per plot. Polyethylene funnels, of the same design as the fiberglass ones used over the moss traps, are used to concentrate the larvae. The plastic prevents small larvae from crawling through the mesh and decreases the chance of dead larvae lodging on the funnel. The funnels are placed under the crowns of trees, rather than at random, in order to obtain as many larvae as possible, especially at low population levels.

In the laboratory, the strainers are rinsed in alcohol, examined and the numbers of fully-fed, healthy larvae are recorded. An experienced worker can recognize these fully-fed larvae by their size and coloration. Alternatively, the mature larvae can be identified by drying and weighing the larvae (Ives 1967a) but this procedure is very time consuming. Several other categories and stages can be recognized by their appearance. The total number of healthy larch sawfly larvae per trap provides an index of the larch sawfly population dropping to spin cocoons each year in each plot.

Similarly, we obtain indices of the abundance of *Anoplonyx luteipes*, *A. canadensis* and *Semiothisa sexmaculata* Packard. The first index is probably fairly accurate, as the

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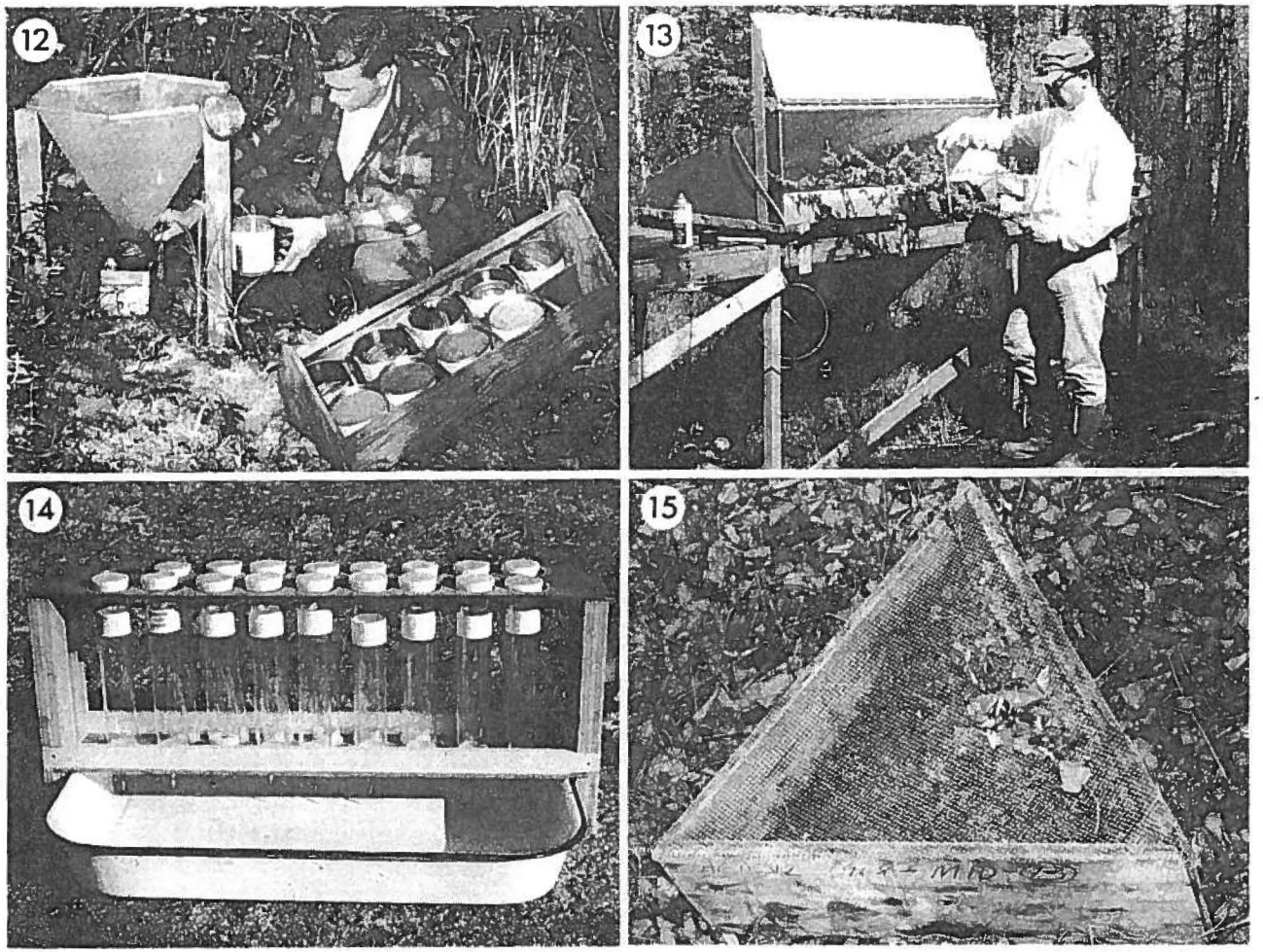
[4] 200 mg per 100 ml of 95% ethyl alcohol.

[5] Carnea pale oil 21, Shell Canada Limited.

[6] Dyrene, Chemagro Corporation.



Figs. 12-15 12. Strainers from oil trap in covered pails for transportation to the laboratory. 13. Funnel and hood used in sampling branch-inhabiting invertebrate fauna. 14. Egg incubation tubes and rack. 15. Triangular cages used during periods of severe larch sawfly infestation to collect cocoons for mortality estimates.

larval-drop period of *A. luteipes* coincides reasonably well with that of the larch sawfly. The indices for the other two species are indicative only, as some of the larvae drop after the traps have been removed from the plots.

Seasonal Abundance of Branch-Inhabiting Fauna

The larch sawfly shares its environment with a number of other invertebrate species. In order to determine the possible effects of these other organisms on the survival of larch sawfly eggs and feeding larvae, it was necessary to devise a technique for sampling the tamarack trees at frequent intervals to obtain estimates of the numbers of each organism present. The technique finally adopted (Ives 1967b) was basically simple but relatively satisfactory. In each plot, twenty branches, seven from the upper and middle crowns, six from the lower, are sampled at weekly intervals. The branches are not selected at random, as they are collected from untagged trees, but we try to obtain a representative sample. The branches are removed from tamarack trees with clamp-equipped pole pruners and taken to a centrally located table in each plot for examination. All larch sawfly eggs and larvae are removed. The eggs are placed in special cages for incubation (described in a later section) and each colony of larvae is placed in alcohol in a labelled vial. The branches are then placed on racks over large metal funnels enclosed by hoods (Fig. 13) and fitted with alcohol-filled collecting vials. An aerosol containing pyrethrins and piperonyl butoxide [7] is sprayed over the foliage, the hood door closed, and carbon dioxide, at 10 lbs. per square inch pressure, is directed into the enclosure through 1/4-inch tubing for 2 minutes. After an additional 3 minutes, the branches are shaken gently to dislodge any invertebrates still clinging to them, and the sides of the funnels are brushed down to direct any material into the collecting vial. Two hoods and funnels are used in each plot, to avoid delays.

In the laboratory the larch sawfly eggs are incubated until hatching is complete. The egg scars and numbers of larvae are then counted and recorded. The colonies of larvae are classified by instar and similar counts of the numbers of egg scars and larvae are made.

The material removed from the branches by this treatment contains a considerable amount of debris which is removed in the laboratory. Later, the fauna are identified by experienced workers. Because most of the specimens are immature, we usually classify to orders and families only, although we are able to identify some of the more important groups to the generic and in some cases specific level.

The mean numbers per branch of sawfly eggs and larvae, and other invertebrates, provides us with an estimate of the numbers of prey, predator species, and associated fauna present on the trees in each plot throughout the season.

MORTALITY ESTIMATES

The differences between the numbers of larch sawfly eggs, cocoons and adults in each of the plots provide estimates of the mortality during the intervening periods. They do not provide much information on when the mortality occurred, or give any indication of the factors responsible for it. We have therefore found it necessary to develop methods for defining, more precisely, the stage at which the mortality occurred or for ascertaining how much mortality is attributable to a specific factor during a given interval in the life cycle of the larch sawfly.

Eggs and Feeding Larvae

Egg clusters and colonies of larvae with associated scarred shoots, in addition to those obtained from the 20-branch samples, are collected at weekly intervals in each plot. The numbers of egg clusters or colonies collected in each plot each week varies with availability: we try to obtain at least 20 of the most prevalent stage of development.

[7] Fly-bane, West Chemical Products Ltd., Montreal.

The eggs are placed in glass incubating tubes (Fig. 14), transported to the laboratory in insulated containers cooled by artificial ice packs, and incubated in an insectary until hatching is complete (Ives 1962). Larval colonies are placed in labelled vials containing alcohol.

The percentage hatch or survival of larval colonies is determined by counting the number of egg scars and the number of larvae. The larval instars can be identified easily, so survival to each instar can be determined. The estimation of percentage hatch under field conditions is not so easily determined. Direct counting of hatched eggs is not practical, because the chorions of larch sawfly eggs are very fragile and often missing, once the larvae have hatched. On the other hand, survival of field-collected eggs generally increases with the length of incubation period, despite the fact that the eggs are incubated under artificial conditions. This apparent anomaly is presumably due to the removal of the eggs from the adverse effects of factors in the natural environment. However, we have found that we can obtain reasonably satisfactory estimates of the percentage hatch by combining incubation results and field estimates of first-instar survival. The resulting estimate is somewhat less than incubation estimates and more than first-instar larval survival.

At high population levels we usually are able to obtain enough samples to obtain reasonably accurate weekly estimates of the survival, by larval instars, for most of the season. However, at low population levels we have to group the weekly data to obtain an average estimate for the season for each larval instar.

Initial Parasitism by *Olesicampe benefactor*

The recently-introduced parasite of the larch sawfly, *Olesicampe benefactor,* attacks the sawfly during the first larval stadium. Usually, most of the parasite larvae have hatched by the time the host larvae enter the second instar. Theoretically, then, any larval instar after the first can be dissected to determine the percentage parasitism at that particular stage of development. Practically, however, we have found this to be too time-consuming. The parasite larvae are very small, even in late-instar host larvae, and consequently dissection is extremely slow and demanding work if accurate results are to be obtained. We have found that the only practical way to estimate the percentage of attack by this parasite is to clear and stain the host larvae. Late-instar larvae cannot be cleared satisfactorily, but if second-instar larvae are used the parasites are readily visible. Experience has shown that very little host mortality occurs between the first and second instars and thus we obtain a fairly reliable estimate of initial parasitism by *O. benefactor.*

To handle the relatively large numbers of larvae involved, a suitable "mass production" technique (Fig. 16) was developed for clearing and staining the larvae (Hinks & Muldrew 1969). It is important that the procedure be followed closely as the integuments of the parasite larvae are quite fragile and easily destroyed. With care, however, satisfactory results can be obtained. Examination of the cleared and stained material requires a little practice, as the larvae have to be "rolled" slightly to find all the parasites, but this technique can soon be mastered.

Premature Larval Drop and Other Mortality

Larch sawfly larvae dropping during or before the early fifth larval stadium are unable to complete their development without additional food. As most of these larvae are unable to reach tamarack foliage to resume feeding, any such premature drop of otherwise healthy larvae represents a source of larval mortality. The larvae caught in the oil traps (Fig. 11) retain their original size and coloration, so that we can determine their stage and condition at the time they dropped. The different larval instars can be determined by head capsule size, while body size and coloration separates healthy early and late fifth-instar larvae. It is therefore easy to determine the percentage of healthy larvae that have dropped prematurely,

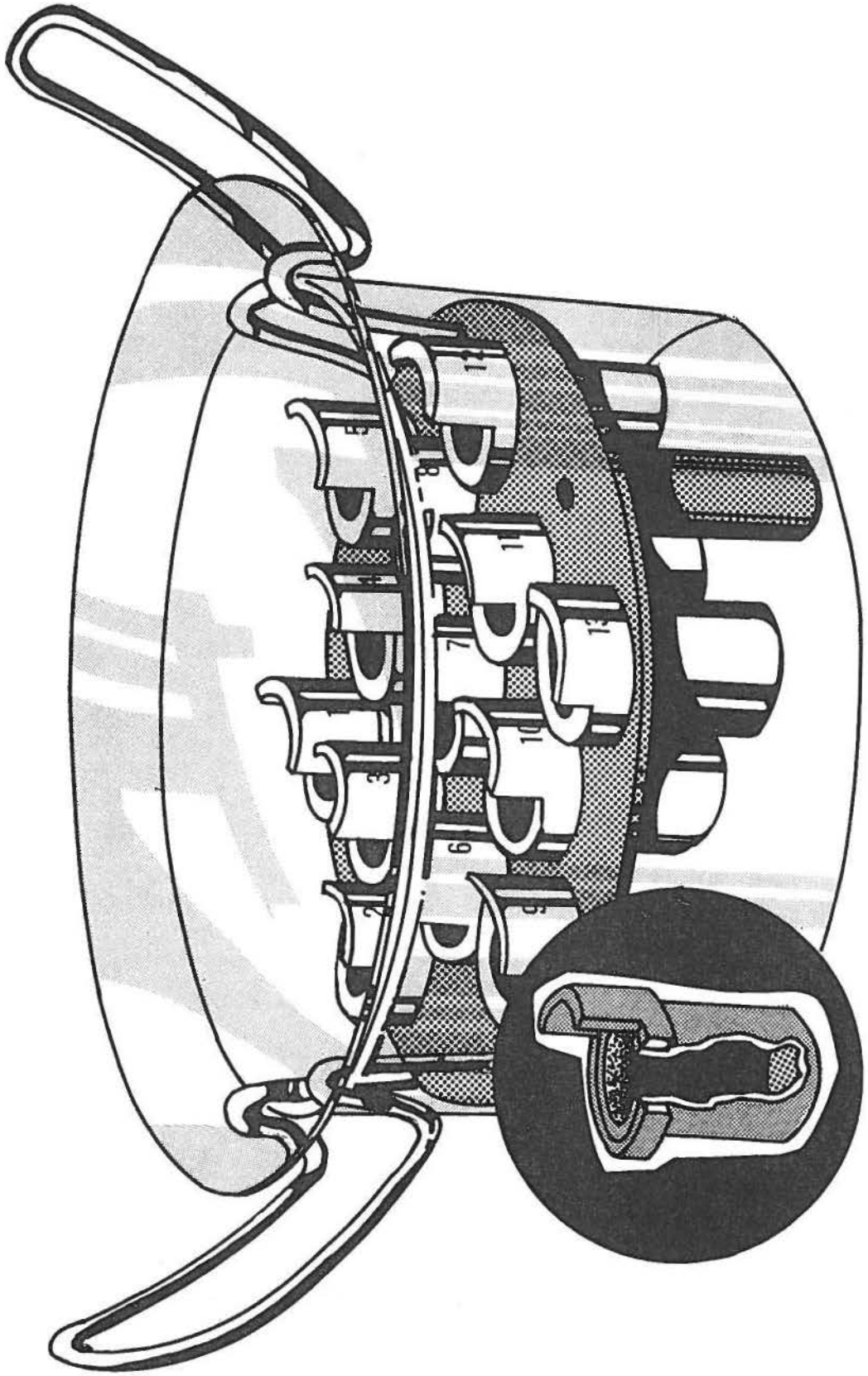


Fig. 16 Containers and rack used for clearing and staining second instar larch sawfly larvae.

providing *O. benefactor* is not present. The dwarfing caused by this parasite makes separation of instars and the determination of premature fifth-instar larval drop much more difficult.

In addition to premature larval drop we can also obtain an index of the relative abundance of mortality due to other factors: diseased larvae become discolored; larvae attacked by spiders or pentatomids are flaccid or shrivelled; and larvae attacked by birds or wasps are mutilated. We do not feel that any of these estimates are reliable, as only a portion of the affected individuals are caught.

Initial Parasitism by *Bessa harveyi* (Townsend)

The healthy late fifth-instar larvae caught in the oil traps provide material for estimating the initial parasitism by *Bessa harveyi* (Townsend), a tachinid that lays conspicuous white eggs on the integument of larch sawfly larvae. Most, but not all, oviposition by *B. harveyi* is on fifth-instar larvae, and continues until the larvae drop from the trees. Consequently, not all of the parasite eggs have hatched when the larvae burrow into the moss to spin cocoons. There is a considerable amount of egg loss during this interval and allowance must be made for this when calculating initial parasitism.

The healthy late fifth-instar larvae are examined carefully after having been preserved in 70% ethyl alcohol for at least a month. The integument is then moderately transparent and the respiratory funnels and maggots of the parasite can be detected without dissecting the larvae. Unhatched eggs are also readily detectable. The proportion of newly formed cocoons containing established *B. harveyi* is estimated by summation of the proportion of larvae containing maggots and the estimated proportion of successful establishment of maggots from unhatched eggs. The latter is obtained as the product of the proportion of larvae bearing unhatched eggs and a constant derived from laboratory experiments. The assumption is made that the rate of sloughing before maggot establishment remains constant. The validity of this assumption has yet to be tested, but it seems reasonable at the present time. The resulting estimate of initial *B. harveyi* parasitism is somewhat less than the total parasitism recorded on the healthy late fifth-instar larvae, but is usually considerably more than subsequent adult *B. harveyi* emergence from larch sawfly cocoons.

Mortality of Larch Sawfly in Cocoons

Larch sawflies spend about 10 months of their annual life cycle in cocoons in the moss or duff. These cocoons provide the insects with excellent protection, but a large amount of mortality still occurs. Because direct sampling of the forest floor has been impractical we have been forced to use other means for estimating mortality of larch sawfly in the cocoon phase. Two sources of cocoons are currently used, those collected from the moss traps and those collected from special triangular cages that do not concentrate the larvae (Fig. 15). The latter are used to provide supplementary estimates of mortality during periods of high infestation, as we have found that the moss traps tend to over-estimate mortality under these conditions (Turnock and Ives 1962).

After the cocoons from the moss traps have been counted we place them temporarily in small plastic containers or covered jelly jars with a small amount of moss to keep them moist until they can be examined. They are then stored at room temperature in an insectary. When all of the moss has been sorted, experienced workers examine the cocoons to determine their condition. Those parasitized by *O. benefactor* are first separated from normal cocoons on the basis of size as outlined by Muldrew (1967) except that we do not measure them: an experienced observer can make a surprisingly accurate assessment of their size by visual comparison only. The two groups of cocoons, normal and small, and their accompanying records are kept completely separate to check the accuracy of the original sorting. The cocoons are next examined carefully for other symptoms of mortality. Fall-emerging *B. harveyi* leave jagged holes in the ends of the cocoons, except for those where the maggot does not burrow out of the cocoon. This is usually a small percentage, but all obviously dead

cocoons are opened to see if a *B. harveyi* puparium or maggot is inside. Fall-emerging *O. benefactor* cut a characteristic hole in one end of the cocoon, and leave a thin cocoon inside the larch sawfly cocoon. Invertebrate predators, primarily elaterid larvae and carabid adults, leave characteristic holes in the cocoons. Larvae dying of fungal diseases often become mummified and can usually be identified. Some cocoons, without holes, are completely collapsed, others are turgid and liquid-filled while still others obviously contain dead larvae, but no apparent cause of death can be ascertained, and are classified as "miscellaneous dead" unless they contain *B. harveyi.*

The apparently-sound cocoons are packaged with moist moss in folded squares of dacron marquisette, a mildew-resistant material. They are placed between layers of sphagnum moss in screen-covered, mouse-proof cages and are placed under additional moss in a well-drained outside location for overwintering.

In early spring, the cocoons are examined again and any additional mortality recorded. They are then placed in plastic containers with a small amount of slightly moist sphagnum moss and placed in insulated boxes sunken into a bog, where the temperature ranges from 10-15°C. They are checked twice a week until adult emergence starts: after this they are checked daily, taking care to keep exposure to room temperature to a minimum. Emergence of larch sawfly and of the various parasites is recorded, by species and sex, and the corresponding cocoons removed. Obviously dead cocoons are also removed at intervals and recorded. When emergence has stopped the remaining cocoons are opened to determine if the insects are dead or in prolonged diapause.

The procedure followed with the triangular cages is slightly different. These moss-filled cages are sunken into moss early in the spring or late in the previous fall. Typically, a total of 45 cages is used in each plot. Thirty cages are placed out the first year, 10 each in high, medium and low topographic locations. The contents of 15 of these are removed after larval drop is complete, and the other 15 are covered with window screening and left in position until the following fall. The 15 empty cages are refilled with moss cut from a black spruce swamp and are returned to their original positions. An additional 15 cages are also sunken into the moss, 5 in each topographic location, to make a total of 30 cages ready for the next season's larval drop. The 30 cages subsequently emptied each fall are refilled and replaced annually.

Cocoons from the triangular cages removed in the fall of the first year are treated in exactly the same manner as those from the moss traps. The fate of those left in the bogs until the fall of the second year is determined by the appearance of the cocoons.

Small mammal predation is an important source of mortality during the cocoon phase. Because the cocoons we use for estimating other sources of mortality have been protected from small mammals, we have to estimate their predation separately (Buckner 1959). Apparently-sound cocoons are attached to the ends of each wire on wired 4-inch painted wooden tree tags and are buried about 2 inches in slits cut into the moss. One hundred tags are placed out in each plot. To avoid "attracting" the small mammals it is necessary that the tags be allowed to weather before use. We therefore place any new tags in the bogs in May. In August, the tags from last year are examined and fresh cocoons put in their place. The cocoons removed from the tags are examined and classified into the categories of sound (holdover), sawfly emerged, parasite emerged (*B. harveyi, M. tenthredinis,* or *O.benefactor),* dead, mouse predation or shrew predation. The latter two categories can be identified by the characteristic teeth marks on the cocoons (Buckner 1958). Mice and voles leave a scalloped edge, while shrews leave a serrated edge.

In order to estimate mortality during the cocoon phase under field conditions we have to make a number of assumptions: 1) that mortality of sawfly in cocoons from the traps is similar to that among the parent population; 2) that larvae dying in cocoons before the fall examination will not be attacked by small mammals; and 3) that small mammals will not discriminate between parasitized and unparasitized overwintering larvae. The first of these assumptions is probably the weakest. We know that we tend to overestimate the unknown causes of mortality, especially at high population levels, and that we underestimate mortality

during wet years when adverse moisture conditions are an important source of mortality. The triangular cages provide more reliable estimates, but are impractical to use when population levels are low, as the numbers of cocoons obtained do not justify the work involved.

PHYSICAL MEASUREMENTS

We consider that three aspects of the physical environment are of considerable importance in the population dynamics of the larch sawfly, and we have developed techniques for measuring them. These aspects are microtopography, water levels and weather.

Microtopography

The microtopography in stands of tamarack growing in bog sites in Manitoba is typically flat with minor irregularities. The degree of irregularity varies considerably between stands. We have therefore developed a method for measuring the microtopographic relief or portions of our study plots (Ives and Turnock 1959).

Typically, we measure the microtopography on 25 6-ft squares laid out in a 5 x 5 grid at 1/2-chain intervals in each plot. Two-by-two wooden stakes are driven at the corners of each 6-ft square. Their tops are placed in a horizontal plane by means of a levelling device consisting of water-filled plastic hose attached to a chicken fount (Fig. 17). Provided care is used to eliminate all air bubbles, this simple device works very well.

We measure the distance from the horizontal plane to the moss surface at 36 locations in each 6-ft square by means of a special jig (Fig. 18). The measurements are taken to the nearest 1/2 inch at 1-ft intervals in a 6 x 6 grid.

The frequency distribution of the microtopographic measurements is then calculated, expressed as distances above the lowest point measured in each plot.

Water Levels

The water levels in tamarack bogs typically fluctuate quite widely. In the spring of the year, and during wet seasons, there is often a large amount of surface water. During periods of prolonged drought, however, the water table is often several feet below the surface. We have found that it is a simple matter to measure these water levels by driving 5- or 6-ft lengths of heavy-walled electrical conduit into the soil. Before driving, the lower end of the conduit is closed, and 3/16 inch holes are drilled at 6-inch intervals. After conditions have stabilized (a day or so later) the water level in each pipe can be determined by carefully lowering a graduated stick into the pipe until the lower end touches the water. We usually have four of these pipes in each plot, one at each corner, and relate them to the topographic datum. We measure the distances to the water table at weekly intervals during the summer, and intermittently during the rest of the year.

The distance from the top of each pipe to the horizontal plane used in making the microtopographic measurements is known, so it is a simple matter to convert the water table measurements to the same base as is used in the microtopographic measurements. This allows us to calculate an estimate of the percentage of surface flooding at any time. In addition, we can estimate the proportion of the volumetric cocoon universe that is inundated or adversely affected by excess moisture.

Weather

Our larch sawfly study plots are located in widely separated areas in southeastern Manitoba. The weather in this region is variable, especially during the summer months when violent thunderstorms and other weather phenomena are often quite localized. We therefore decided that we should obtain as much weather information as possible for each of our study plots. Since regular weather stations were not operating near any of these plots, we had to set up our own (Figs. 19-22).

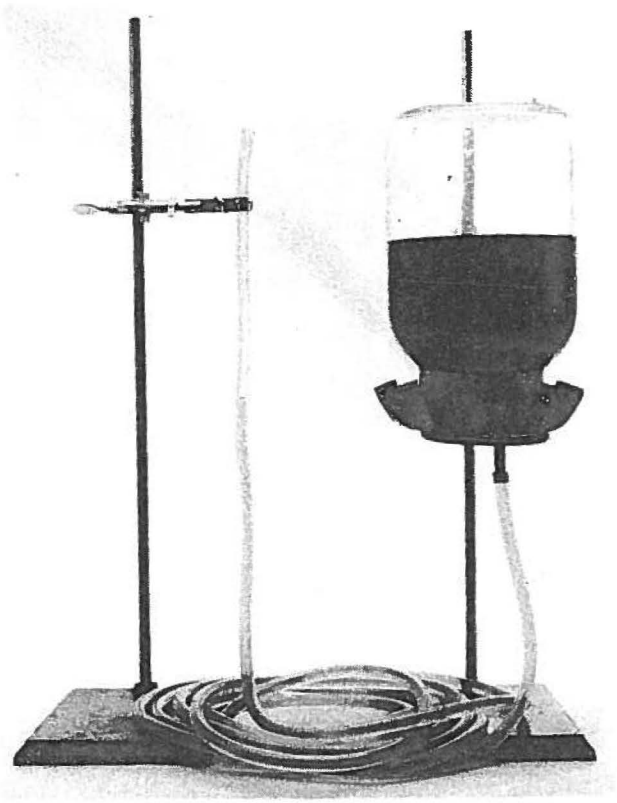


Fig. 17 Levelling device used in driving stakes to a horizontal plane.

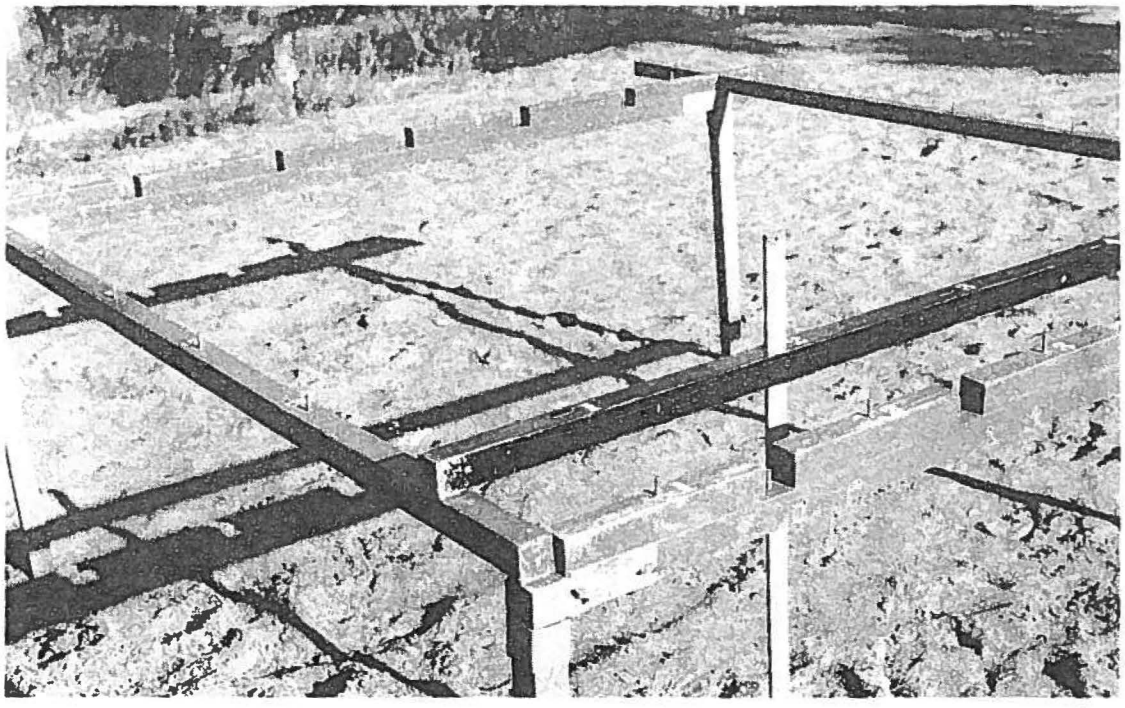
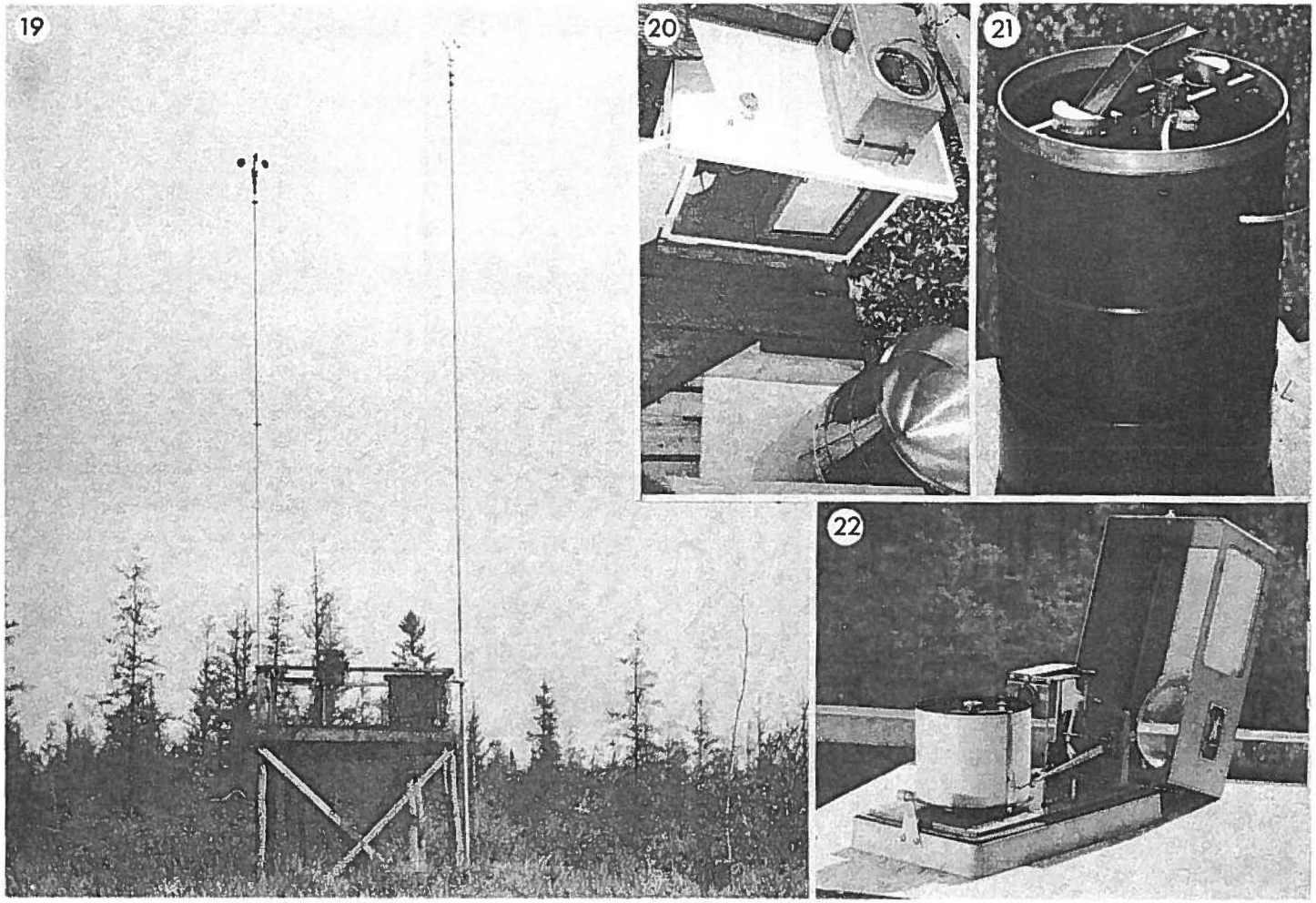


Fig. 18 Jig used in making microtopographic measurements.



Figs. 19-22 Meteorological equipment used to obtain weather data. 19. general view of tower; 20. tipping bucket rain gauge, strip-chart recorder and pyranometer; 21. tipping-bucket rain gauge with collecting funnel removed; 22. pyranometer with cover elevated.

The type of equipment that we used in our plots was dictated by two prime factors, cost and remote operation capability. We could not afford expensive equipment, and the equipment that we did use had to be driven by 8-day spring-wound clocks or by batteries. We developed none of our own equipment, but used available recording equipment. This consisted of; hygrothermographs, pyranometers, and strip chart recorders which kept simultaneous records of rainfall (in .01-inch amounts), miles of wind per hour, and wind gust velocity. Signals for the last three measurements were generated by a tipping bucket rain gauge, a contact-type cup anemometer, and a rotating-cup generating anemometer. None of these instruments are particularly sophisticated, but they provide us with adequate meteorological data for assessing the effects of weather on larch sawfly survival.

DISCUSSION

Some indication of the problems faced in developing larch sawfly sampling techniques has already been given, we will now consider some of the characteristics and limitations of these techniques.

No mention has been made of sampling variation: this does not mean that we have not been concerned about it. In the development of these sampling techniques we have had to maintain a balance between the accuracy that is statistically desirable and that which is practicably attainable. Statistical considerations were usually given maximum attention in our areal estimates. Minimum attention was given them in some of our indices, such as the seasonal abundance of branch-inhabiting fauna, where available time was the factor limiting sample size. Estimates of sampling variation are given in some of the published papers (Buckner 1957; Ives 1955, 1959, 1967; Ives and Turnock 1959; Turnock 1960).

A number of our techniques have inherent weaknesses that have been impractical to overcome and which may affect the reliability of the estimates. We have given considerable thought to the problem of how these weaknesses might be rectified, but in spite of this we have been unable to remove them. A discussion of some of these may alert the reader against possible pitfalls when developing similar techniques for other forest insects.

In egg population sampling, determination of the numbers of branches on our sample trees has always been a problem: it would be even worse on other coniferous species where dense foliage remains on the trees at all times. With tamarack, counting live branches early in the spring, just as the foliage begins to flush, has helped us considerably. There is also the problem of what to call a branch, especially on trees with a large amount of adventitious growth. We have attempted to solve this by defining a branch as being anything over 12 inches in length. However, if these short branches occur on large trees, a number of them will be concealed from view by the trunk. No satisfactory solution to this problem has been found, but we try to partially overcome it by having two observers count from different angles, so that they will be seeing different branches. Both of their counts will nonetheless tend to underestimate the true number of branches present. The problem is less important for trees with well developed branches, since at least a portion of these branches will usually be visible.

The placement of larval drop funnels and adult emergence traps has also been a problem, as a number of the randomly-selected positions include a tree trunk. We could have designed special equipment to accommodate these situations but each would have had to be custom-fitted and this seemed impractical. As a compromise, we have placed the emergence cages or larval drop funnels as close to the designated locations as possible by placing them against the tree trunk unless the location contained a tree in the middle. In this case we selected another location at random. There is a possibility, and some statistical evidence, that this procedure gives us a slight underestimate of the true population values. This is especially so during wet years, when the hummocks around the trees may provide a more favorable overwintering environment than the lower areas farther away from the trees.

No completely satisfactory means of censusing small mammals is yet available. Differences in trap reactions as a result of such factors as species, age, sex, breeding conditions, and season tend to bias trapping results, and the techniques developed and adopted in our program are compromises that tend to minimize these variations. There is an initial choice when mammal census techniques are being considered: live trapping and kill trapping. We accepted the former because the areas under investigation were limited, and a disturbance of the mammal populations using kill trapping techniques would have certainly caused artificial disruption in the population processes of the larch sawfly. Having made the choice in favour of the more laborious live-trapping methods, considerable emphasis was placed upon the reactions of the various species encountered in the sawfly infested bogs of the study area. The predominant small rodent was found to be the red-backed vole, *Clethrionomys gapperi* (Vigors), and the predominant shrew the common cinereous or masked shrew, *Sorex cinereus* Kerr, and both these species react with minimal adverse behavior to the techniques employed.

Studies on bird population census techniques have lagged because there are upwards of 70 species of birds frequenting our sawfly-infested areas, and the study of avian predators was not likely to be productive from a model building standpoint inasmuch as the difficulties in measuring impact for so varied an avifauna seemed insurmountable with our resources. We have therefore not attempted to develop sophisticated methods: our crude techniques were designed solely to interpret major population trends.

We encountered a number of problems in estimating foliage production. The counting of branches has already been discussed. We also found that the foliage weight increased steadily throughout the season, so that a considerable bias can be introduced into the estimates if the samples are not all collected at the same phenological time. The dried foliage samples in the bags contain a large amount of debris. Unless this is removed the estimates will be seriously biased. We originally used soil sieves to clean the foliage but this was extremely time consuming. The mechanical separator referred to in this paper has largely eliminated this problem.

As previously mentioned, tamarack is very responsive to adverse conditions, especially larch sawfly defoliation. However, assessment of the impact of this defoliation on the host tree is not a simple matter, because other environmental factors also cause growth reduction and mortality. In upland sites, prolonged drought may adversely affect the trees: in bog sites, flooding is more important. Suppression also plays an important role in restricting the growth of some of the trees in the stand. The utilization of radial growth patterns to detect infestations proved to be impossible (Nairn *et al* 1962). Their use for assessing the impact of larch sawfly on growth and mortality is also extremely difficult, because it is almost impossible to separate the effects of the different factors. Experimental studies have shown that light to moderate defoliation of young tamarack causes marked reductions in growth and vigour (Graham 1931, Ives and Nairn 1966b), but only repeated severe defoliation (over 75%) causes mortality. These studies were based on experimental defoliation, where the degree of defoliation was known. In our study plots, we can only estimate the defoliation, and this has proven to be an extremely difficult problem. The method that we used was designed to minimize human bias, but because of the variability of foliage production and defoliation we have only been partially successful. Fluctuations in the growth and vigour of the trees are relatively easy to measure but the establishment of cause and effect relationships between these and the environmental factors are difficult to establish. We hope that we will have sufficient data to isolate these factors and establish quantitative relationships.

Because the larch sawfly adult is parthenogenetic, relatively short-lived and does not feed, the problem of assessing its reproductive capacity is simplified. Furthermore the absence of any evidence of mass dispersal of adults makes it valid to base estimates of the reproductive capacity of a population on dissections of adults emerging from cocoons collected within the plot. The assessment of reproductive capacity by means of adult

dissections is very laborious, but indirect estimates based on correlations between size and egg productivity are invalid with the larch sawfly (Heron 1966). Although quantitative and probably qualitative nutritional differences are demonstrably the most important determinants of reproductive capacity in the larch sawfly and although size measurements provide good indices of their effects, they do not account for all the individual variability. The residual variability appears to be largely due to differences in the extent to which fat body reserves are utilized for ovarian development. There is no simple procedure for measuring the effect of this component. The dissection and oocyte classification technique is quite simple and can soon be learned by a technician but interpretive errors are not entirely ruled out.

The estimation of egg and larval survival presented a number of problems. Reference has already been made to the difficulty encountered in obtaining estimates of the proportion of eggs hatching under field conditions. The proportion surviving is estimated by dividing the number of larvae in each colony by the number of eggs laid in the associated shoot. The females often probe with their ovipositors without laying eggs, and the resulting scars must not be included in the counts. Survival estimates can only be made for colonies that can be associated with specific scarred shoots. Sometimes all of the larvae are missing: these shoots cannot be included in the estimates because it is impossible to determine when the larvae disappeared. Fortunately, these missing colonies form a small part of the total, so the bias introduced into the estimates is probably small. During severe infestations, the feeding of late-instar larvae frequently disrupts that of earlier stages to the extent that it is impossible to associate many of them with specific shoots. The exclusion of these colonies also introduces a bias into the estimates. It has been found to be almost impossible to determine the causes of the observed mortality: occasionally invertebrate predators are found near the eggs or larvae and are assumed to have been at least partly responsible.

Errors in estimating the percentage parasitism of second-instar larvae by *O. benefactor* are introduced by breakage or incomplete clearing of the host larvae. Damage may occur during collecting, sorting or treatment and the parasite larvae may be lost during the clearing process. The handling technique minimizes breakage but considerable care must be taken in handling the larvae prior to treatment and during examination. Some *O. benefactor* larvae are missed during examination because of incomplete clearing. This occurs most frequently in hosts that were preserved shortly before ecdysis. These larvae have, in effect, two integuments that interfere with penetration of the solutions, clearing and examination. Dissection of apparently-unparasitized, poorly-cleared larvae is necessary to avoid errors.

The oil traps have proven to be an unusually productive source of information on larval mortality. The estimates of the proportions of premature drop and initial parasitism by *B. harveyi* are readily applied to the population data and explain much of the previously unknown mortality. The introduction of *O. benefactor* complicated the assessment of the proportion of prematurely dropped larvae, since the parasitized larvae are dwarfed and it is more difficult to distinguish fully-fed, parasitized fifth-instar larvae from unparasitized larvae dropping prematurely. However, since the introduction of *O. benefactor* has resulted in low sawfly populations (Muldrew 1967) and premature drop is infrequent except at high sawfly populations (Ives 1967b), this complication has a minor effect on analysis and interpretation of the data. The estimates of the proportions of larvae killed by disease and predators are less amenable to quantitative analysis because an unknown portion of the larvae killed by disease and invertebrate predators remain stuck to the branches while the larvae found in the funnels that were killed by birds and wasps represent only those dropped or discarded by the predators. Despite these limitations, some knowledge of mortality that is exceedingly difficult to measure is obtained through this technique.

Our branch sampling for obtaining indices on the abundance of invertebrate fauna has not encountered major difficulties. The insecticide-carbon dioxide treatment is very

effective in removing the organisms from the branches. A possible weakness is the loss of material during removal of the branches from the trees and while carrying them to the examination tables. We feel that losses of immature stages (except for late-instar larvae) are probably minimal, but adult insects such as mirids often leave the branches as soon as they are disturbed. For this reason we do not place much reliance on indices of adult insect abundance.

The measurement of mortality attributable to the parasite *B. harveyi* is complex because of peculiarities in the life cycle of the parasite and its host. Early in the study it was found that estimates based on the emergence of *B. harveyi* from cocoons in the spring seriously underestimated the total mortality attributable to this parasite because some *B. harveyi* emerged in fall, and other parasitized hosts died in the cocoon. Mortality attributable to fall-emerging parasites is measured satisfactorily by examining cocoons for the typical exit holes. The method for determining initial parasitism of cocoons, from the oil drop larvae, is still being tested. The most serious weakness of this estimate is the assumption that the proportion of unhatched eggs that are sloughed is a constant.

Estimation of mortality during the cocoon phase of the larch sawfly has also presented a number of problems. As already mentioned, the concentrating of the cocoons to reduce the work involved in sorting has introduced a bias in the estimation of mortality because the cocoons are in an artificial environment. The funnels also concentrate the amount of water passing through the traps. The effect of this on sawfly survival is dependent upon weather conditions. During dry years the increase in moisture is probably beneficial to the insects, as desiccation may be a major source of mortality under these conditions (Graham 1956, Graham and Satterlund 1959). During wet years the increase in moisture is detrimental, because survival is greatly reduced by excess moisture even though the cocoons are not actually inundated (Ives and Nairn 1966a). There is also a differential mortality between sawfly parasitized by *B. harveyi* and unparasitized ones (Heron 1960): the parasitized larvae are much more susceptible to adverse moisture conditions than are the healthy larvae. Conversely, because the traps in low positions are elevated, we do not obtain true estimates of mortality due to flooding. However, this mortality can be estimated indirectly from our microtopographic and water table measurements. Larvae dropping into pools, or spinning cocoons near the water table nearly all die (Turnock, unpublished data). The cocoons in the traps are intentionally protected against small mammal predation and incidentally from predation by elaterids and carabids. However, the latter predation is small in field-collected cocoons, so the bias is probably of minor importance.

A planting technique was adopted in assessing mammalian predation on the cocoon population because of the previously mentioned difficulties involved in directly sampling the cocoon universe. The technique takes advantage of the fact that the openings made in the cocoon by the various predators, parasites, and the sawfly itself provide a record of the fate of each insect. Predation may be attributed only to the broad mammalian orders Insectivora and Rodentia: the specific identification of the predator is often possible because frequently only one representative of each order is present. The chief disadvantage of the method lies in the "new object reaction" of mammals. Foreign articles introduced into the habitat are usually thoroughly investigated by the mammal fauna, so that a suitable interval between the placing of the tags and the wiring of the cocoons on them must take place in order to avoid this behavioral reaction. We have found it convenient to search for tags set out the previous season in May and to replace any missing units at that time so that a suitable period between familiarization of the foreign object in the environment and the beginning of the next season's estimate would elapse. Current cocoons are then set out on the weathered tags when the main period of larval drop has passed. So sensitive are the reactions of the predators to foreign objects in the environment that if these procedures are not followed the results may be suspect. Frequently we find tags with cocoons missing. It has been assumed that these cocoons have been hoarded by small mammals, but in reality their fate remains unknown.

In the data-gathering phase of this study consideration had to be given to the collection of sufficient information to allow for the analysis of two important, closely interrelated, phenomena; (a) overlapping mortality and (b) changed vulnerability to contemporaneous or succeeding factors due to prior attack by a given factor.

The overlapping of mortality factors refers to the fact that a given individual host larva may be "overkilled" in the sense that it may be attacked by a series of factors each one of which by itself would have been sufficient to have killed the host. If two or more parasites are involved in this process it is often important to determine which one is the successful competitor. In the analysis of data, the stage at which the effect of a given parasite is measured often determines its apparent influence as a controlling factor. For example, at Pine Falls in 1966 if the mortality caused by *Olesicampe benefactor* is calculated following the calculation of the effects of small mammals, *Bessa harveyi,* adverse moisture, etc., then the reduction of the cocoon population due to it is 5.4% whereas in actual fact 93% of the cocoons were parasitized by *O. benefactor.* If our objective is to assess the value of a particular factor in reducing the population of the host or of assessing a particular biotic agent with a view to its use in a biological control program in another area -- some attempt should be made to eliminate the "masking" of the influence of the factor in question by one or more other factors. This could be accomplished by attempting to assess the influence of the factor as closely as possible to the time that the action against the population is first exerted.

Morris (1965) emphasized that when attack by one mortality factor changes the susceptibility of the host to contemporaneous or subsequent attack by one or more other factors, this can have a very pronounced effect on population trend. He showed that even if the degree of discrimination being exerted is not great it can have a large effect on population trend if this mortality is added during an age interval in which mortality is already high.

Data on a change in vulnerability of affected hosts are difficult to obtain, particularly since the extent of this change may decrease as the incidence of affected hosts increases, but in view of the importance of such changes Morris urges that an attempt be made to measure them. Quantitative estimates can sometimes be obtained by multivariate analysis but often the experimental approach is the best one to use.

An attempt to estimate a number of such changes is currently being undertaken in the larch sawfly study. One approach uses the technique of marking the current year's larvae with vital stain dyes (Heron 1968, Buckner 1968) prior to releasing them when they are ready to spin cocoons, and classifying the recovered cocoons according to their fate the following summer.

A known example of a change in vulnerability has already been mentioned; that of the greatly increased degree of mortality among larvae parasitized by *B. harveyi* during the cocoon stage. This is probably mainly due to the likelihood that the wounds made when *B. harveyi* larvae penetrates the host's integument provide a portal of entry for disease organisms. Hosts parasitized by *B. harveyi* are also more susceptible to death due to submergence, possibly because of the more rapid depletion of the oxygen supply in cocoons containing such hosts (Heron 1960). Similarly, it has been observed that almost all of the sawfly larvae killed by *Entomophthora* sp.[8] that are found clinging to larch twigs and needles during the summer have suffered prior attack by *B. harveyi.*

Sawfly larvae parasitized by *O. benefactor* are markedly reduced in size (Muldrew 1967). Some evidence was obtained, when the incidence of *O. benefactor* parasitism was low, that *B. harveyi* preferentially selected normal-sized host larvae but this was not detected at higher levels of *O. benefactor* parasitism and requires further study. It was found, with relatively good consistency in three replicates, that the percentages parasitized by *O. benefactor* at depths of 1", 2", or 3" and 4" were 86, 62, 36 and 26 respectively, (Muldrew unpublished). It seems certain that the cocoons at the lower depths are more likely to be

[8] Formerly *Empusa* sp. (class Phycomycetes: family Entomophthoraceae).

killed by flooding or excess moisture and thus the normal-sized cocoons would suffer comparatively greater mortality. Conversely, although this requires further testing, it may be that the cocoons near the surface are more readily attacked by small mammals and this would render the small cocoons comparatively more vulnerable to them. Small mammals also show a high degree of discrimination between dead larvae in cocoons as compared to healthy ones and, in addition, the cinereous shrew has the ability to reject hosts containing *B. harveyi* larvae in an active stage of development (i.e., mainly the "fall-emerging" portion of the total *B. harveyi* population occurring in the host larvae).

The greatest hope for an intelligent approach to environmental management appears to lie not in the single-factor research prevalent prior to the mid-point of this century, but in ecosystem research that has been gaining stature steadily since that time. The skeletal framework for the field methodology of an ecosystem approach to the study of the system in which the larch sawfly is an inhabitant is now well-advanced. It is true that considerable emphasis has been directed towards the larch sawfly and its host plant, and that many components have been ignored. This however remains a matter of balance between importance of components versus research resources available. In developing the study every effort has been made to obtain the maximum information about the system using the minimum of resources. Mechanization of much of the data collecting process has increased the output of our crews, allowing us to increase replication, add new measurements to the study and reduce human error.

Since the test of a data-collecting system is its ability to produce a body of data upon which theories can be tested and questions answered, these data must be accessible and capable of easy manipulation. Data processing for electronic computers is essential, partially for ease and flexibility in analysis and partly because computer languages are well adapted to analyse and describe complex ecological processes (Watt 1966). Preliminary analyses have shown that our program collects most of the pertinent data for understanding and interpreting the complex system. Data necessary for the study of several important energy transfers in the system is either available or readily derived from the data.

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AN APPRAISAL OF GAMMA IRRADIATION FOR INSECT CONTROL IN CEREAL FOODS [1/, 2/]

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The preservation of food from insects is important to consumers as well as to those concerned with its storage, distribution, and sale. From the time grain is harvested it is subject to attack by insects. Common symptoms of insect damage in cereal grains are losses in weight, germinative power, and nutritive value. In processed foods, the presence of insects, excrement and webbing often causes whole packages or shipments to be condemned.

World losses of cereals attributed to insects and rodents have been estimated at more than 20% of total production. In Canada, loss during storage is probably less than 1% of production; in contrast, annual losses of food grains in India due to stored-product insects is estimated at 5 to 10% (Sarid and Murthy 1965). In a world afflicted with acute food shortages, serious losses can no longer be tolerated and all methods of pest control must be utilized.

Gamma radiation derived from Cobalt-60 has proved to be an effective means of controlling insects (Cornwell 1966). Special equipment has been developed for the irradiation of cereal grains and food products. Extensive research in Europe and North America has shown that grain is not damaged at the doses used for insect control. Several hundred papers have already been published on various aspects of irradiation of food products. The present review concerns the lethal and sterility effects of gamma radiation on stored-product insects.

Role of Chemical Insecticides

The control of stored-product pests throughout the world is made possible by a wide range of insecticidal chemicals. The choice of insecticide depends on the species to be controlled, its habitat, the extent of infestation, and factors such as temperatures that influence insecticidal effectiveness. Insecticides that kill by contact, such as DDT, lindane and malathion, are sprayed on interior surfaces of food storage warehouses to control infestations and to prevent damage to stored foods. Malathion and pyrethrins possess low mammalian toxicities and may be applied directly on bulk grain, as it is binned, to control insects in the grain or to prevent infestation and damage during storage. Large bulks of infested grain may be treated with fumigants applied as solids, liquids or gases. The toxic vapors so formed diffuse throughout the commodity and are effective against insects, including those distributed at considerable distances from the point of application.

Though insecticides are indispensable as pest control agents some limitations are now evident. First, restrictions have been placed on the amounts of insecticides or their degradation products that may be legally present in certain foods; second, since insecticides are poisonous to man as well as to insects they must be applied carefully to prevent accidental contamination of foodstuffs; third, there are several reported instances of resistance to insecticides in certain insect species (Parkin 1965); and fourth, when used near packaged foods, insecticides must be used with caution to prevent taint or toxic deposits on the commodity. Though reported instances of sub-lethal effects of insecticides on insects are few, there is evidence that fecundity of granary weevils exposed to wheat unevenly treated with malathion may actually increase under certain conditions (Watters 1959).

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[2] This paper is based on a report prepared at the request of Atomic Energy of Canada Limited, Ottawa.

Insecticides are used widely for insect control in Canada and the United States. They are used less in the developing countries where extensive losses occur and where the high cost of insecticides, ignorance of their value and methods of application, and social or religious taboos tend to inhibit the implementation of modern agricultural practices. Consequently in developing countries insecticides are used mainly at central food depots operated by government agencies.

Gamma Irradiation

In recent years ionizing radiation has been recommended as a possible alternative or supplement to chemical insecticides for controlling insects in stored cereals and cereal products. Gamma radiation produced by the radioactive decay of Cobalt-60 has already proved to be highly effective against a wide range of insect pests (Cornwell 1966a). The method can be easily adapted to automated bulk handling procedures already well developed in the grain trade and cereal processing industries. Use of grain irradiators may not be justified economically in countries such as Canada which generally have low levels of infestation. However, the irradiation technique might be useful in the processed foods industry to ensure that packaged foods are free of infestation when they leave the manufacturers. Infested foods not only lead to spoilage and waste, but also to loss in reputation to the manufacturer. After foods have been irradiated additional measures must be implemented to ensure that the packages remain impervious to insect penetration while in transit. Such protection requires the use of specially constructed containers made from fabrics of high tensile strength.

Gamma radiation could also be used in the enforcement of quarantine regulations to guard against the inadvertent importation of pests from other countries. Extensive intercontinental air travel is increasing the possibility that new insect pests will be interchanged between widely scattered countries and new measures must be considered to meet this threat.

Ionizing radiation produces two apparent biological effects on insects: (1) lethal effects, which affect somatic tissues and cause death in from one day to several weeks after exposure depending upon the applied dose; and (2) sterility effects, which involve the reproductive tissues of both sexes. The threshold doses that cause immediate sterility will permit adult survival for several weeks and generally are much lower than those that cause immediate death. Much of the research conducted with stored-product insects has been concerned with the dosage levels needed to kill insects. However, insects do not die immediately after they have been irradiated and the susceptibility of species to gamma radiation varies widely. For example, a dose (12.5 krad) which caused complete mortality of *Tribolium confusum* within 2 weeks after treatment permitted survival of some individuals of the more tolerant species, *Rhyzopertha dominica,* for 16 weeks (Watters and MacQueen 1967).

Effectiveness Against Stored-Product Pests

Much research has been directed towards determining the minimum doses required either to kill insects or to significantly shorten their life span, and sterilize them. Cornwell (1966a) refers to a series of papers that report extensive research carried out with stored-product pests at the Atomic Energy Station at Wantage, England. Other studies have been reported by Hasset and Jenkins (1952), Baker *et al* (1953, 1954) and Tilton *et al* (1961, 1966a, b) in the United States, and Watters and MacQueen (1967) in Canada. These papers show that results of experiments with high energy ionizing radiation are not always in agreement. Differences in techniques of handling insects and exposing them in radiation sources may account for the different results. There may also be differences in susceptibility among strains within a species. Acceptance of radiation as a pest control measure has been slow because the insecticidal effects are not as spectacular or rapid as those obtained with chemical insecticides. In contrast, sterility effects produced by radiation are immediate and at doses well above the sterility threshold appear to be permanent. However, Watters and MacQueen (1967) found that sterility of *T. castaneum* irradiated at 6250 rad was reversible.

Table I. Summary of effectiveness of gamma radiation for the control of stored-product pests

Species	Dose, rad x 10^3	DAYS REQUIRED FOR 50% mort.	DAYS REQUIRED FOR 95% mort.	Author
Confused flour beetle, *Tribolium confusum*	6.25	7-14	21	Watters & MacQueen. 1967
	8.5	24	—	Shipp *in* Cornwell. 1966
	9.37	28	—	Banham *in* Cornwell. 1966
	12	20.5	26	Farkas. 1966
	12.5	7-14	14	Watters & MacQueen. 1967
	12.8	—	28	Banham *in* Cornwell. 1966
	13.2	17	26	Tilton *et al.* 1966
	15,000 r	15	—	Cork. 1957
	17.5	21	<28	Tilton *et al.* 1965
	17.5	9	16	Tilton *et al.* 1966
	25	11	19	"
	25	19.4	25	Farkas. 1966
	45	9	14	Tilton *et al.* 1966
	50	13	17	Cornwell *et al.* 1957
	50	16	20	Farkas. 1966
	50	< 7	< 14	Watters & MacQueen. 1967
	64	—	14	Hassett & Jenkins. 1952
	75	< 7	< 7	Watters & MacQueen. 1967
	100,800 r	6	—	Dennis. 1961
	151,200 r	—	6	"
	216,000 rep.	2	4	Proctor *et al.* 1954
	500,000 rep.		1	Baker *et al.* 1954
Red flour beetle, *Tribolium castaneum*	13.19	21	—	Banham & Crook *in* Cornwell. 1966.
	18.75	14-21	21	Watters & MacQueen. 1966
	21.5	—	21	Banham & Crook *in* Cornwell. 1966.
	50	24	—	Cornwell *et al.* 1957
	50	14-21	21	Watters & MacQueen. 1967
	75	14-21	21	"
	150	7	14	"
Lesser grain borer, *Rhyzopertha dominica*	9.5	45	—	Cornwell. 1966
	12.5	63	105	Watters & MacQueen. 1967
	13.2	35	75	Tilton *et al.* 1966
	16	30	—	Cornwell. 1966
	18.75	35	77	Watters & MacQueen. 1967
	17.5	27	47	Tilton *et al.* 1966.
	20	25	56	Cornwell. 1966
	25	28	56	Watters & MacQueen. 1967
	25	22	33	Tilton *et al.* 1966
	37.5	<21	< 35	Watters & MacQueen. 1967

(Continued)

Table I. (Continued)

Species	Dose, rad x 10^3	DAYS REQUIRED FOR 50% mort.	95% mort.	Author
	45	18	26	Tilton *et al.* 1966
	50	24	—	Cornwell *et al.* 1957
	50	14-21	21	Watters & MacQueen. 1967
	64	—	22	Hassett & Jenkins. 1952
Granary weevil,	6	15	18	Cornwell & Bull. 1960
Sitophilus granarius	6.25	< 7	21	Watters & MacQueen. 1967
	6,400 rep.	12	—	Cornwell. 1966
	12	13	18	Cornwell. 1960
	12.5	< 7	14	Watters & MacQueen. 1967
	15,000 rep.	11	—	Cornwell. 1966
	50,000 rep.	7.5	14	Cornwell *et al.* 1957
	50	< 7	7	Watters & MacQueen. 1967
	100,800 r	6	—	Dennis. 1961
	250,000 rep.		1	Baker *et al.* 1954
Rice weevil	6	11	17	Cornwell & Bull. 1960
Sitophilus zeamais	13.2	11	21	Tilton *et al.* 1966
	25	10	17	"
	50,000 r	11	14	Cornwell. 1957
	66	7	11	Tilton *et al.* 1966
	100	3	6	"
	100,800 r	—	6	Dennis. 1961
Saw-toothed grain beetle	50	11	14	Cornwell *et al.* 1957
Oryzaephilus surinamensis	100,800 r	—	< 60	Dennis. 1961
cathode (	50,000 rep.		12	Proctor *et al.* 1954
rays (	400,000 rep.		1	Proctor *et al.* 1954
Rusty grain beetle	6.25	21	217	Watters & MacQueen. 1967
Cryptolestes ferrugineus	12.5	7	14	"
	50	15	21	Cornwell *et al.* 1957
Flat grain beetle	50	8	14	Cornwell *et al.* 1957
Cryptolestes pusillus				
Cryptolestes turcicus	6	17	—	Cornwell *et al.* 1957
Khapra beetle	5	36	> 73	Nair & Rahalker. 1963
Trogoderma granarium	6	15	47	"
(freshly hatched larvae)	10	< 9	15	"
Trogoderma glabrum	13.2	22	32	Tilton *et al.* 1966
	25	24	34	"
Black carpet beetle	13.2	9	20	Tilton *et al.* 1966
Attagenus piceus	25	15	27	"
Cigarette beetle,	13.2	25	38	Tilton *et al.* 1966
Lasioderma serricorne	25	22	40	"
Grain mite, irradiated (	13.2	8	14	Burkholder *et al.* 1966
Acarus siro as larvae (	25	3	5	"
irradiated (	13.2	7	12	"
as adults (	25	7	13	"
A mite				
Tyrophagus dimidiatus	50	27	—	Farkas. 1966
	100	19	—	

Table I summarizes mortality data for several species of stored-product pests. Though there are wide differences in results obtained by different workers, possibly due to technique and strain differences it is possible to reach several general conclusions. First, very high doses of 250,000 to 500,000 rad are needed to produce complete mortality, within 24 hr. of treatment (Cornwell 1966a); doses of 150,000 rad result in complete mortality within a week (Baker *et al* 1954); at 50,000 rad complete mortality occurs within 1 to 4 weeks, depending on the susceptibility of the species to gamma irradiation (Watters and MacQueen, 1967).

Immediate sterilization occurs at radiation doses that would permit survival for several weeks. For example, after irradiation of *R. dominica* adults at 6.25 krad no progeny were obtained, yet it took 28 weeks before all the irradiated adults died; at 50 krad it took 4 weeks for complete mortality (Watters and MacQueen 1967). Cornwell (1966a) reported wide differences in susceptibility among 13 strains of *S. granarius* tested at Wantage. At 6500 rep., the LT50 of a laboratory strain (P.I.L. standard) was 12.3 days compared with 16.5 days for a strain from France.

Though strain differences may account in part for the wide diversity of the results reported in Table I, differences in methods of treating mortality data may also lead to divergent results. For instance, Cornwell *et al* (1957) applied a correction to their mortality data (Abbott 1925) which takes into account control mortality. Frequently, when lethal effects are delayed and observations are continued for several weeks high control mortalities occur. Instead of applying a correction most authors report both the treatment and control mortalities. It is inevitable, therefore, that in some cases a portion of the mortality attributed to the treatment is in fact due to "natural" causes. In contrast, most classes of chemical insecticides kill rapidly, control mortalities are low, and virtually all of the mortality responses is directly attributable to the treatment.

Another major difficulty in comparing the results of various authors on the basis of median dose response with respect to time is that such comparisons are generally valid only for log-probit regression curves. Much of the data reported in Table I is taken from curvilinear response curves constructed from data that are not amenable to probit analysis. The 50% and 95% points are, therefore, estimated directly from the curves. Despite the errors inherent in comparing data from different sources, some results such as those at the 50% mortality level agree closely.

Table I shows that no moderately low dose of radiation will control all species of stored-product insects. Cornwell (1966a) has stated that complete and immediate kill of insects can only be obtained at 250 krad to 500 krad. The data given in Table I indicate that at doses of 20 krad complete control of all species of beetles except *R. dominica* can be obtained in about 3 weeks; when *R. dominica* is present in stored grain, the dosage must be increased to 50 krad. In contrast, all individuals were sterilized at 12.5 krad. There is evidence that the saw-toothed grain beetle, *Oryzaephilus surinamensis*, is more resistant to gamma radiation than most of the other species reported in Table I, but more work is required with this and the related species, *O. mercator*.

Lepidoptera (moths) appear to be more resistant to the lethal and sterilizing effects of gamma radiation than other orders of insects. Pendelbury *et al* (1966) and Cogburn *et al* (1966) showed that the life spans of the moths *Cadra cautella* and *Plodia interpunctella* exposed to large doses (45 krad) were not shortened. The greater resistance of moths to sterilization may be due partly to the "batch" production of eggs compared with serial oogenesis in the Coleoptera (Pendelbury *et al* 1966). In addition, Bushland (Personal communication) has suggested that the smaller size of the chromosomes in Lepidoptera may account in part for their resistance to gamma radiation.

Cogburn *et al* (1966) studied the effects of different doses of gamma radiation on metamorphic stages of the Indian-meal moth, *Plodia interpunctella*, and the Angoumois grain moth, *Sitotroga cerealella*. Eggs of both species, and larvae of *P. interpunctella* were killed at 13.2 krad, the lowest dosage used but some larvae of *S. cerealella* survived. Genetic damage in the F_1 generation was apparent when adults of both species were irradiated at 13.2 krad. The authors suggested that a dose of 17.5 krad should be sufficient to eliminate eggs and young larvae of both species that may be present in food packages.

Puparium formation in *Ephestia (Anagasta) kuhniella* was delayed by doses of 20 to 30 krad (Cornwell 1957). Kuzin *et al* (1968) found that injection of ecdysone in irradiated larvae corrected this defect and concluded that the absence of puparium formation was due primarily to damage to the neurosectretory cells and not to a disturbance of the DNA of the hypodermis.

Pendelbury *et al* (1966) reported a significant difference in susceptibility to radiation between sexes of *C. cautella*: 11.6 krad allowed emergence of only 50% of females but 28.4 krad were required to similarly limit emergence of males. There was no significant difference in the radiation susceptibility of the sexes of *P. interpunctella.*

A factor that may perhaps offset the high resistance of Lepidoptera to gamma radiation is the fragility of both moths and larvae. Hence there could be high mortality during transportation of infested grain to and from an irradiation source. Eggs and young larvae may suffer less damage from physical handling than the older stages, but the younger stages are, in turn, more susceptible to gamma radiation.

Mites were generally more resistant than insects to radiation. Kumyantsev and Ratanova (1958) reported that the mite *Tyrophagus putrescentiae* was 20 to 30 times more resistant to ionizing radiations (produced by x-rays) than were insect pests of stored cereals (Burkholder *et al* 1966). Golumbic and Davis (1966) reported that the minimum dose needed to completely arrest development of the flour mite, *Acarus siro,* was 40 to 100 krad and that needed to obtain complete sterility was 25 to 45 krad. According to Farkas (1966) reproduction of *Tyrophagus dimidiatus* was completely inhibited at 25 to 50 krad. Burkholder *et al* (1966) found that the eggs and hypopus were the most resistant stages and the larvae was the least resistant.

Post Irradiation Effects

The long period between irradiation and death of insects is characteristic at dosages up to 50 krad, which are considered to be economically feasible. Intervals of several weeks are not uncommon, but the exact period depends on both inherent susceptibility of the species and on stage of development. In contrast, sterility effects are immediate and generally irreversible although Watters and MacQueen (1967) found that at 6.25 krad certain *T. castaneum* adults recovered fertility after being irradiated. Cornwell (1966b) suggested that sterile survivors of gamma radiation could confer partial protection against future infestation since the invading insects could mate with their sterile partners.

Doses insufficient to sterilize insects may actually prolong their lives. Cork (1957) reported that 30% of *T. confusum* adults exposed to 3 krad and 13% of controls survived 400 days. He suggested that certain physiological processes are retarded by irradiation and in addition, repair mechanisms within irradiated animals may be stimulated. Cornwell (1964) listed several examples of apparent stimulatory effects of ionizing radiation whereby the life spans of the khapra beetle, *Trogoderma granarium,* adult wasps,*Habrobracon sp.* and soil inhabiting *Collembola* have been increased. There is evidence that irradiation of immature stages leads to the production of deformed adults (Cogburn *et al* 1966, Cornwell 1964). Doses that cause these aberrant effects are usually much lower than the minimum doses recommended for effective insect control.

Adults of *T. confusum* appeared lethargic immediately after irradiation at 150 krad (Watters and MacQueen 1967). These symptoms were not apparent at 75 krad or lower doses. Banham and Crook (Cornwell 1966a) found that the doses required for 99.9% kill of adults, larvae and eggs were 12.8 krad, 5.2 krad, and 4.4 krad, respectively. Since larvae are more susceptible than adults and also consume more food, doses that permit adult survival for 4 or 5 weeks may substantially reduce damage because of high larval mortality. Cornwell (1964) has shown that after treatment at 16 krad the granary weevil, *S. granarius,* ingested approximately half as much food as did untreated insects. Watters and MacQueen (1967) noted that *S. granarius, T. confusum, T. castaneum, C. ferrugineus* and *R. dominica* irradiated at 6.25 krad all damaged untreated wheat. In some instances walking ability of survivors seems to be impaired.

Minimum Effective Dose

Since the cost of treatment is directly related to dose, it follows that foodstuffs should be treated at the lowest dose required to kill insects within a reasonable period. From Table I, it is clear that certain species are more resistant than others. Thus, the minimum effective dose must control the most resistant species in the commodity or food processing plant. If the confused flour beetle was involved, a dose of 12.5 krad would be adequate to achieve control of all stages within 2 to 4 weeks, depending on the susceptibility of the strain. On the other hand if the saw-toothed grain beetle was involved, a dose of 50 krad would be required to obtain complete control within 14 days (Table I).

Based on laboratory and field experiments, Cornwell (1964, 1966a) reported that a dose of 16 krad was adequate to inhibit reproduction of the granary weevil. He found that doses of 10 to 12 krad were substerilizing and that a population so treated was able to maintain itself at a low level for about 4 months. Watters and MacQueen (1967), and Cornwell (1966a) found that though several common species of stored-product beetles could be sterilized by similar doses, they differed considerably in their mortality response. A minimum effective dose of 12.5 krad would be adequate to sterilize and control the most susceptible stored product insects.

Infestations of moths and mites require larger doses to achieve control than do infestations of beetles. Since there are no sterility and mortality data for many common species of moths and mites, it is not possible to state the doses required for their control. Dose recommendations must be set in accordance with data obtained for related species.

Effect on the Product

Extensive research has been carried out to determine whether cereals and processed cereal products are damaged as a result of irradiation. Raica and Howie (1966) have reported the results of long-term toxicity studies on rats, monkeys, and humans that were fed irradiated food. They concluded that irradiated foods are as suitable and acceptable as non-irradiated foods. The United States Food and Drug Administration have approved dosages of 4.5 krad (Co-60 or 10-MeV electrons) for bacon, 50 krad for wheat and wheat products, and 10 krad (2-MeV electrons) for potatoes (Raica and Howie 1966). Since this paper was published, the United States Food and Drug Administration have ruled that "wheat and wheat products" was too broad and indefinite a category and the existing regulation was restricted to "wheat and wheat flour" (United States Federal Register, March 4, 1966).

Cornwell (1966a) reported that the chemical, physical and baking characteristics of flour milled from wheat irradiated at 20 krad were not altered except for a slight darkening of the flour. Watters and MacQueen (1967) reported no gross changes in milling, baking and allied characteristics of flour milled from hard red spring wheat irradiated at 6.5 krad to 150 krad. Deschreider (1966) has suggested that the baking quality of European wheat flour has actually been improved by irradiation.

Irradiation of barley and wheat at 6.25 krad resulted in a slight decrease in germination of barley of 13% moisture content but that of wheat was not changed (Watters and MacQueen 1967). The germination tests indicated that the higher moisture content in both wheat and barley appeared to confer some protection against the adverse effects of irradiation on seed viability.

Conclusions

High energy ionizing radiation produced by radioisotopes is an important new weapon for use in maintaining the storage life of foods. Much research has been done to evaluate the effectiveness of this new control measure and to determine whether any toxicological hazard or nutritional loss accompanies its use. The general consensus is that the technique is effective and safe for the purposes outlined. Because of the wide range in susceptibility of stored-product pests to gamma radiation a minimum effective dose will apply only to the most

susceptible species. For instance, a dose of 16 krad may be adequate to control the granary weevil (Cornwell 1966a), but a dose of 50 krad may be necessary to achieve control of certain moth larvae, grain mites or saw-toothed grain beetles. Therefore, each infestation problem in a food processing plant or terminal grain facility must be considered separately according to the pest species involved. Hence, it should then be possible to recommend for a specific pest problem the lowest economical dose consistent with the degree of control required to insure the keeping quality of the food.

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EFFECT OF FOOD QUALITY ON THE REPRODUCTION OF MESOSTIGMATA: A REVIEW [1]

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The Acarina found in stored grain have, in general, been studied from two points of view. Some, such as *Acarus siro* L., *Cheyletus eruditus* (Schrank) and others of the Acaridae, have been examined from a strictly agricultural standpoint with regard to their distribution, abundance, and control. Others such as *Androlaelaps (= Haemolaelaps) casalis* (Berlese), *Haemogamasus pontiger* (Berlese) and other Mesostigmata have been almost exclusively of medical interest (Furman 1959, McKinley 1963) because they are closely related to species that feed on warm blooded animals; the ability of some Mesostigmata to transmit diseases has stirred the interest of many acarologists. The ticks and chiggers will not, however, be discussed here. In both groups of Acarina there are some species that are of both medical and agricultural importance. *Glycyphagus domesticus* (De Geer) has caused dermatitis in small children (Barriga and Reyes 1965), asthmatic symptoms in humans (Spieksma and Spieksma-Boezman 1967) and is a pest of stored grains as well (Hurlock 1963, Barker 1968a).

Studies on some species are hampered by a lack of information on requirements for rearing the mites in the laboratory, whereas other species are able to prosper under most laboratory conditions. Often, medical acarologists will first attempt to feed mites collected from vertebrates or their nests on blood before using other foods (Furman 1959). For example, *Blattisocius keegani* (Fox) was first found on a rat (Fox 1949) yet was later shown to feed on eggs of beetle pests of stored grain (Barker 1967b). On the other hand, agricultural acarologists first test microorganisms and other arthropods as foods (Sinha 1964, Barker 1967a, Barker 1967b). Both approaches have merit though not infrequently valuable colonies are lost because the first foods chosen are unsuitable.

Sinha (1964) showed that the rate of increase in mite populations varied with the species of fungus host organism. It is difficult to know whether the reproductive rates of particular species are low due to abnormally high mortality or to low offspring production when the effect of food on mortality has not been thoroughly examined. It is, therefore, important to discover exactly how the rate of multiplication of a species of mite varies with the quality and quantity of food that is ingested. There is some information which indicates that in the Mesostigmata there is low offspring production when food is in short supply or is of poor quality.

The quantity of food available generally has a great influence on the number of offspring produced by each female. Chant (1961) showed that the number of prey consumed by *Typhlodromus (T.) occidentalis* Nesbitt per unit of time was proportional to the density of prey per unit area and beyond a certain density consumption remained constant. Production of offspring per unit of time varied directly with the number of prey consumed during the same period. For example the maximum number of prey (*Tetranychus telarius* L. protonymphs) consumed by *T. (T.) occidentalis* was 11.3 and the maximum number of eggs laid per day was 1.9. Similarly, Barker (1967b) showed that the number of eggs produced per day by *B. keegani* females was proportional to the number of *Cryptolestes turcicus* Grouvelle eggs consumed per day. Thus, the number of progeny produced per female predator per unit of time is proportional to the number of prey consumed per unit of time.

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Oviposition by the Mesostigmata is influenced not only by the quantity of food consumed, but also by the quality of the substrate on which feeding takes place. Rodriguez and Wade (1961) showed that a manure substrate with a pH of 4 is unfavourable for oviposition by *Machrocheles muscadomesticae* (Scopoli), a mite that eats fly eggs, but that at pH7, fresh manure was very good for oviposition. When soybean meal was incorporated into the manure *M. muscadomesticae* fed on the soybean meal as well as on the housefly eggs placed on the substrate for food, and produced many more eggs than when it was fed on fly eggs alone.

McKinley (1963) showed that the quality of food has an important effect on the state of development of the progeny at the time of birth. For many years the eggs and larvae of *A. casalis* were unknown even though the species had been cultured in the laboratory. Colonies of *A. casalis* fed on many foods, had very low reproductive rates, and the youngest individuals observed in the cultures were protonymphs. However, when *Dermanyssus gallinae* (De Geer), *Tyrophagus putrescentiae* (Schrank) and *A. siro* were offered as food, the reproductive rate of the predator increased greatly and larvae were often found in cultures. More recently (Barker 1968b) examined the bionomics of *A. casalis* that were fed on *G. domesticus;* he was able to measure the duration of the larval stage and also observed some eggs. From these observations he surmised that *A. casalis* will retain eggs while the embryos develop if the food is deficient in some particular quality.

Another instance where quality of food also determines reproductive rates of predatory Mesostigmata is apparent with *H. pontiger* (Barker, unpublished). Females reared on *G. domesticus* throughout their lives produced an average of 0.06 offspring per female per day, but when damaged larvae of *Tribolium confusum* (Duval) were added to the diet, about 0.9 offspring were produced per female per day. Usually, the eggs of *H. pontiger* require about 2 days for development between oviposition and eclosion if the mother's food included *T. confusum* larvae and *G. domesticus;* if the mother's food did not include *T. confusum* larvae, the few eggs that were produced hatched almost immediately after oviposition.

Not all predatory Mesostigmata obtain their nutrients exclusively from prey species; Barker (1968b) found that immature *A. casalis* developed when fed on brewer's yeast only. Swirski *et al* (1967) in some very detailed experiments demonstrated that females of *Typhlodromus athiasae* P. and S. laid far more eggs per day when fed on the pollen of maize and *Carpobrotus edulis* than when fed any of 12 different foods including 4 species of mites and 6 species of insects. Chant (1959) also found that *Typhlodromus pyri* (Scheuten) would oviposit if fed on pollen grains. He also demonstrated that 4 species of *Typhlodromus* could obtain some nourishment from the leaves of the plants on which they lived.

Food quality plays a very important role in the reproduction of the Acarina. Among the Mesostigmata there is evidence that the number of offspring produced per unit of time and the length of the life cycle of the progeny are both affected by the quality and quantity of food available. Thus it is important to determine how the life histories of predatory species are affected by the diverse food components in the environment.

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GOLDENROD GALL PRODUCERS

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ABSTRACT

Une étude sur les producteurs de galles de la verge d'or, *Solidago* sp., a été entreprise dans une prairie en friche à Sherbrooke, P. Québec. Les insectes recueillis se classèrent de la façon suivante: *Gnorimoschema gallesolidaginis* Riley (Lépidoptère: Géléchiidé); *Epiblema* (Eucosma) *scudderiana* Clemens (Lépidoptère: Olethrutidé); *Apanteles* sp. (Hyménoptère: Braconidé); sous-familles Eurytominé, Toryminé et Eulophiné (Hyménoptère: Chalcidoidé) et enfin plusieurs espèces de Diptères (Cécidomyidés). En tout, 5,185 plantes ont été examinées et 221 paires de plantes, chacune comprenant une plante parasitée et une plante saine immédiatement voisine, ont été ramenées au laboratoire les galles rencontrées se trouvaient la plupart du temps seules sur le plant et comptaient une seule loge. En général, les plants parasités étaient plus petits que les plants sains et le diamètre des plants attaqués différait statistiquement (>95%) de celui des plants sains. Finalement, tant chez les plants parasités que chez les plants sains, les hauteurs variaient en fonction directe de leur diamètre.

A study of goldenrod gall makers was conducted in a meadow in Sherbrooke, P. Quebec. The insects associated with goldenrod were classified as follows: *Gnorimoschema gallaesolidaginis* Riley (Lepidoptera: Gelechiidae); *Epiblema* (Eucosma) *scudderiana* Clemens (Lepidoptera: Olethrutidae); *Apanteles* sp. (Hymenoptera: Braconidae); subfamilies Eurytominae, Toryminae and Eulophinae (Hymenoptera: Chalcidoidae) and various species of Diptera (Cecidomyidae). Of 5,185 plants examined, 221 parasitized plants were found. Generally, host plants harbored single galls involving a single chamber. Parasitized plants were smaller than the healthy ones, while the diameter of the infected plants was significantly larger (95% level) than the diameter of the latter ones. The heights of both parasitized and unparasitized plants were related directly to their respective diameters.

INTRODUCTION

Studies on the interactions of insects and plants have a long history and are of both economic and theoretical importance. Galls and gall production form an interesting and easily accessible component of insect-plant interactions and opportunities to examine these relationships are frequently close at hand. Galls are any deformation of a plant resulting from attack by parasites (animal or plant) and arise from the reaction of the host plant tissues to the presence of parasites. In the case of insect parasitism, the resultant swelling of the host tissues provides food and shelter for the developing parasite (Grassé 1951, Souchon 1965).

An opportunity to study such a host-parasite relationship was provided in 1967, while the senior author was completing his final year of the undergraduate curriculum in biology at l'Université de Sherbrooke. The study involved the investigation of several relationships between galls formed by Diptera and Lepidoptera on goldenrod (*Solidago* sp.) hosts. Principal species of goldenrod encountered in the study were *Solidago canadensis* L. and *S. graminifolia* (L.) Salish. A few specimens of *S. rugosa* Mill were also examined.

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A preliminary survey of 15 randomly collected plants yielded 4 insect galls, indicating about 27% parasitism. On the basis of this survey, further studies were initiated.

THE STUDY AREA

Studies were made in a large meadow adjacent to buildings of "la Faculté des Sciences de l'Université de Sherbrooke". This meadow was bounded on the south-east by a coniferous forest and on the north-west by a deciduous forest. The coniferous and deciduous forests joined on the south side, forming a mixedwood stand of hardwoods and softwoods in about equal proportions, and it was at right angles to this mixedwood forest that our studies took place.

The majority of herbacious plants encountered in the meadow were *Solidago* sp. Several other species of composite plants also occurred, the most common of which was *Leontodon autumnalis* L. Chief cover plants were *Graminea* sp. and a large variety of herbs.

METHODS

Three plots were selected for investigation: these graded from forest edge to open meadow. The plots were of uniform dimensions, 60 ft x 60 ft, for a total area in each of 3,600 sq ft. All *Solidago* plants were removed from each of these plots by cutting them as close to the ground as possible. Whenever possible, plants were removed in couplets, the closest plant to the one being cut being regarded as its couplet. Only couplets containing parasitized plants were retained for further studies: those containing only unparasitized plants were recorded and then discarded.

From the plants that were retained, the following measurements were taken (Fig. 1): a) length of unfoliated portion of stem; b) length of foliated stem and c) length of floral head. Diameter measurements (in mm) were also made as close to the ground as possible for both parasitized and unparasitized plants of each couplet.

The gall portion of the stem was cut from the diseased plants and carried to the laboratory in plastic bags. Length, diameter and shape of each gall were recorded and each gall was then placed separately into a test tube along with a small amount of water. All emerging insects were collected, recorded and retained for identification. After emergence was completed, the galls were examined to determine the numbers of chambers in each.

RESULTS

Of 5,185 *Solidago* sp. plants examined, 221 parasitized plants yielded 231 galls, for an overall parasitism of 4.26% (Table I). The lowest degree of parasitism occurred in the plot nearest the forested area, while the highest was found in the central plot. Differences, although significant at the 95% level, are not great. It is interesting to note that about half the number of galls collected were taken from plot 1, and that a preponderance of galls occurred on the floral heads. Towards the middle of the field (plot 2) there was a tendency for galls to occur on the lower parts of the plant, and at the forest edge (plot 3) this tendency was very pronounced (Table I).

Table I. Gall formation on *Solidago* sp. in a meadow at Sherbrooke, P.Q.

Plot	No. *Solidago* plants taken	No. plants parasitized	Location of galls on plants A*	B*	C*
1	2,502	101	27	28	48
2	1,292	66	29	31	14
3	1,391	54	31	19	4

* For area designations, see Fig. 1.

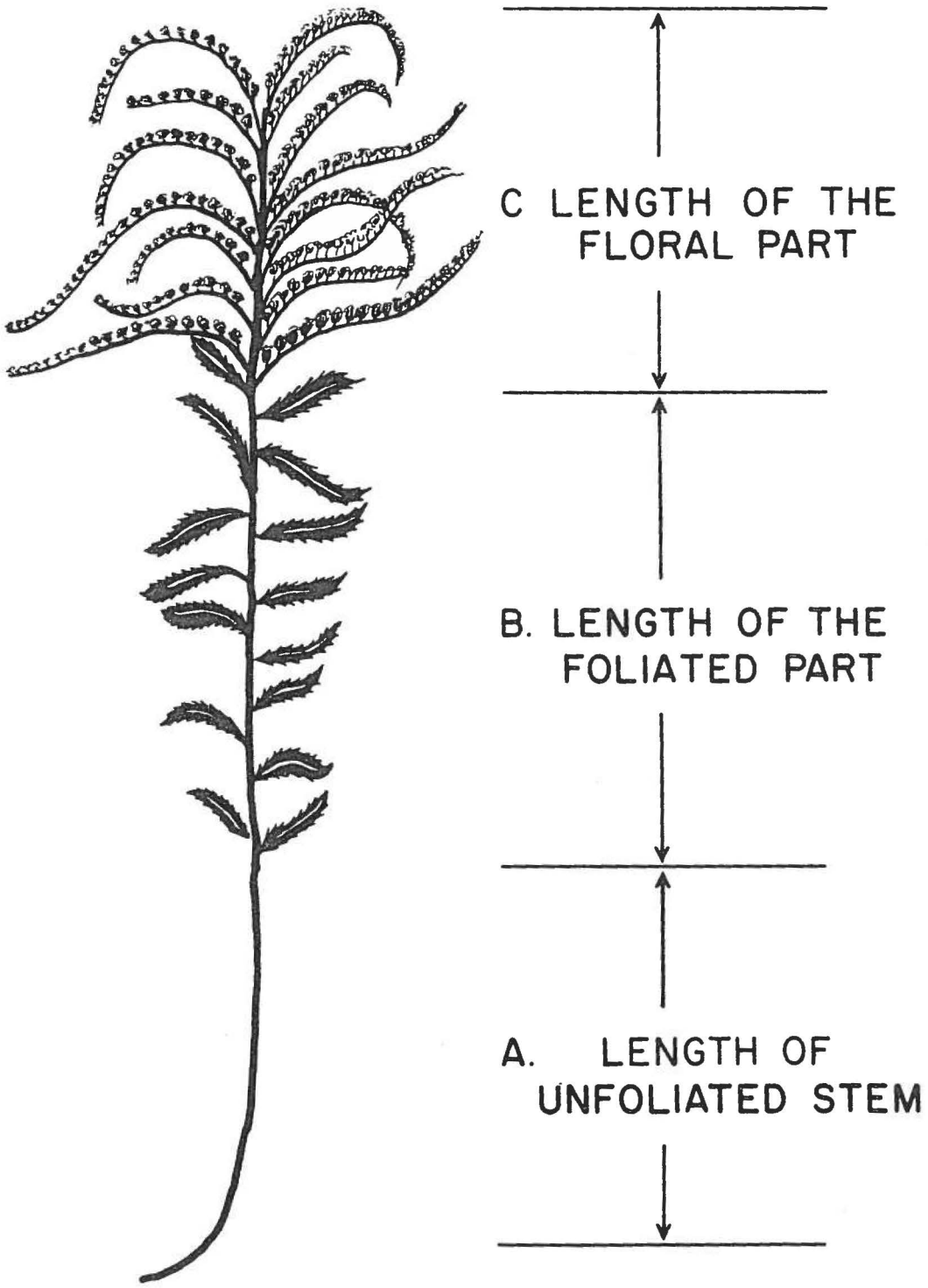

Fig. 1. Drawing of *Solidago* indicating anatomical areas studied.

We also considered the number of galls that could be formed on individual plants and the number of chambers per gall (Table II). It was noted that the trends were towards the formation of a single gall per plant, and a single chamber per gall: 96% of the cases examined had this peculiarity.

Of the 216 galls[2] that were placed in test tubes, 64 yielded insects the following month. These insects were classified as follows: subfamilies Eurytominae, Toryminae and Eulophinae (Hymenoptera: Chalcidoidae) from 39 galls (61%); various species of Diptera (Cecidomyidae) from 17 galls (27%); *Gnorimoschema gallaesolidaginis* Riley (Lepidoptera: Gelechiidae) and *Epiblema* (Eucosma) *scudderiana* Clemens (Lepidoptera: Olethrutidae) from 12 galls (19%); *Apanteles* sp. (Hymenoptera: Braconidae) from 5 galls (8%) and Vespidae from 1 gall (2%). The Chalcidoidae were the most common insects while the Vespidae was the least abundant. Their order by rank of number of individual specimens was: Chalcidoidae 286 (69.9% of the collected insects); Cecidomyidae 95 (23.2%); Braconidae 15 (3.7%); Gelechiidae and Olethrutidae 12 (2.9%), and Vespidae 1 (0.2%) for a total of 409 specimens.

Table II. Rate of gall formation on parasitized *Solidago* plants and the numbers of chambers per gall.

	No. galls per stem				No. chambers per gall					
Plot	1	2	3		1	2	3	4	5	6
1	94	6	0	1*	86	9	3	2	1	0
2	64	1	2		49	11	4	1	1	1
3	45	3	0		31	14	2	1	0	0

* 1 stem with eight small galls

Two main gall shapes were observed and compared with their emerging insects (Table III and IV). The first kind had a spindle form with one or two chambers (common name - goldenrod elliptical gall). Of the 64 galls that showed emergence, 27 had the spindle form and 12 insects (Lepidoptera adults and larvae) emerged from them (56% of these galls failed to show any emergence). The second kind had a cylindrical shape (common name unknown) with many chambers and 17 of 27 galls reared yielded Diptera (38% were assumed to be parasitized). These Diptera were assumed to be the gall producers or inquilines. Usually, when Lepidoptera emerged, Chalcidoidae and Braconidae did not, but when the latter two species were collected (mean=6), no Lepidoptera emerged. Chalcidoidae were also considered as gall producers, parasites of gall producers or inquilines in cylindrical galls. Sometimes, Diptera emerged with the Chalcidoidae and the Braconidae, all probably inhabiting the same gall.

By the *t* test of paired values we examined the relationship between height, diameter and gall location in parasitized and unparasitized plants (Table V). It will be noted that except in plot 3, where the reverse situation occurred, healthy plants tended to be taller than the parasitized ones but the differences were not significant ($P<0.95$). The diameter of parasitized plants were significantly larger (at the 95% level) from those of non-parasitized plants. Furthermore, we found that the heights of both parasitized and unparasitized plants were in direct relation with their diameters (Fig. 2). Bare stalk lengths (part A, see Fig. 1) of healthy plants did not differ significantly (at the 95% level) from those of the attacked plants. The foliated portion of stalks (part B, see Fig. 1) are generally shorter in parasitized than unparasitized plants, except in plot 3. The floral parts (part C, see Fig. 1) showed varying characteristics between attacked and normal plants, depending upon their location in the field. In the parasitized plants of plot 1, the floral parts were significantly longer than the floral heads of the unparasitized plants (95% level), but this relationship did not hold in the other two plots.

[2] Some of the galls were damaged and therefore discarded.

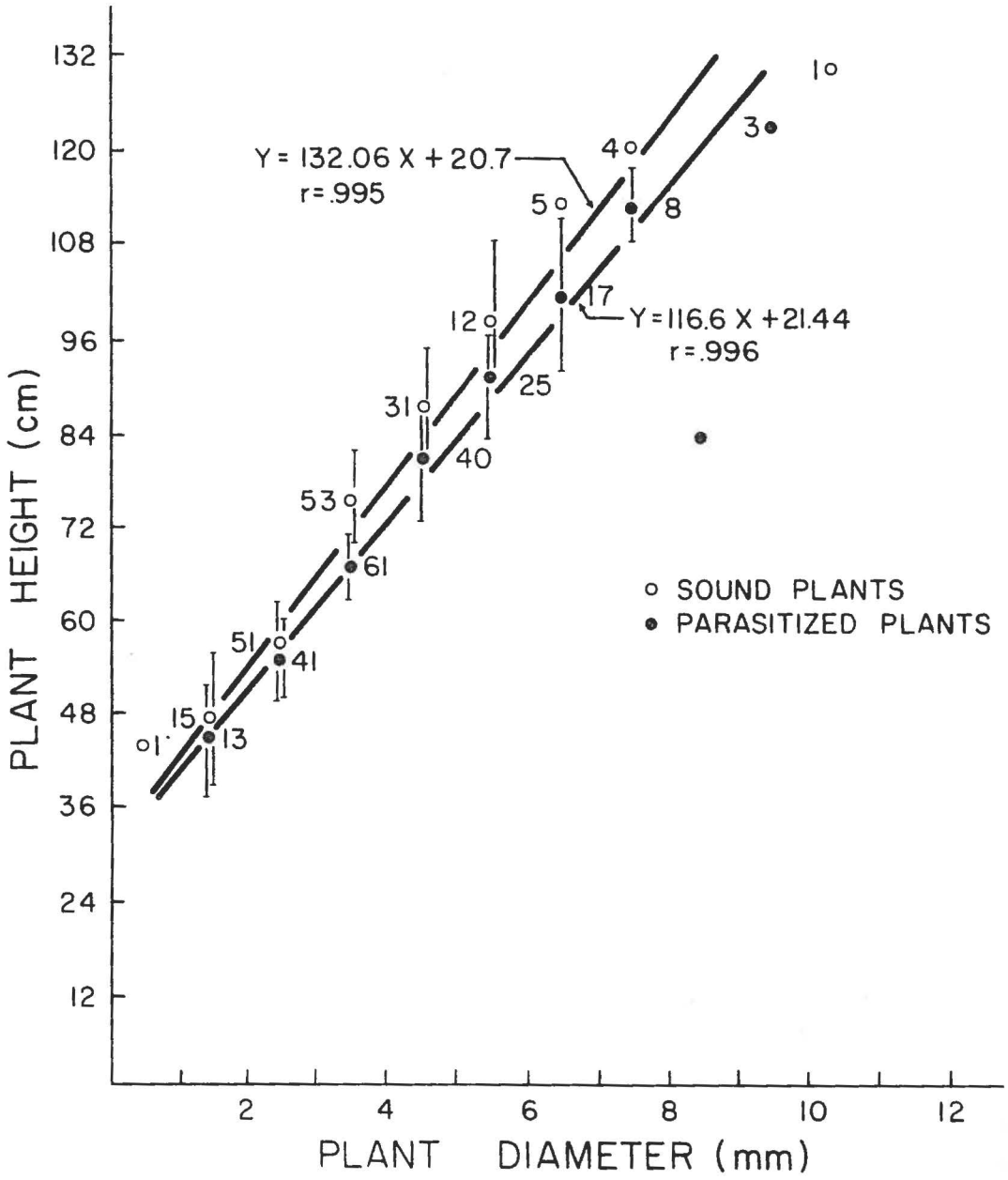

Fig. 2 Relationship between diameter and height of *Solidago* sp. (95% C.I. indicated by vertical bars).

Table III. Relationship between gall shape and yield on Plot 1.

Plant No.	Lepidoptera	Diptera	Chalcididae	Braconidae	Gall Shape *
2			7(2) **		a (2)
11	1 larva				b (1)
12	1 adult				b (1)
17	1 Vespidae				a (2)
22			3(2)		b (1)
23			23(2)		a (1)
30			11(1)		—
35	1 larva				b (1)
40			2(1)		c (2)
43		1	24(1)		—
52			2(1)		c (4)
55			56(3)		a (2)
61			13(1)		—
65			1(1)	6	a (1)
70			8(1)		—
72	1 larva				a (2)
78	1 adult				b (1)
80	1 adult				b (1)
87		2	3 pupa 2 adults (2)		c (6)
88		2	15(1)		c (4)
92			2(2)	1	a (1)
95		3	1(1)		c (5)
96	1 larva				b (1)
101			11(2)		a(1) b (1)

*Galls shape a) spindle gall with some bulges (goldenrod elliptical gall)
b) spindle gall (goldenrod scarred gall)
c) cylindrical gall with many rooms. The number in brackets indicates the number of chambers in the galls.

**For the Chalcids, the number in brackets means the number of species collected for a given gall.

Table IV. Identification of insect material recovered from goldenrod galls

Insect recovered	Type of gall involved*	Probable status of insect
Gnorimoschema gallaesolidoginis Riley (Lepidoptera: Gelechiidae)	a	Causal agent or gall producer
Epiblema (Eucosma) *scudderiana* Clemens (Lepidoptera:Olethrutidae)	b	Causal agent or gall producer
Apanteles sp. prob. *cacoeciae*	a, b	Primary parasite of gall producers
Various species of Hymenoptera, Chalcidoidae, subf. Eurytominae Toryminae Eulophinae	a,b,c	Parasites of gall producers in galls of types a and b. Gall producers, parasites of gall producers or inquilines in galls of type c.
Various species of Diptera, Cecidomyidae	a,b,c	Inquilines in galls of types a and b. Gall producers or inquilines in galls of type c.

* a - spindle gall with some bulges; common name: goldenrod elliptical gall.
b - spindle gall; common name: goldenrod scarred gall.
c - cylindrical gall with many chambers; common name and causal agent unknown.

Table V. Relationship between height, diameter and anatomical areas in parasitized and unparasitized *Solidago* sp. plants

Parameter measured	Plot	Mean measurement (cm) of parasitized plants + 95% C. I.	Mean measurement (cm) of unparasitized plants + 95% C. I.
Height	1	85.35±5.36(93) *	86.20±5.68(68)
	2	57.44±3.40(66)	60.53±4.48(63)
	3	77.62±5.12(51)	74.19±6.42(44)
Diameter	1	0.57±0.04(98)	0.51±0.04(69)
	2	0.36±0.00(67)	0.33±0.02(63)
	3	0.40±0.02(52)	0.35±0.00(44)
Anatomical area A**	1	41.38±2.92(87)	37.67±3.29(47)
	2	27.48±1.94(55)	28.23±2.30(48)
	3	40.39±2.94(46)	40.65±3.28(30)
Anatomical area B**	1	29.51±2.08(83)	34.83±2.32(61)
	2	22.80±1.90(51)	27.48±2.68(43)
	3	28.85±2.48(46)	33.36±3.14(30)
Anatomical area C**	1	20.58±1.96(81)	15.39±1.84(62)
	2	13.93±2.04(46)	13.21±1.98(44)
	3	11.97±2.58(40)	10.87±3.52(29)

* Nos. in parentheses = Number of measurements
** See Fig. 2

Gall size and their height above ground level are recorded in Table VI. In the first plot, the galls appeared (as mentioned earlier) to be much higher than those in the other two plots. There was no relationship between gall height and gall diameter, but there was a significant relationship between plant diameter and gall height above ground level (Fig. 3).

Table VI. Relationship between length, diameter and height above the ground surface of galls found on *Solidago* sp. plants

Parameter measured	Plot	Mean value (cm) + 95% C. I.
Height above ground	1	53.79±6.22(105) *
	2	30.30±4.80(73)
	3	31.00±7.54(54)
Length	1	2.26±0.16(109)
	2	1.92±0.20(74)
	3	1.78±0.22(54)
Diameter	1	0.95±0.04(110)
	2	0.82±0.06(74)
	3	0.90±0.08(54)

* Number in parentheses = Number of measurements

DISCUSSION

In the meadow, we noticed that the insects tend to lay their eggs increasingly lower in the plant stem as they get nearer the forest edge. If we may recall, nearly 50% of the galls were formed in the floral part in plot 1, compared with close to 60% of the galls that were in a low part of the plants in plot 3 near the edge of the forest. The explanation is likely that we are dealing with different species of insects. As Table VII indicates, Lepidoptera, forming spindle or fusiform galls, are most common in the first plot, while Diptera or other insects forming a cylindrical gall are mostly encountered in the second and third plots. The reasons for this gradient of distribution are as yet unclear.

Table VII. Relationship between gall shape and the location of their formation

Gall shape	Plot	No. galls
a*	1	7
	2	3
	3	1
b*	1	8
	2	4
	3	4
c**	1	5
	2	11
	3	10

* Spindle form galls

** Cylindrical form galls

Data in boxes indicate main population trend.

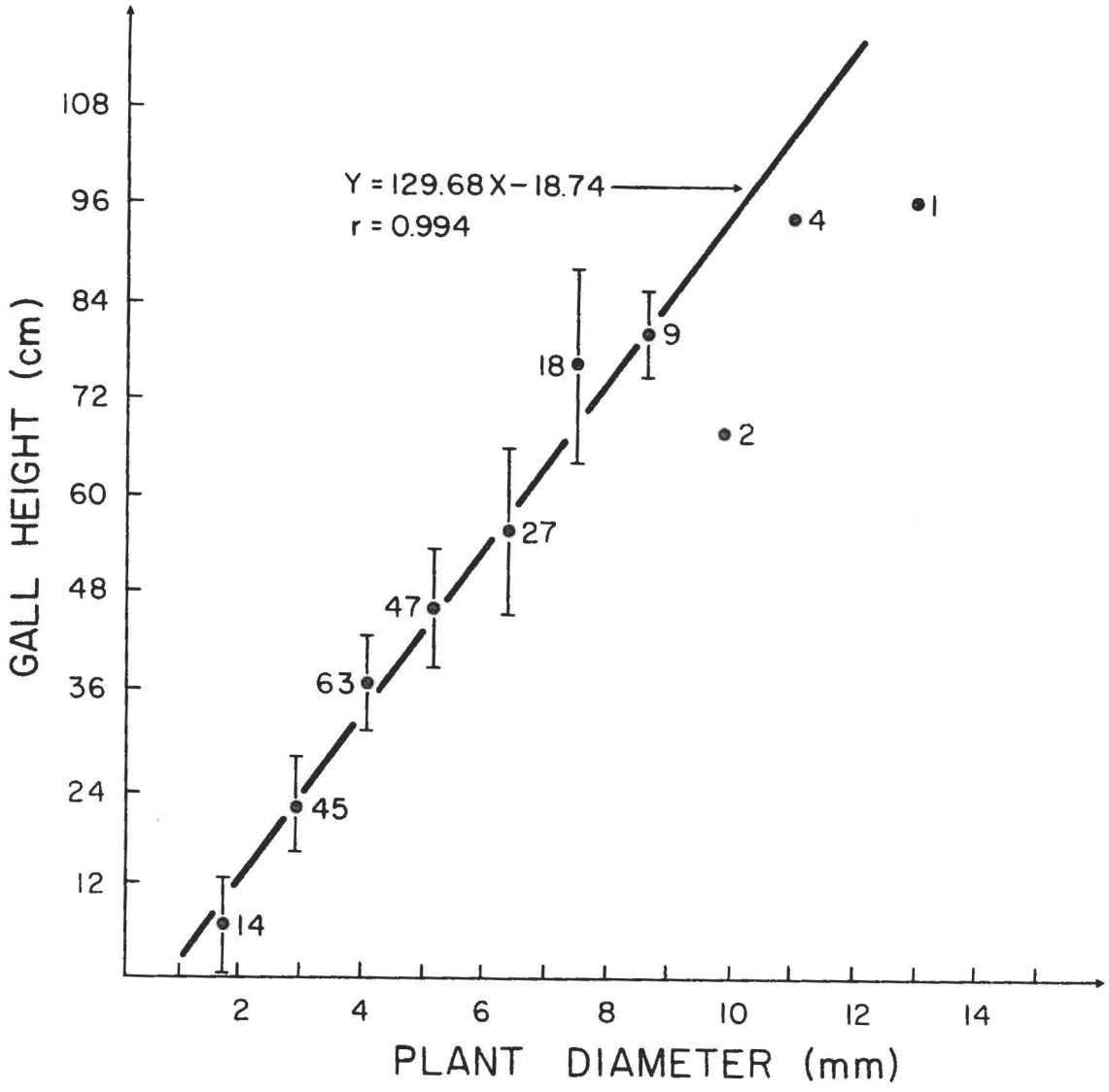

Fig. 3 Relationship between diameter of *Solidago* sp. and the height of galls above ground surface (95% C.I. indicated by vertical bars).

We have also found that 96% of the galls were formed of only one chamber and that they were almost exclusively solitary on the host. It appears that once a plant is attacked by a gall producer, the other insects tend to avoid laying their eggs in it. In the cases of plants that had more than one gall, the choice of the plant, if that choice existed, could depend on the area offered by a plant in the community. The diameters of the parasitized plants were statistically larger (at the 95% level) than those of the healthy ones. Either the insects choose plants with a wide enough diameter to permit their eggs to survive to maturity, or the developing gall interfered with the normal flow of sap, transporting growth hormones and nutrients, with the result that, although height growth was not affected, diameter growth was promoted by gall development. It should also be noted that some of the data given herein show that with increasing stem diameters, galls are located increasingly higher on the stems (Fig. 3) of individual plants, and that a tendency towards the occurrence of galls low on the stems in plots 2 and 3 (Tables I and V) is related to the small diameter of plants in these plots. This may indicate that at least some of the insects involved here (apparently not the Lepidoptera) are influenced by plant diameter at the time of egg deposition, so that the locus of egg deposition is a response to plant diameter.

The two parts of the plant, A and B (see Fig. 1) either did not vary significantly between parasitized and healthy plants, or else, B was larger in healthy plants than in parasitized ones. This may or may not have a bearing in the host-parasite relationships involved here. However, it should be noted that the floral parts in the first plot were significantly larger (at the 95% level) among the parasitized plants. We observed that *Solidago graminifolia* sp. was the most frequent plant in the plot and since the species has a large floral head, it could give the insects a larger target to attack. Added to this may be mentioned, in this particular plot, a preponderance of Lepidopterous galls located within the floral heads. It may be that the gall-forming Lepidoptera on *Solidago* sp. are particularly attracted by the flower heads, with the result that plants with large floral heads serve as beacons which harbor larger populations located mainly in the flower-bearing part of the plants.

According to Milne (1940), death from causes inherent to the species was the most common one (31 specimens 250 galls) while external influences accounted for the death of only 8 individuals. Although we did not specifically study intrinsic mortality factors, it is interesting that only 64 galls of 216 yielded living insects. The 152 remaining galls were either parasitized, and the parasites did not emerge, or the gall producer itself died from intrinsic factors. Among the 409 insects collected from the 64 galls, the 15 Braconidae and 114 Chalcidoidae were assumed to be parasites. Diptera collected from spindle shaped galls were thought to be inquilines. Based on the description by Hughes (1934), the 172 other Chalcidoidae could be mostly parasites of the cylindrical gall producers. At least 3 families of Hymenoptera are known to be involved in the parasitism of gall producers: Chalcidoidae (Hughes 1934), Eurytomidae (Milne 1940) and Braconidae (Judd 1953).

In spite of the works done by Fyles (1894), Harrington (1895), Synder (1898) and Ping (1915), all the remaining Diptera (57 that were not classified as inquilines of spindle shaped galls) are thought to be either gall producers or inquilines in cylindrical galls. As recorded, Diptera and Chalcidoidae were the only insects emerging from these latter galls and the producers are either one or the other of these.

ACKNOWLEDGEMENTS

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A REVISED LIST OF THE APHIDS OF MANITOBA

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ABSTRACT

The preliminary list of the aphids of Manitoba is revised with the inclusion of additional species and changes in generic and specific names to make them conform with current concepts in aphid taxonomy. The list contains the names of 235 species.

INTRODUCTION

Since publication of the preliminary list of the aphids of Manitoba (Robinson and Bradley 1965), various additions to and deletions from the list have become necessary. Some of these have come about through changes in the synonymy; others have resulted from species previously unrecorded in Manitoba.

This list deals mainly with the southern part of Manitoba. It contains the names and host plants of the 235 species of aphids now known to occur in Manitoba.

Acyrthosiphon caraganae (Cholodkovsky). *Caragana arborescens.*
Acyrthosiphon pisum (Harris). *Lathyrus odoratus, Medicago sativa, Melilotus alba, Melilotus officinalis, Pisum sativum.*
Acyrthosiphon pseudodirhodum (Patch). *Spiraea* sp.
Acyrthosiphon scariolae (Nevsky). *Lactuca scariola.*
Amphorophora agathonica Hottes. *Rubus* spp.
Amphorophora laingi Mason. *Matteuccia struthiopteris.*
Anoecia graminis Gillette and Palmer. *Hordeum jubatum* (roots).
Anoecia oenotherae Wilson. *Oenothera biennis* (roots).
Anoecia querci (Fitch). Suction trap.
Anoecia setariae Gillette and Palmer. *Equisetum laevigatum* (roots).
Aphis armoraciae Cowen. *Achillea millefolium, Artemisia frigida, Artemisia* sp., *Taraxacum officinale* (all on roots).
Aphis asclepiadis Fitch. *Asclepias* sp.
Aphis ceanothi Clarke. *Ceanothus ovatus.*
Aphis corniella Hille Ris Lambers. *Cornus stolonifera.*
Aphis craccae Linnaeus. *Vicia cracca.*
Aphis fabae Scopoli. *Arctium minus, Aster* sp., *Cirsium arvense, Dahlia* sp., *Gladiolus* sp., *Lilium* sp., *Philadelphus* sp., Rhubarb, *Tropaeolum majus, Viburnum* spp., *Zinnia* sp.
Aphis farinosa Gmelin. *Salix* spp.
Aphis gossypii Glover. *Cucumis* sp.
Aphis helianthi Monell. *Cornus stolonifera, Helianthus* sp.
Aphis heraclella Davis. *Cicuta maculata, Heracleum Lanatum, Sium* sp.
Aphis knowltoni Hottes and Frison. *Taraxacum officinale* (roots).
Aphis maculatae Oestlund. *Populus* spp., *Populus tremuloides.*
Aphis monardae Oestlund. *Monarda fistulosa.*

Aphis nasturtii Kaltenbach. *Alisma* sp., *Polygonum* sp., *Rhamnus cathartica, Rumex* sp., *Sagittaria* sp.
Aphis neogillettei Palmer. *Cornus stolonifera.*
Aphis neomexicana (Cockerell). *Ribes* sp.
Aphis oenotherae Oestlund. *Epilobium angustifolium, Oenothera biennis.*
Aphis oestlundi Gillette. *Oenothera* spp.
Aphis pomi DeGeer. *Malus* spp. *Sorbus* sp.
Aphis ramona Swain. *Agastache foeniculum.*
Aphis ribiensis Gillette and Palmer. *Ribes* sp.
Aphis rubifolii Thomas. *Rubus* spp.
Aphis spiraecola Patch. *Cosmos* sp., *Cotoneaster acutifolia, Spiraea* sp., *Zinnia* sp.
Aphis spiraephila Patch. *Spiraea* spp.
Aphis thaspii Oestlund. *Thaspium barbinode.*
Aphis varians Patch. *Ribes alpinum.*
Aphis viburniphila Patch. *Viburnum* spp.
Aphthargelia symphoricarpi (Thomas). *Symphoricarpos albus.*
Asiphonaphis pruni Wilson and Davis. *Prunus virginiana.*
Asiphum rosettei Maxson, *Populus tremuloides.*
Asiphum sacculi Gillette. *Populus tremuloides.*
Aspidaphis adjuvans (Walker). *Polygonum aviculare.*
Atarsos grindeliae Gillette. *Grindelia squarrosa.*
Aulacorthum solani (Kaltenbach). *Pelargonium* sp. (house plant). *Salvia* sp.

Betulaphis quadrituberculata (Kaltenbach). *Betula papyrifera.*
Brachycaudus helichrysi (Kaltenbach). *Chrysanthemum, Gloxinia, Gynura, Matricaria* (house plants).
Brachycaudus rociadae (Cockerell). *Delphinium* sp.
Brachycolus tritici Gillette. (In yellow pan trap).
Brevicoryne brassicae (Linnaeus). *Brassica* spp. (Cabbage, cauliflower, turnip).

Calaphis betulaecolens (Fitch). *Betula papyrifera.*
Calaphis granovskyi-viridipallida grp. *Betula papyrifera.*
Calaphis manitobensis Richards. *Betula pumila.*
Callipterinella calliptera (Hartig). *Betula pendula laciniata.*
Capitophorus elaeagni (Del Guercio). *Cirsium arvense, Elaeagnus commutata. Shepherdia argentea.*
Capitophorus hippophaes (Walker). *Elaeagnus commutata, Polygonum* sp., *Shepherdia argentea.*
Capitophorus xanthii (Oestlund). *Xanthium strumarium.*
Cavariella aegopodii (Scopoli). *Anethum graveolens, Apium graveolens, Salix* spp., *Sium suave.*
Cavariella essigi (Gillette and Bragg). *Salix* sp.
Cepegillettea betulifoliae Granovsky. *Betula glandulosa.*
Chaetosiphon fragaefolii (Cockerell). *Rosa* spp.
Chaetosiphon scalaris Richards. *Potentilla* sp.
Chaitophorus nigrae (Oestlund). *Salix* spp.
Chaitophorus nudus Richards. *Populus tremuloides, P. balsamifera.*
Chaitophorus populialbae (Boyer de Fonscolombe). *Populus alba nivea.*
Chaitophorus populicola (Thomas). *Populus* spp., *Populus tremuloides.*
Chaitophorus populifolii (Essig). *Populus* spp.
Chaitophorus stevensis Sanborn. *Populus* spp.
Chaitophorus viminalis Monell. *Salix* spp.
Cinara abieticola (Cholodkovsky). *Abies balsamea.*
Cinara banksiana Pepper and Tissot. *Pinus banksiana.*
Cinara bogdanowi (Mordvilko). *Picea glauca.*
Cinara braggii (Gillette). *Picea glauca.*
Cinara canatra Hottes and Bradley. *Pinus banksiana.*
Cinara coloradensis (Gillette). *Picea glauca; P. mariana.*

Cinara cronartii Tissot and Pepper. *Pinus banksiana.*
Cinara curvipes (Patch). *Abies balsamea.*
Cinara fornacula Hottes. *Picea glauca; P. mariana.*
Cinara gracilis (Wilson). *Pinus banksiana.*
Cinara harmonia Hottes. *Pinus resinosa.*
Cinara hottesi (Gillette and Palmer). *Picea glauca; P. mariana.*
Cinara juniperi (DeGeer). *Juniperus communis.*
Cinara laricifex (Fitch). *Larix laricina.*
Cinara manitobensis Bradley. *Juniperus horizontalis.*
Cinara obscura Bradley. *Picea glauca.*
Cinara ontarioensis Bradley. *Pinus banksiana.*
Cinara palmerae (Gillette). *Picea glauca.*
Cinara pergandei (Wilson). *Pinus banksiana.*
Cinara petersoni Bradley. *Juniperus horizontalis.*
Cinara pinea (Mordvilko). *Pinus sylvestris* L.
Cinara piniradicis Bradley. *Pinus banksiana.*
Cinara pinivora (Wilson). *Pinus banksiana.*
Cinara rara Bradley. *Picea mariana.*
Cinara saskensis Bradley. *Picea glauca.*
Cinara spiculosa Bradley. *Larix laricina.*
Cinara strobi (Fitch). *Pinus strobus.*
Cinara subterranea Bradley. *Larix laricina.*
Colopha ulmicola (Fitch). *Ulmus americana.*
Coloradoa absinthii (Lichtenstein). *Artemisia absinthium.*
Coloradoa artemisiae (Del Guercio). *Artemisia absinthium.*
Cryptaphis bromi Robinson. *Bromus inermis.*
Cryptomyzus galeopsidis (Kaltenbach). In flight.
Cryptomyzus ribis (Linnaeus). *Ribes* spp.

Dactynotus ambrosiae (Thomas). *Ambrosia trifida. Solidago* spp.
Dactynotus caligatus Richards. *Solidago* sp.
Dactynotus cirsii (Linnaeus). *Cirsium arvense.*
Dactynotus erigeronensis (Thomas). *Erigeron canadensis.*
Dactynotus hieracicola Hille Ris Lambers. *Hieracium umbellatum.*
Dactynotus nigrotuberculatus Olive. *Solidago* spp.
Dactynotus paucosensoriatus Hille Ris Lambers. *Aster* sp.
Dactynotus pseudambrosiae Olive. *Lactuca scariola.*
Dactynotus richardsi Robinson. *Grindelia squarrosa.*
Dactynotus rudbeckiae (Fitch). *Rudbeckia laciniata.*
Dactynotus russellae Hille Ris Lambers. *Anaphalis margaritacea.*
Dactynotus taraxaci (Kaltenbach). *Taraxacum officinale.*
Drepanaphis acerifoliae (Thomas). *Acer negundo.*
Drepanaphis spicatum Smith. *Acer spicatum.*
Dysaphis tulipae (Boyer de Fonscolombe). Iris and tulip in greenhouse.

Epameibaphis frigidae (Oestlund). *Artemisia frigida.*
Eriosoma americanum (Riley). *Ulmus americana.*
Eriosoma crataegi (Oestlund). *Crataegus* sp.
Eriosoma lanigerum (Hausmann). *Ulmus americana.*
Euceraphis deducta Baker. *Betula papyrifera.*

Forda formicaria Heyden. *Agropyron repens* and *Poa* spp. (on roots).
Forda marginata Koch. *Agropyron repens* and *Poa* spp. (on roots).

Gypsoaphis oestlundi (Hottes). *Lonicera* spp.

Hamamelistes spinosus Shimer. *Betula papyrifera.*
Hayhurstia atriplicis (Linnaeus). *Chenopodium album.*
Holcaphis frequens (Walker). *Agropyron repens.*
Hoplochaitophorus quercicola (Monell). *Quercus macrocarpa.*
Hyadaphis foeniculi (Passerini). *Sium suave.*
Hyalopterus pruni (Geoffroy). *Phragmites communis. Prunus nigra.*
Hyperomyzus lactucae (Linnaeus). *Ribes* spp., *Sonchus oleraceus.*
Hyperomyzus nabali (Oestlund). *Prenanthes alba.*
Hyperomyzus pallidus Hille Ris Lambers. *Ribes* spp., *Sonchus oleraceus.*
Hysteroneura setariae (Thomas). *Prunus nigra, Prunus pumila, Triticum aestivum.*

Kakimia cynosbati (Oestlund). *Ribes alpinum, Ribes* sp.
Kakimia essigi (Gillette and Palmer). *Aquilegia* sp.
Kakimia potentillae (Williams). *Potentilla* sp.
Kakimia ribiella (Davis). *Ribes aureum.*
Kakimia robinsoni Richards. *Delphinium* sp.

Lachnus montanus (Wilson). *Quercus macrocarpa.*
Lipaphis pseudobrassicae (Davis). *Brassica* sp., *Thlaspi arvense.*
Longistigma caryae (Harris). *Tilia americana.*

Macrosiphoniella absinthii (Linnaeus). *Artemisia absinthium.*
Macrosiphoniella frigidicola (Gillette and Palmer). *Artemisia abrotanum, Artemisia biennis.*
Macrosiphoniella ludovicianae (Oestlund). *Artemisia ludoviciana.*
Macrosiphoniella pennsylvanica (Pepper). *Achillea millefolium.*
Macrosiphoniella tanacetaria (Kaltenbach). *Tanacetum vulgare.*
Macrosiphum avenae (Fabricus). *Aegilops* sp., *Agropyron cristatum, Agropyron intermedium, Agropyron repens, Agropyron trachycaulum, Agropyron trichophorum, Agrostis scabra, Agrostis stolonifera, Alopecurus pratensis, Andropogon gerardi, Avena fatua, Avena sativa, Bromus inermis, Elymus* sp., *Elymus junceus, Elymus striatus, Hordeum vulgare, Panicum miliaceum, Phleum pratense, Secale cereale, Setaria* sp., *Setaria italica, Setaria viridis, Sorghum sudanense, Triticum aestivum, Typha latifolia.*
Macrosiphum californicum (Clarke). *Salix* sp.
Macrosiphum coryli Davis. *Corylus* sp.
Macrosiphum euphorbiae (Thomas). *Althaea rosea, Amaranthus retroflexus, Brassica* sp. (rapeseed), *Cucurbita* sp. (pumpkin), *Fragaria* sp., *Gladiolus* sp., *Iris* sp., *Iva xanthifolia, Lactuca sativa, Lactuca scariola, Linum* sp., (flax), *Papaver* sp., *Paeonia* sp., (peony), *Phaseolus* sp. (garden bean), *Polygonum aviculare, Portulaca oleracea, Rosa* spp., *Solanum tuberosum, Spiraea* sp., *Tulipa* sp., *Verbena* sp., *Zinnia* sp.
Macrosiphum geranii Oestlund. *Geranium* sp.
Macrosiphum hamiltoni Robinson. *Humulus lupulus.*
Macrosiphum kickapoo Hottes and Frison. *Polygonatum canaliculatum.*
Macrosiphum pallidum (Oestlund). *Agrimonia triata, Aster* sp., *Chenopodium album, Cicuta maculata, Gladiolus* sp., *Lysimachia* sp., *Oenothera* sp., *Ranunculus* sp.
Macrosiphum ptericolens Patch. *Pteridium aquilinum.*
Macrosiphum rosae (Linnaeus). *Rosa* spp.
Macrosiphum valerianae (Clarke). *Epilobium* spp.
Maculolachnus sijpkensi Hille Ris Lambers. *Rosa* spp.
Masonaphis (Ericobium) alni Mason. *Alnus* sp.
Masonaphis (Ericobium) grindeliae s. sp. *palmerae* MacGillivray, *Grindelia squarrosa.*
Masonaphis (Eriocobium) richardsi MacGillivray. *Anaphalis margaritacea.*
Masonaphis (Oestlundia) rubicola (Oestlund). *Rubus* spp.
Masonaphis (Eriocobium) spiraecola (Patch). *Spiraea* sp.
Masonaphis (Eriocobium) wahnaga (Hottes). *Convallaria majalis.*

Metopolophium dirhodum (Walker). *Avena sativa, Festuca pratensis, Hordeum vulgare, Lolium perenne, Phalaris arundinacea, Rosa* spp., *Triticum aestivum.*

Microlophium carnosum (Buckton). *Urtica dioica.*

Microsiphoniella artemisiae (Gillette). *Artemisia ludoviciana.*

Mindarus abietinus Koch. *Abies balsamea, Picea glauca.*

Misturaphis shiloensis Robinson. *Artemisia caudata.*

Mordvilkoja vagabunda (Walsh). *Populus* spp.

Myzocallis (Neomyzocallis) discolor (Monell). *Quercus macrocarpa.*

Myzocallis (Neomyzocallis) punctata (Monell). *Quercus macrocarpa.*

Myzus cerasi (Fabricius). Prunus pennsylvanica, Prunus virginiana.

Myzus ornatus Laing. House plant.

Myzus persicae (Sulzer). *Amaranthus retroflexus, Antirrhinum* sp., *Brassica* spp., *Calceolaria* sp., *Capsella bursapastoris, Chrysanthemum* sp., *Crocus* sp., *Dentura* sp., *Lilium* sp., *Oleander* sp., *Petroselinum hortense, Saintpaulia* sp., *Thlaspi arvense,* (mostly in greenhouses or on house plants.)

Nearctaphis bakeri (Cowen). *Crataegus* spp.

Nearctaphis crataegifoliae (Fitch). *Crataegus* sp.

Nearctaphis (Amelancheria) sensoriata Gillette and Bragg. *Amelanchier* sp.

Neoceruraphis viburnicola (Gillette). *Viburnum* spp., *V. lentago, V. opulus.*

Neomyzus circumflexus (Buckton). Resting on leaves of *Quercus* sp.

Neoprociphilus aceris Monell. *Smilax herbacea, Acer negundo.*

Oestlundiella flava (Davidson). *Alnus rugosa.*

Paraprociphilus tessellatus (Fitch). *Alnus* sp.

Paraschizaphis scirpicola Hille Ris Lambers. *Scirpus* sp.

Pemphigus balsamiferae Williams. Roots of *Beta vulgaris* (sugar beet), *Chenopodium album, Lactuca sativa.*

Pemphigus junctisensoriatus Maxson. *Populus* sp.

Pemphigus monophagus Maxson. *Populus balsamifera.*

Pemphigus nortonii Maxson. *Populus* sp.

Pemphigus populicaulis Fitch. *Populus* sp.

Pemphigus populitransversus Riley. *Populus* sp.

Periphyllus negundinis (Thomas). *Acer negundo.*

Phorodon humuli (Schrank). *Humulus lupulus.*

Pleotrichophorus gnaphalodes (Palmer). *Artemisia ludoviciana.*

Pleotrichophorus pseudoglandulosus (Palmer). *Artemisia frigida.*

Prociphilus americanus (Walker). *Pinus sylvestris.*

Prociphilus fraxinifolii (Riley). *Fraxinus* sp.

Pseudocercidis rosae Richards. *Rosa* spp.

Pseudopterocomma canadensis Richards. *Populus tremuloides.*

Pterocallis alnifoliae (Fitch). *Alnus rugosa.*

Pterocomma bicolor Oestlund. *Salix* spp.

Pterocomma populifoliae (Fitch). *Populus balsamifera.*

Pterocomma salicis (Linnaeus). *Salix* sp.

Pterocomma smithiae (Monell). *Salix* spp., *Populus tremuloides.*

Rhodobium porosum (Sanborn). *Rosa* sp.

Rhopalomyzus lonicerae (Siebold). *Lonicera* spp.

Rhopalosiphum cerasifoliae (Fitch). *Prunus virginiana.*

Rhopalosiphum enigmae Hottes and Frison. *Typha* sp.

Rhopalosiphum fitchii (Sanborn). *Cotoneaster acutifolia, Crataegus* spp., *Malus* spp., *Sorbus americana.* Cultured in greenhouse on *Triticum sativum* (wheat), *Avena sativa* (oats), and *Hordeum vulgare* (barley).

Rhopalosiphum maidis (Fitch). *Agrostis stolonifera, Alopecurus pratensis, Avena sativa, Bromus inermis, Echinochloa crusgalli, Elymus striatus, Festuca pratensis, Hordeum jubatum, Hordeum vulgare, Phalaris arundinacea, Phalaris canariensis, Phleum pratense, Poa pratensis, Setaria* sp., *Setaria italica, Setaria viridis, Zea mays.*

Rhopalosiphum nigrum Richards. *Alisma* sp., *Zizania aquatica.*
Rhopalosiphum nymphaeae (Linnaeus). *Alisma* sp., *Ceratophyllum* sp., *Prunus virginiana.*
Rhopalosiphum padi (Linnaeus). *Aegilops* sp., *Agropyron cristatum, Agropyron repens, Agrostis stolonifera, Alopecurus aequalis, Alopecurus pratensis, Avena sativa, Bromus inermis, Echinochloa crusgalli, Elymus striatus, Festuca pratensis, Hordeum jubatum, Hordeum vulgare, Phalaris arundinacea, Phleum pratense, Poa pratensis, Prunus padi, Prunus virginiana, Secale cereale, Setaria italica, Setaria viridis, Triticum aestivum, Zea mays.*
Rhopalosiphum rufulum Richards. *Crataegus* sp.
Schizaphis graminum (Rondani). *Aegilops* sp., *Agropyron intermedium, Agropyron repens, Agropyron trachycaulum, Agropyron trichophorum, Agrostis stolonifera, Alopecurus pratensis, Avena fatua, Avena sativa, Bromus inermis, Dactylis glomerata, Danthonia* sp., *Echinochloa crusgalli, Elymus* sp., *Elymus junceus, Festuca pratensis, Hordeum jubatum, Hordeum vulgare, Lolium perenne, Panicum miliaceum, Phalaris arundinacea, Phleum pratense, Poa pratensis, Secale cereale, Setaria viridis, Triticum aestivum.*
Schizolachnus piniradiatae (Davidson). *Pinus resinosa.*
Sipha kurdjumovi Mordvilko. *Aegilops* sp., *Agropyron cristatum, Agropyron repens, Agropyron trachycaulum, Agropyron trichophorum, Agrostis stolonifera, Bromus inermis, Hordeum jubatum, Hordeum vulgare, Phleum pratense, Setaria viridis, Triticum aestivum.*
Sitomyzus (Glabromyzus) rhois (Monell). *Rhus glabra.*
Stegophylla quercicola (Monell). *Quercus macrocarpa.*
Symydobius americanus (Baker). *Betula papyrifera.*

Tamalia coweni (Cockerell). *Arctostaphylos uva-ursi.*
Tetraneura ulmi (Linnaeus). *Poa pratensis* (roots).
Thecabius affinis (Kaltenbach). *Populus balsamifera.*
Thecabius populiconduplifolius Cowen. *Populus balsamifera.*
Thecabius populimonilis (Riley). *Populus balsamifera.*
Therioaphis riehmi (Börner). *Melilotus alba, Melilotus officinalis.*
Tinocallis (Melanocallis) ulmifolii (Monell). *Ulmus americana.*
Trama rara Mord. *Taraxacum officinale* (roots).
Tuberolachnus salignus (Gmelin). *Salix* spp.

Utamphorophora crataegi (Monell). *Crataegus* sp.
Utamphorophora humboldti (Essig). *Physocarpus opulifolius.*

Wahlgreniella vaccinii (Theobald). *Vaccinium* sp.

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LOCOMOTION IN TWO SPECIES OF ACARINA [1]

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ABSTRACT

The walking patterns of 2 species of Acarina were studied using cinematography and a stop-motion projector. Locomotion that utilizes 2 and 3 pairs of legs was studied in larval and adult *Hypoaspis aculeifer* (Canestrini). Walking with 4 pairs of legs was examined in *Tyrophagus putrescentiae* (Schrank). Larvae of *H. aculeifer* moved only one leg at a time, the third leg before the second leg and both legs on one side before the legs on the opposite side. The legs of adults of *H. aculeifer* moved as alternating triangles formed by the second and fourth legs on one side and the third leg on the opposite side. The legs of adult *T. putrescentiae*, moved as alternating quadrangles formed by the first and third legs on one side and the second and fourth legs on the other side. Legs on one side of the body moved in metachronal sequence i.e . movement of each leg was followed by movement of the leg immediately in front of it, movement of the first leg being followed by movement of the last leg.

INTRODUCTION

The complex patterns of animal locomotion have interested biologists for many years (Packard 1909). Often, these studies have been related to the function of the nervous system (Ponz and Estartus 1951, Wigglesworth 1953, Hughes 1957).

An hypothesis has been proposed to account for the sequences of events that occur in insects during walking (Wilson 1966). Large spiders, however, have a different method of locomotion because a greater number of legs are used (Wilson 1967).

Though the walking patterns of many different orders of animals have been studied, the Acarina, possibly because of their minuteness, have been neglected. The species of mites used in this study were chosen because of their slow gait. *Tyrophagus putrescentiae* (Schrank), one of the Acaridae, walks on all four pairs of legs. *Hypoaspis aculeifer* (Canestrini), one of the Mesostigmata, in contrast, walks on the last three pairs of legs and uses the first pair as tactile organs in the manner of antennae. Larvae of mites have only three pairs of legs; *T. putrescentiae* uses all legs for locomotion, whereas *H. aculeifer* uses the first pair of legs in the manner of antennae and only the last two pairs of legs for walking. In this paper three methods of walking among the Acari, based on the number of pairs of legs used for locomotion, have been compared without artificial reduction of the number of legs.

MATERIALS AND METHODS

The mites were photographed on Kodachrome II (Type A) film with an 8 mm Sekonic cine camera at 32 frames per second. With the zoom lens system and the diaphragm for automatic light control removed, the camera was mounted on a binocular dissection microscope [2] and photographs were taken at magnifications of either 25X or 50X. The microscope was focussed before the camera was mounted over it and no further adjustments

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[2] Manufactured by Wild Optical Co., Heerbrugg, Switzerland.

were required. The mites were viewed through the reflex viewing system of the camera to ensure they were at the centre of the field and were illuminated by light from a 15 W lamp focussed onto a 1 cm^{sq} area of the observation chamber. The chambers were made from "hanging drop" microscope slides and cover slips.

RESULTS AND DISCUSSION

The larvae of *H. aculeifer* do not feed and therefore, do not need to move either rapidly or efficiently. We have observed in the laboratory that larvae of Mesostigmata such as *H. aculeifer, Haemogamasus pontiger* Berlese, *Androlaelaps casalis* (Berlese) and *Blattisocius keegani* (Fox) seek a protected place under debris or in a cell corner as soon as they hatch. Once the hatchling has found a place where it is undisturbed it will stay there until it molts to the protonymph stage. This state of rest can be considered as the simplest form of behaviour of the larval mite. When the larvae of *H. aculeifer* are disturbed they exhibit an ungainly method of walking in which the cycle of motion begins with a forward stroke of the third leg on one side followed by a forward stroke of the second leg on the same side. The same sequence is then followed on the other side and one complete cycle would be, for example: third left, second left, third right, second right (Figure 1). Usually there is a brief pause between the movement of one leg and the next so that the larva rests on four legs between steps and on three legs during a step. This is probably the simplest pattern of appendage movement. In this type of locomotion the mite gains stability but sacrifices speed of movement. Stability is probably more important than speed to a mite in its normal habitat composed of particles of uneven sizes. A similar sequence of events occurs when *Mantis sp.* moves at a slow pace (Roeder 1953).

In general, the sequence of movement of legs on one side of the larva is similar to that observed in other animals; forward movement of appendages is started with the rear leg and is followed by the neighbouring leg in front, and so on, until the first ambulatory leg on the same side has made a forward stroke. This sequence of movements has been called a metachronal sequence (Wilson 1967) and represents the passage of a nerve impulse.

The first pair of legs of adult *H. aculeifer* serve as antennae during locomotion and the method of walking conforms to the pattern described for insects by Packard (1909). The mite rests while walking on a supporting triangle formed by the second and fourth leg on one side and the third on the other, while it carries forward the other three legs. Of the supporting triangle, the second leg acts as a tractor, the third serves for support and the fourth acts as a propulsor. During walking, the movements of the appendages on one side of a segment alternate with those of the other side, as has been observed for *Nereis diversicolor* (Gray 1939).

A frame-by-frame examination of the film showed that the three legs forming the triangle were not lifted simultaneously, but in the following order: the second, the opposite third leg and the fourth leg on the initial side (Figure 2). There is a brief moment, however, when all three legs of the triangle being carried forward are not in contact with the substrate. There are also moments during slow walking and turns when the mite rests on more than three legs at one time. When the legs of one side are considered, activity occurs in a metachronal sequence; as soon as the fourth leg finishes its stroke forward, the third leg is carried forward, and this is followed, in turn, by a forward movement of the second leg.

Adults of *T. putrescentiae* use all four pairs of legs for locomotion. The mite is supported during walking on a quadrangle formed by the first and third legs on one side and the second and fourth on the other, while it moves the other four legs forward. The first leg acts as a tractor while the fourth leg acts as a propulsor. The second and third legs probably act mainly as supporters during most of the cycle. In a quadrangle, the first leg moves forward slightly before the third leg on the same side, and the second leg on the opposite side moves before the fourth leg. When the legs of only one side were studied it was seen that activity proceeded from the rear leg to the first in a metachronal sequence. The sequence of movement was: the fourth, third, second and first leg. The metachronal sequences follow each other closely and when one metachronal sequence reaches the second leg, the following sequence starts on the rear leg. Similarly, when a sequence reaches the first leg, the next

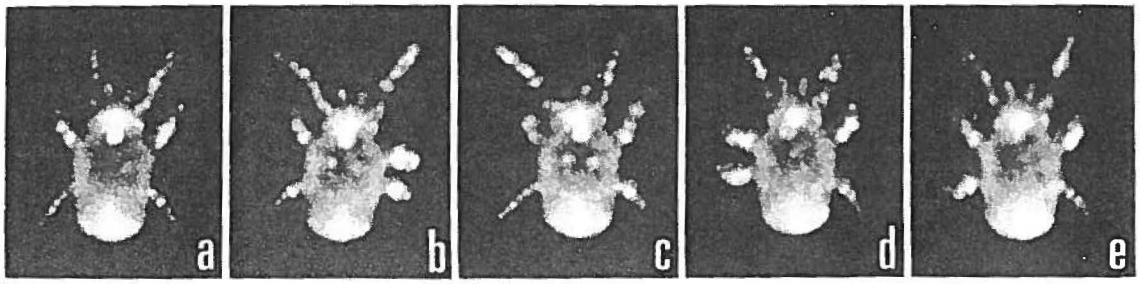

Figure 1. Larva of *H. aculeifer*. A, all legs extended. B, right third leg moved forward. C, right second leg moved forward. D, left third leg moved forward. E, left second leg moved forward and all legs are once again extended as in A.

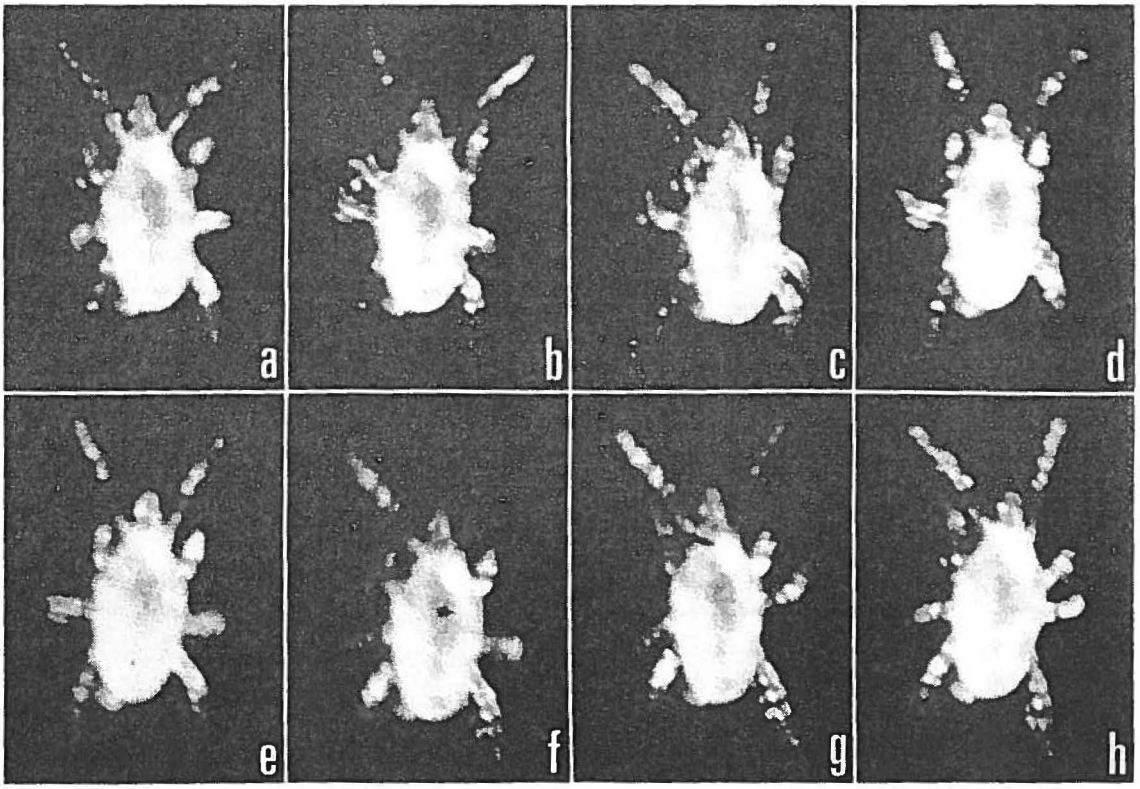

Figure 2. Adult *H. aculeifer*. A, all legs extended. B, C and D right second, left third and fourth right legs are carried forward. In E, F, G and H the left second, third right and fourth left legs are carried forward.

sequence reaches the third leg. Thus, a supporting quadrangle is composed of four metachronal sequences, two on each side of the mite.

In general, the patterns of appendage movement for the mites studied are similar to the patterns exhibited by other arthropods (Hughes 1952 , Wilson 1967). The pattern followed by larvae of *H. aculeifer* has no counterpart among normal arthropods since it has only two pairs of ambulatory legs. Its pattern of locomotion seems to fit most closely that exhibited by the Oriental Cockroach, *Blatta orientalis* L. when both hind legs were amputated (Hughes 1957). Of course, amputation presumably alters the centre of gravity of an animal whereas no such change has occurred in a normal *H. aculeifer* larva. Adult *H. aculeifer* use the alternating tripod method of walking and move their appendages in metachronal sequences as do many species of insects. The alternating quadrangle method is illustrated by adults of *T. putrescentiae;* they utilize all four pairs of legs for locomotion and in this respect resemble spiders.

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THE EFFECT OF *CUTEREBRA* spp. ON WEIGHT, SURVIVAL AND REPRODUCTION IN *MICROTUS PENNSYLVANICUS*

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ABSTRACT

During August to September 1967 and July to October 1968 cuterebrid larvae were externally visible on 16.7% of a total of 756 animals captured. A higher percentage of males than females was parasitized, but female hosts carried more larvae per animal than did males. Parasitized mice weighed less than nonparasitized mice, but the cuterebrids had no apparent effect on survival and caused only a slight decrease in the number of young produced for the season.

INTRODUCTION

During a study of the dynamics of a population of *Microtus pennsylvanicus* in southeastern Manitoba, mice bearing cuterebrid larvae were observed. Since parasitism could affect the fitness of the population, records were kept on infested mice in 1967 and 1968. To our knowledge, Buckner (1958) and Jacobsen (1966) have published the only previous records of *Microtus* as host to cuterebrids in Manitoba. Although we have not raised adults from larvae, Buckner successfully achieved adult emergence of two larvae, one from *Microtus* and one from *Peromyscus maniculatus,* which were identified as *Cuterebra grisea.* As this species is to our knowledge the only cuterebrid collected on the Prairies, it is probable our records are of this species also.

Sillman (1955 and 1956) and Sillman and Smith (1959), in extensive studies of *Cuterebra angustifrons* and *C. grisea* infesting *Peromyscus leucopus* in Ontario, summarize what is known of the method of infestation. The eggs of the fly are probably laid on vegetation where they may hatch and enter the host through the mouth, nostrils or skin, or the eggs may be ingested and hatch in the mouth or esophagus of the host (Sillman and Smith 1959). Sillman (1956) suggests that development of the larva of *C. angustifrons* in the host probably averages 25-30 days. The cycle for *C. grisea* may be quite similar.

RESULTS AND DISCUSSION

End-points of the annual infestation cycle, and the time of peak parasitization, vary from year to year. Our results (Figure 1) are within the more extensive records given by Buckner (1958) for a parasitized population of *Microtus* in southeastern Manitoba. While the shape of the 1968 curve appears to support the suggestion of Dunaway *et al* (1967) of an early peak followed by a lower, short plateau, the results for 1967 do not.

Jacobsen's (1966) study of *Cuterebra* parasitization in Manitoba indicated from 1 to 4 larvae per mouse was typical. Although as many as 7 larvae infest a single mouse (Sillman 1955), previous counts of swellings caused by larvae give comparable results to ours of 69.6% having 1 larva, 23.2% having 2, 2.4% having 3, 4.0% with 4 and 0.8% having 5, out of a total of 125 mice.

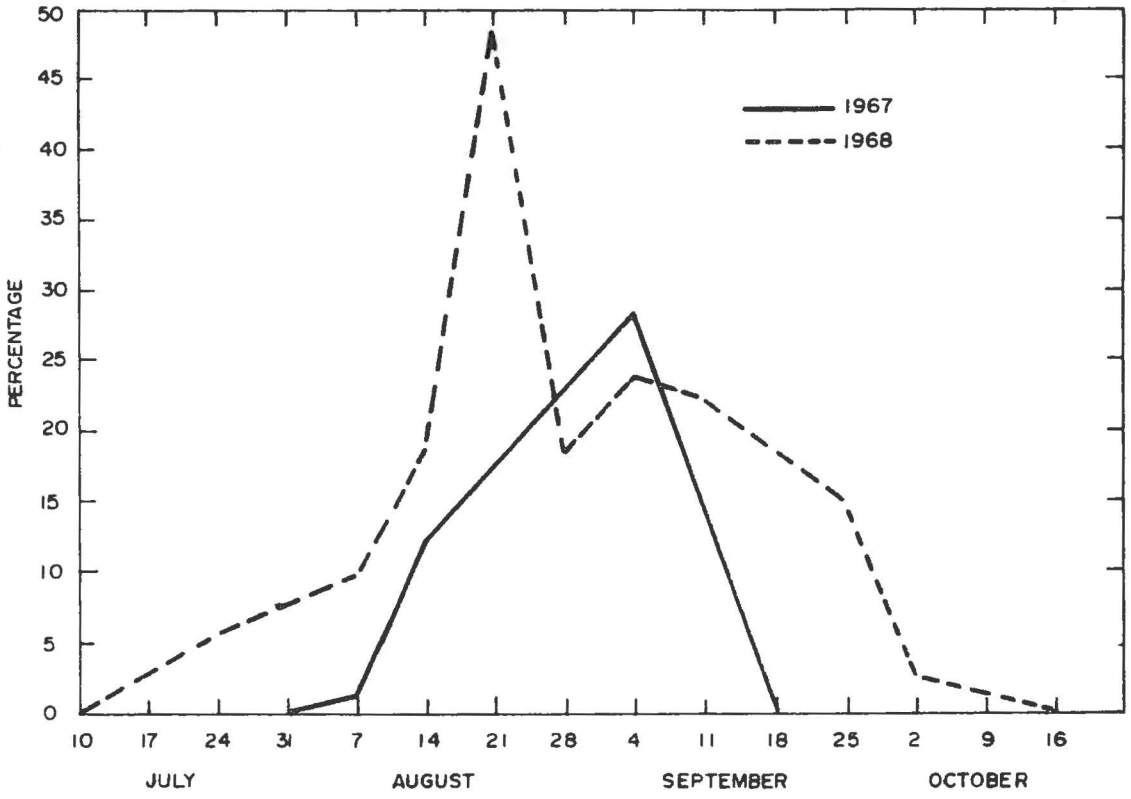

Figure 1. Percentage of captured *Microtus* parasitized during the two seasons when cuterebrid larvae were present.

Of 756 mice captured during the 2 seasons when *Cuterebra* were present, 16.7% were parasitized. Males were parasitized to a greater extent than females (Table I). A similar trend has been found previously in *Microtus* (Jacobsen 1966) and *Peromyscus* (Goertz 1966, Sealander 1961). However, parasitized females apparently are hosts to more larvae per mouse than are males (Table II). This result has not been previously reported, to our knowledge.

Table I. Percentages of male and female *Microtus* parasitized during the two seasons cuterebrid larvae were present. Sample sizes are given in brackets.

YEAR	MALES	FEMALES	TOTAL
1967	17.2 (227)	17.3 (226)	17.2 (453)
1968	25.2 (103)	11.0 (200)	15.8 (303)
TOTAL	19.7 (330)	14.3 (426)	16.7 (756)

Table II. Mean number of larvae per mouse during the two seasons. Number of parasitized mice examined is given in brackets.

YEAR	LARVAE PER MALE	LARVAE PER FEMALE
1967	1.38 (39)	1.51 (39)
1968	1.31 (26)	1.45 (22)
TOTAL	1.35 (65)	1.49 (61)

One of the obvious parameters for investigation of the effect of parasitization is that of weight of the host. Dunaway *et al* (1967) found that when the weight of the larvae was subtracted from that of the host, there was little difference between hosts and those not parasitized. Clough (1965) found that in a sample of 18 males, infested mice were heavier, whereas his sample of 12 infested females, was lighter. However, neither author took into account the age of the host mouse. Scott and Snead (1942) and Sealander (1961) both found that a higher proportion of adult mice were parasitized than were young mice. Since young mice would, in most cases, weigh less than adults, examination of a non-age segregated sample would tend to indicate that parasitized mice weighed more.

Our results indicate that when the effect of age on weight is taken into account, parasitized animals weigh less than do comparable nonparasitized animals. The comparison of weights of young animals for 1968 (Table III) would appear to indicate parasitized mice weigh slightly more than parasite-free young. However, animals classed as young in 1968 were known, by our live-trapping data, to have been born during that summer. Thus young born earliest in the year would be heavier and have a greater probability of being parasitized, whereas those born late in the summer would be lighter and have had less exposure to parasitization. The sample is therefore biased, and the comparison not valid.

Table III. Mean weights in grams of hosts and parasite-free animals grouped according to age. The asterisk indicates significant differences at the 95% confidence level and sample sizes are given in brackets.

YEAR	ADULTS NOT PARASITIZED		ADULTS PARASITIZED	YOUNG NOT PARASITIZED		YOUNG PARASITIZED
1967	27.7 (145)		26.5 (44)	17.3 (219)	*	16.6 (33)
1968	30.4 (71)	*	27.1 (13)	24.8 (183)	*	25.9 (34)

In 1967, since the live-trapping program did not start until the middle of the summer, animals were aged on the basis of weight alone, and animals classed as young are comparable. Here, infested mice weighed slightly less than not parasitized ones. Animals classed as adults in 1967 were composed of overwintered adults plus the oldest sub-adults born in early 1967. Therefore, adult results should be comparable. They indicate again that infested mice weigh less.

Since the 1968 sample of adults was all known, by live-trapping records, to have been born before November, 1967, this should be a highly homogeneous group. The greatest difference between comparable groups is found here, indicating once again that parasitized mice weigh less. As Dunaway *et al* (1967) pointed out, comparisons are more real when the weight of the larvae is subtracted from that of the host. Mature larvae of the species of concern in this study weigh about 0.6g, and host mice therefore weigh even less than indicated in Table III.

Although weight is often a good indication of an animal's fitness, the effect of parasitism on survival in the population can also be considered. Speculation and research on this effect has a history dating into the 1800s, with a number of authors mentioning locomotory awkwardness (Scott and Snead, 1942; Sealander, 1961; Dunaway, *et al* 1967) or a loss of vitality (Buckner, 1958) which may lead to higher predator loss of infected animals. Sillman (1955) found an impairment of agility only within a few days of larval emergence, when often only 3 limbs were used in running.

In eastern Manitoba, Buckner (1958) recaptured 39 small mammals after *Cuterebra* infestation, and noted no serious effects in any case. Dunaway *et al* (1967) caged 40 *Peromyscus* and in no instance did mortality occur when the larvae emerged. Numerous studies noted that the wounds left after larval emergence normally heal within 3 - 7 days. A hematological approach by Sealander (1961) in Ontario *Peromyscus* showed that infested mice had significantly lower hemoglobin concentrations and packed cell volumes but that these levels returned to normal about a week after the larva emerged. However, he suggested lowered blood values coupled with various natural stresses could contribute to a population decline. Clough (1965), using *Microtus* in Wisconsin, found that survival time in cold water was slightly less in parasitized voles, and that they had a lighter thymus and heavier spleen. He concluded that the infestation had only a minor effect on cold water survival, and that the effect of cuterebrids parasitic on small mammals was not great.

Table IV gives the proportion of mice surviving for 28 days, calculated by the method of Chitty and Phipps (1966), and applies to all mice live-trapped in the 2 seasons in which *Cuterebra* were present in the population. Results for each year separately and for the 2 season totals indicate no observable difference in survival, whether parasitized or not. Thus, although *Cuterebra* apparently affect weight adversely, the effect is not sufficient to decrease survival.

Table IV. Proportion of parasitized and not parasitized animals surviving for 28 days. Sample sizes are given in brackets.

YEAR	PARASITIZED	NOT PARASITIZED
1967	.292 (40)	.308 (171)
1968	.195 (25)	.196 (161)
TOTAL	.255 (65)	.253 (332)

Since mortality and natality directly affect population numbers, gains to, as well as losses from, the population may be influenced by the presence of cuterebrids. The possibility of locomotory disability interfering with the location of a mate, or direct emasculation has been mentioned in previous studies (see Sealander 1961). Dunaway *et al* (1967) report

many cases of inguinal larvae apparently causing one or both testes to temporarily ascend into the abdominal cavity.

Clough (1965) found total reproductive inhibition in his sample of 12 parasitized females and Sealander (1961) suggests that the slight anemias associated with pregnancy and lactation may be increased by those associated with parasitism, leading to termination of pregnancy. Inhibition is not total however, since Buckner (1958) observed birth of a litter to a parasitized *Microtus* and Sillman (1955) reports 4 litters borne by parasitized *P. leucopus.* In the cases reported by Sillman, however, none of the litters was successfully reared.

Our data (Table V) indicate a high degree of reproductive inhibition since we observed only one pregnant female out of a total of 52 that were parasitized. By utilizing the pregnancy rates of nonparasitized females we can calculate the number of pregnancies that should have been observed throughout the summer if the parasites had not been present. We can then compare the observed percentage pregnant with the calculated percentage as an indication of reproductive inhibition of the population of females for the whole reproductive season. When this is done we find that the adult females were reproducing at 97.1% of the rate that would be expected if no parasites were present while young females were reproducing at 92.7% of the expected rate. This indicates that while inhibition of individual females was nearly 100% the total effect on the population was quite small.

Table V. Percentages of parasitized and not parasitized females pregnant. The 1967 sample is not separated by age since accurate ageing techniques were not in use that year. Sample sizes are given in brackets.

	1967 Aug. and Sept.	1968 July — Oct.	Total
Adults Not Parasitized		25.0 (40)	
Young Not Parasitized		16.0 (94)	
Total Not Parasitized	4.1 (123)	18.7 (134)	11.7 (257)
Adults Parasitized		0.0 (7)	
Young Parasitized		0.0 (10)	
Total Parasitized	2.9 (35)	0.0 (17)	1.9 (52)

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COMPARATIVE FOOD PREFERENCES OF WIREWORMS *(COLEOPTERA: ELATERIDAE)* FROM SANDY SOIL UNDER PINE WOODS[1]

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ABSTRACT

In laboratory tests, larvae of three elaterid species, *Athous subfuscus* Mull., *Dolopius marginatus* L., and *Ectinus aterrimus* L., collected from pine woods in the Netherlands, were found to prefer insects (pupae) to plant (potato) food. Smaller larvae ate more plant food than the larger ones. Food preferences were influenced by the degree of sclerotization of the pupal integument and by pupal movement: elaterid larvae generally preferred soft-bodied to heavily-sclerotized pupae and dead to living sclerotized pupae. The generally low percentages of elaterid predation on pupae of the pine looper, *Bupalus piniarius* L., in pine woods of the Netherlands may be related to the heavily sclerotized pupal integument, pupal movement and the presence of alternate animal foods.

INTRODUCTION

The larvae of most species of elaterids found in forest habitats are omnivorous (Schaerffenberg 1942, Zacharuk 1963). Several species which occur in the pine woods of the Netherlands and Germany feed on living pupae of the pine looper, *Bupalus piniarius* L., but the percentage predation is generally considered to be low (Schaerffenberg 1942, Klomp 1966). Schaerffenberg (1942) attributed the low level of predation in Germany to the relative scarcity of pine looper pupae and to a preference by almost all elaterid species for decayed organic substances rather than dead or living insects.

In the Netherlands, a long-term study of the population dynamics of the pine looper has been conducted by Prof. H. Klomp (1966) but detailed studies of the factors influencing wireworm predation on pine looper pupae were lacking. During a one-year period (1966-1967) a study of wireworm predation on pine looper pupae was made in collaboration with Dr. Klomp. As part of this study, larvae of the common species found in the pine woods were offered choices of plant (potato) and animal food, including living and dead pine looper pupae, to determine whether larval size and the food preferences of elaterid larvae could affect the level of predation on pine looper pupae. This paper describes the results of the tests and the possible effect of food preferences on elaterid predation on pine looper pupae.

METHODS AND RESULTS

The elaterid species studied were *Athous subfuscus* Mull., *Dolopius marginatus* L. and *Ectinus aterrimus* L., collected as larvae from sandy soil beneath a Scots pine plantation in the northwestern part of the National Park, "De Hoge Veluwe", near Otterlo, province of Gelderland, Netherlands. The area is described in detail by Klomp (1966). These three species were the most abundant elaterids in the pine woods: 99% of the larvae collected were *A. subfuscus; D. marginatus* larvae made up nearly 1%; *E. aterrimus* and other species were rare. Larval size was measured by the width of the ventral mouthparts (see McDougall 1934). Among larvae collected from September 1966 to May 1967, the ventral mouth part widths for *A. subfuscus* varied from 0.16 to 0.79 mm, for *D. marginatus* from 0.16 to 0.59 mm and for *E. aterrimus* from 0.34 to 1.43 mm.

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[1] Data collected while on postdoctoral transfer-of-work from Canada Department of Forestry and Rural Development, Winnipeg, to Department of Zoology, Agricultural University, Wageningen, Netherlands.

The larvae used in food preference tests were collected in December, 1966. From 1 to 10 larvae of the same species and size were placed in a plastic petri plate (about 9 cm diameter) containing dune sand from De Hoge Veluwe to a depth of 1 cm. The sand had previously been air dried, then moistened to 30% of saturation. All tests were conducted at 10°C. In the first test, in which only *A. subfuscus* larvae were used,each group was given a 1 cm cube of potato, one living *Galleria melonella* (L.) pupa, and one living *B. piniarius* pupa. The tests were started during December and examined at weekly intervals for 6-8 weeks. At each examination, any food item showing evidence of feeding was replaced and dead elaterid larvae removed. Larvae that had molted were remeasured and placed with an appropriate size-group. In this test larvae of all sizes showed a preference for the soft pupae of *G. mellonella* (Table I). Potato was eaten by the smaller larvae. None of the larvae fed on the pupae of *B. piniarius.* The incidence of larval deaths and ecdyses was highest among the smaller larvae.

Table I. Feeding by groups of *A. subfuscus,* each group divided with a piece of potato, one *Galleria mellonella* pupa, and one living pupa of *Bupalus piniarius.* Each group observed weekly for 6-8 weeks.

Ventral mouthpart width (mm)	No. of larvae	Mortality (%)	Molting (%)	No. of observations	Food fed on (% of observations) [2]	
					Potato	Galleria
.14—.25	55	33	22	54	2	24
.27—.37	46	28	7	49	18	24
.39—.45	19	11	0	18	0	56
.54—.62	3	0	0	11	0	73

[2] No feeding on *B. piniarius* pupae was observed.

In the second test, larvae of all three species were used, including the survivors of the first test and others collected at the same time and held at 10°C with pupae of *G. mellonella.* The physical environment was the same but the foods offered were potato plus one living and one dead pupa of *B. piniarius.* Three observations of the larvae were made during a 13-week period beginning 16 February 1967. Food items showing evidence of feeding and dead or molted larvae were removed as described previously. In this test, larvae of *A. subfuscus* again showed a preference for animal food (Table II). Larvae in the three largest size groups preferred dead pupae to potato; very few attacks on living pupae were recorded. In the smallest size group (0.17 to 0.25 mm) feeding was observed only once: most of the larvae must have been in a non-feeding state.

Table II. Feeding by groups of wireworms, each group provided with potato and one living and one dead *B. piniarius* pupa. Each group observed thrice in a 13-week period.

Species	Ventral mouthpart Width (mm)	No. of larvae	Mortality (%)	Molting (%)	No. of Observations	Food fed on (% of obs)		
						Potato	Live pupae	Dead pupae
A. subfuscus	.17—.25	32	34	19	11	0	9	0
	.27—.37	82	20	16	17	6	0	29
	.39—.45	31	6	6	15	13	7	20
	.51—.79	52	2	8	23	4	1	30
B. marginatus	.19—.30	6	50	0	5	40	0	20
	.34—.42	5	0	0	6	33	17	0
	.51—.59	4	25	0	5	0	0	20
E. aterrimus	1.10—1.33	3	0	0	9	0	22	11

D. marginatus larvae of the largest size group fed exclusively on dead pupae of *B. piniarius* but smaller larvae preferred potato to pupae (Table II). Feeding preferences between living and dead pupae showed no consistent relation to larval size. As with *A. subfuscus*, many of the smaller larvae did not feed.

Larvae of *E. aterrimus* preferred living to dead pupae of *B. piniarius* and did not feed on potato. In other rearings, this species fed voraciously on pupae of *G. mellonella*.

Ecdysis was recorded for all three elaterid species during these tests or in other rearings using the same foods. No evident morphological abnormality was observed and a few larvae molted thrice in the laboratory. Although mortality of the smaller larvae was fairly high, the cause of death was not evident and other larvae in the same containers fed, grew and molted normally. The dead larvae showed no evidence of cannibalism and death may have been caused by the effect of disturbance during observation on larvae in the pre- or post-molt stages.

Successful attacks on living pupae of *B. piniarius* in both the laboratory and field were generally made by the larger larvae of *A. subfuscus* (Table III). In the pine woods, larvae with mouthpart widths $\geq$ 0.47 mm were always associated with attacks on living pupae.

Table III. Number of observed attacks on living *B. piniarius* pupae by *A. subfuscus* of different sizes in the laboratory and the pine woods.

Ventral mouthpart width (mm)	Pine Woods		Laboratory
	Alone or largest	Associated with larger [3]	
.25			1
.32		1 (.42, .54)	
.34			1
.39		1 (.47)	1
.42		1 (.54)	1
.44		1 (.47)	1
.47	3	2 (.49, .54)	
.49	1		
.52			2
.54	5		
.57	1		
.59	1		1
.62	2		
.66	2		1
.69			1

[3] Size of the larger larvae in brackets.

Attacks by smaller larvae occurred only in association with larger ones, suggesting that a successful attack attracts nearby larvae to the food. All observed attacks were on living pupae. In the laboratory, successful attacks by smaller larvae (width $\geq$ 0.25 mm) were recorded. The difference between the field and laboratory results may be related to the environment of the pupae: in the field, pupae occupy a pupal chamber large enough to allow some movement whereas in the laboratory they were packed in sand. Thus the movements of the pupae may protect them from attack from smaller elaterid larvae. *B. piniarius* pupae are also protected from elaterid attack by their heavily sclerotized integument. Successful attacks on 148 pupae collected in April 1967 in "De Hoge Veluwe" were invariably in an inter-segmental area and 65% of these attack points were between the second and third abdominal segments. Similarly, most attacks were reported to be at the boundary between thorax and abdomen by Schaerffenberg (1942) and between segments of the abdomen by Klomp (1966).

DISCUSSION

All larvae of the three species of elaterids tested showed preferences between the insect and plant foods tested and the preferences differed between species. Similar conclusions were reached by Zacharuk (1963) from tests of soil, sand and wood inhabiting elaterids. In the present tests all three species fed on both living and dead pupae of *B. piniarius*, and larvae of *A. subfuscus* and *D. marginatus* also fed on potato. Larvae of *E. aterrimus* ate only the insect foods.

The *E. aterrimus* larvae, at least the large, near-mature individuals tested, appear predaceous and saprophagous (Table II). This does not agree with Schaerffenberg's (1942) observations, that *E. aterrimus* larvae accepted rye seed and potatoes in the laboratory and fed on seedlings in tree nurseries. If, in fact, his observations refer to smaller larvae, a change in food preferences, the smaller larvae being more phytophagous than the larger ones, is indicated.

D. marginatus larvae were predaceous, saprophagous and phytophagous, with the larger larvae preferring insect food (Table II). Zacharuk (1963) also found that large larvae of this species preferred insect to plant food while Schaerffenberg (1942) described it as an omnivore with predominantly saprophagous and phytophagous habits. These contradictory results may be related to a change in food habits from phytophagous among smaller to predaceous and saprophagous among larger larvae.

The larger larvae of *A. subfuscus*, like those of *D. marginatus*, showed a stronger preference for pupae over potatoes than the smaller larvae. Schaerffenberg (1942) reported this species to feed on plants and living insects. Comparison of the results of the two tests (Tables I and II) indicates that the food preferences are modified by the quality of the insect food available. When the soft-bodied pupae of *G. mellonella* were available, the larger larvae ate only those pupae but when the heavily-sclerotized pupae of *B. piniarius* were offered, potato was also eaten. Similarly the dead pupae of *B. piniarius* were attacked more readily than the living. Thus hard integument and movement appear to affect the feeding of smaller larvae to a greater degree than it does the larger larvae.

In the natural habitat of the soils of the pine woods, alternate insect foods in the form of soft-bodied dipterous larvae, immobile pupae and freshly dead insects are much more abundant than pupae of the pine looper. Soil samples collected between September 1966 and May 1967 in "De Hoge Veluwe" yielded an average of over 500 insects per sq m (unpublished data, W. J. Turnock). In contrast, the maximum density of pine looper pupae during the period 1950 to 1966 was 5.9 per sq m (Klomp 1966). The soil samples were taken to a depth of 15 cm, thus including the entire humus layer (mean depth 3.6 cm). No insects were found in the sand underlying the humus layer.

CONCLUSIONS

1. The three most common species of elaterid larvae in the pine woods of "Het Nationale Park De Hoge Veluwe", the Netherlands, *Athous subfuscus, Dolopius marginatus* and *Ectinus aterrimus*, prefer insect (pupae) to plant (potato) food.

2. This preference for insect food was stronger among the larger larvae of *A. subfuscus* and *D. marginatus*: smaller larvae were more phytophagous.

3. Elaterid larvae, particularly the smaller ones, were less successful in attacking living pupae of the pine looper *Bupalus piniarius*: when choices were offered, dead pine looper pupae or soft-bodied pupae of *Galleria mellonella* were preferred.

4. In the natural habitat of the pine woods, soft-bodied and inactive stages of other insects are abundant and may provide most of the needed insect food for elaterid larvae.

5. The generally low percentages of predation of pine looper pupae in the Netherlands may be related to the heavily sclerotized pupal integument, pupal movement, and the presence of more abundant animal food.

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CLEARING AND STAINING INSECT LARVAE TO DETECT INTERNAL PARASITES

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The presence of internal parasites in insect larvae can be determined by careful dissection under low-power magnification but this method has limitations when used to estimate the percentage parasitism in large-scale population studies. Detection of small parasite larvae by dissection is too time-consuming for the examination of the numbers of host larvae required by such a study and, since the host larvae must be pliable when dissected it is necessary to use freshly-killed larvae or those preserved by freezing. These limitations hindered the development of a method for estimating the percentage parasitism by the ichneumonid *Olesicampe benefactor* Hinz in larval populations of the larch sawfly, *Pristiphora erichsonii* (Hartig). Although *O. benefactor* parasitizes first-instar larch sawfly larvae, the parasite remains small (in the first stadium) until the host has completed its feeding (Muldrew 1967). Samples of feeding larch sawfly larvae suitable for the determination of parasitism are routinely collected for the calculation of larval survival ratios (Ives *et. al.* 1969) but these are preserved in 70% alcohol at the time of collection and soon become hardened.

Attempts were therefore made to develop a technique that could use these alcohol-hardened larvae as a source of material. The objective was to dissolve, clear and stain the body contents so that internal parasite larvae would be easily visible under a dissecting microscope. The first method tried was adapted from one used for clearing aphids (Richards 1964). This method, however, because of the high osmotic pressures developed, often caused the hind gut to evaginate and the integument to rupture. This rupturing was reduced by substituting a mixture of xylene, chloral hydrate and phenol for lactophenol and introducing intermediate steps using various concentrations of alcohol.

The technique as finally developed enables large numbers of alcohol-hardened larvae to be processed quickly and makes internal parasites visible. However, the technique does not entirely clear the gut contents and other debris present in the bodies of third-instar and larger larvae. Since most second-instar larch sawfly larvae clear well, restricting the assessment of parasitism by *O. benefactor* to collections of this instar gives maximum speed and accuracy.

To minimize handling, groups of larvae are placed in separate containers in which they remain until treatment is completed. These colony containers are placed in racks which fit loosely into the reagent-containing vessels (Fig. 1). Wire handles on the racks facilitate transfer and provide a space between the reagent dishes and the watch glass covers (190 mm diam.). The latter are placed over the dishes to reduce evaporation. Each rack is constructed from a sheet of polyethylene 3 mm thick. It is 162 mm in diameter with 13 holes, each 1 1/16 inch diameter, drilled at regular spacings. (The three legs supporting the rack are cut from 5/8 inch diam. solid polyethylene rod. They are 1 7/8 inches long and are attached by 3/4 inch No. 6 zinc chromate plated steel screws.). The handles are made from plastic coated clothesline wire. The reagent vessels are crystallizing dishes, 170 mm in diameter and 90 mm deep.

The colony containers are constructed of polyethylene tubing (1 inch O.D., 1/8 inch thick walls) 1 1/2 inches long with a retaining sleeve (1 1/4 inches O.D.) fitted over the upper end. The sleeve is 1/4 inch long except for a projection along 1 inch of its circumference which is an additional 1/2 inch long. This projection facilitates handling and provides space for an identifying number to be stamped on the container. The sleeve is heat-sealed to the central tube by inverting and pressing down on a hot plate previously coated with

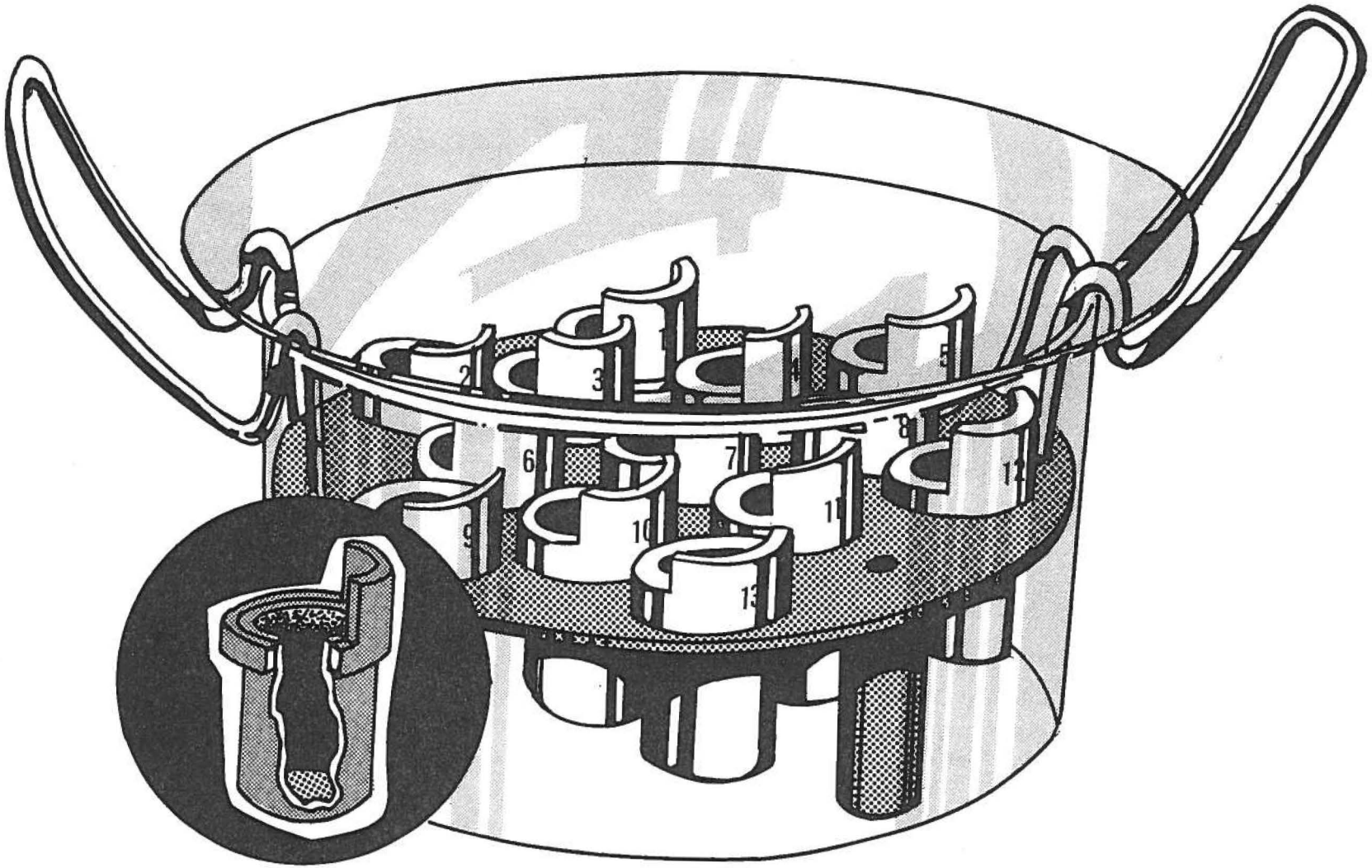

Figure 1. Rack of colony containers in crystallizing dish with watch glass cover. Cutaway view of colony container showing details of construction.

'Fluon'* to prevent sticking. A piece of copper or bronze screening (e.g., paper-mill cylinder wire) is attached to the bottom by heat-sealing on the fluon-coated hot plate.

The procedure for clearing and staining is given in Table I. Steps 1, 4, 9 and 12 are carried out in a fume chamber as shown in Fig. 2. The racks are drained over pads of paper towelling (8 layers stapled together). The reagents for steps 1, 4, 5, 9, 10 and 11 should be changed every four to six "runs" depending on the number of larvae treated per "run". The volume of each reagent should be brought to the 800 cc level before each "run". (Lines can be drawn on the exterior of the reagent dishes to indicate this level). An additional rinse of 95% alcohol can be added after step 10 to more thoroughly remove the xylene-chloral hydrate-phenol before staining.

Table I. Clearing and staining procedure to detect parasitism of second-instar larch sawfly larvae by *Olesicampe benefactor.*

Step	Reagent	Temperature	Time	Remarks
1	95% Ethyl alcohol	Slow boil	5 min.	Drain before next step
2	70% Ethyl alcohol	Room	2 min.	—
3	40% Ethyl alcohol	Room	2 min.	—
4	10% Potassium hydroxide	60°C	30 min.	Drain before next step
5	Distilled water	Room	2 min.	Drain before next step
6	40% Ethyl alcohol	Room	2 min.	—
7	70% Ethyl alcohol	Room	2 min.	—
8	95% Ethyl alcohol	Room	2 min.	—
9	Xylene-chloral hydrate-phenol mixture [a]	60°C	30 min.	Drain before next step
10	95% Ethyl alcohol	Room	2 min.	Drain before next step
11	Acid fuchsin [b]	Room	10 min.	Drain before next step
12	Methyl salicylate and glacial acetic acid [c]	Room	15 min.	—
13	95% Ethyl alcohol [d]	Room	Indefinite	Examine or store in this solution

[a] Mix equal weights of chloral hydrate and phenol crystals in a large beaker and add enough xylene to just cover crystals. Stir over gentle heat (approximately 60°C)until dissolved and store in brown bottles in a cool place. Caution: This mixture should be handled with care as it can cause burns to the skin the severity of which may be masked by its slightly anaesthetic properties. The fumes are also hazardous if inhaled and are irritating to the eyes. Operations using this mixture should be carried out in a fume hood.

[b] Prepare stock solution by dissolving 1 gm of acid fuchsin in 200 cc water. Add ten cc of stock solution to 800 cc 95% ethyl alcohol. Add five cc of glacial acetic acid.

[c] Equal parts by volume.

[d] Acidify by adding 1 cc glacial acetic acid per 500 cc alcohol and add 3 drops of the acid fuchsin stock solution per 500 cc to indicate pH.

Following treatment, each group of larvae is examined separately in a petri dish. The integuments of parasite and host are light pink-red. The gut contents are a translucent brown which obscures vision, but as the larvae may be gently rolled using a curved probe, the parasite will be readily visible in one plane or another. An improvement in the technique can be obtained by starving the larvae for periods up to 24 hours before preserving them, during which time the gut is partly evacuated, but it proved impractical to incorporate this into the larch sawfly study.

* 'Fluon GP—1' is the registered trademark of Canadian Industries Limited for the product polytetrafluoroethylene. A similar product can be obtained in the U.S.A. from E.I. Du Pont de Nemours and Co. (Inc.) and has the registered trademark 'Teflon-S'. The cast aluminum heating surface of the hot plate is cleaned and etched with KOH and then dipped in fluon which is allowed to drain off to leave a layer approximately .002 inch thick; this is allowed to dry for 5 minutes at 90°C and is then sintered at 380°C for 10 minutes.

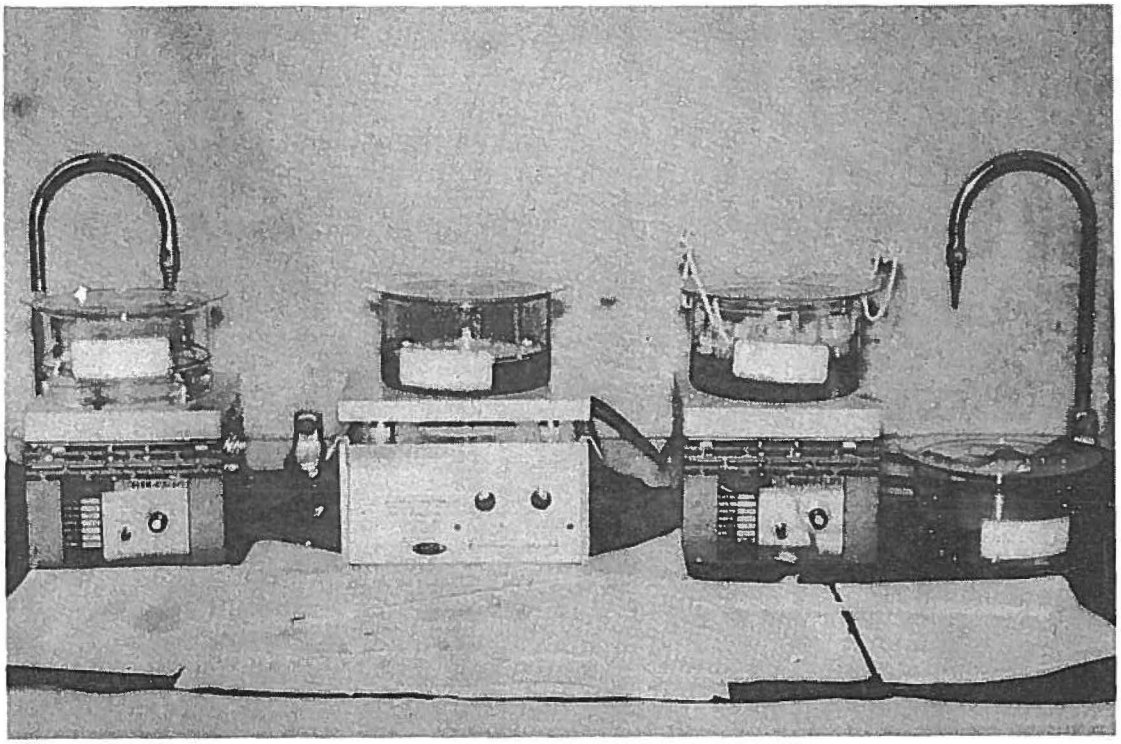

Fig. 2. Setup showing steps 1, 4, 9 and 12 in fume chamber.

Those host larvae in which no parasites can be seen should be sorted into two groups; (a) those that appear to be well cleared throughout and (b) those that have a sufficient amount of opaque or poorly-cleared "debris" in their body cavities to make examination difficult. Most of the latter group in the larch sawfly study were found to be larvae that were about to molt to the third instar when they were preserved and have in effect two integuments that the reagents must pass through. Experience has shown that only the poorly-cleared group (b) need be dissected.

Clearing may be improved by puncturing the larval integuments before treatment, but this increases rupturing and consequent loss of parasites. Rupturing can occur even without deliberate puncturing, but can be minimized by careful handling, i.e., individual larvae should be transferred by medicine dropper rather than forceps.

This technique has proven effective in providing estimates of the degree of parasitism of second-instar larch sawfly larvae collected in the field. No modifications were needed in the field sampling methods and large numbers of samples could be handled efficiently. The method was also tested for larvae of the spruce budworm *Choristoneura fumiferana* Clem., and a jack pine sawfly, *Neodiprion* sp. and yielded results similar to those obtained with the larch sawfly larvae.

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NOTE ON THE BIONOMICS OF *HAEMOGAMASUS PONTIGER* (BERLESE) (ACARINA: MESOSTIGMATA), A PREDATOR ON *GLYCYPHAGUS DOMESTICUS* (DeGEER) [1]

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ABSTRACT

The life history of a predatory mite, *Haemogamasus pontiger* (Berlese), was studied at 24 and 27°C. Eggs and immature mites that became males developed more rapidly at 27 than at 24°C; there was little difference in the rates of development of the females at the two temperatures. *H. pontiger* fed on *Glycyphagus domesticus* (DeGeer) and on damaged larvae of *Tribolium confusum* (du Val). The lowest rate of oviposition was obtained when *G. domesticus* was the only prey available. A maximum of one egg per day was obtained when females were fed on a mixture *T. confusum* larvae that oozed haemolymph and *G. domesticus.*

INTRODUCTION

Species of the genus *Haemogamasus* (Berlese) have often been found in the nests of mammals. *H. ambulans* (Thorell) and *H. horridus* (Mich.) have been found associated with species of rodents of the genera *Apodemus, Sciurus,* and *Talpa; H. hirsutosimilis* Willman was obtained from *Talpa* nesting material (Evans *et al* 1961). Hughes (1959, 1961) stated that *H. pontiger* (Berlese) (=*H. oudemansi* Hirst) completes its life cycle on wheat germ, although Furman (1959) found that, similar to *H. ambulans* and *H. liponyssoides* Ewing, it fed on heparinized blood from the laboratory mouse. Moreover, *Hepatozoon griseisciuri* Clark, a disease organism in the grey squirrel, is probably transmitted by the mite *H. ambulans* (Clark 1958). Sinha (1963) stated that *H. pontiger* is commonly found in stored grain in Western Canada, but the species did not reproduce in the laboratory when fed on any of 14 species of microorganisms tested (Sinha 1964). Recently, *H. pontiger* was found in two granaries near Winnipeg that were infested with *Glycyphagus destructor* (Schrank), *Oryzaephilus mercator* Fauvel, *Tribolium confusum* (du Val) and mice. This study was initiated to assess the role of *H. pontiger* in granaries.

MATERIALS AND METHODS

Five *H. pontiger* females sieved from two samples of heating wheat were transferred with a sable brush to two rearing cells. The rearing cells were made from "culture" microscope slides and coverslips. Two or three 22 x 60 mm coverslips were placed one over another and held in place by "bulldog" paper clips; single coverslips often broke and released the mites. A few grains of brewer's yeast and a brushful of *Glycyphagus domesticus* (de Geer) of mixed ages were placed in each cell. Each day, one injured *T. confusum* larva was added to the cells that contained the adult females. The cells with the progeny from the field collected females were held in desiccators that contained a saturated sodium chloride solution, which provided 70 to 75% relative humidity (r.h.) or free water which provided over 95% r.h. The desiccators were placed at 24 and 27°C.

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[1] Contribution No. 336, Research Station, Canada Department of Agriculture, 25 Dafoe Rd., Winnipeg 19, Manitoba.

RESULTS AND DISCUSSIONS

Eggs of *H. pontiger* obtained from females collected in the granaries were large and hatched about 3 days after oviposition (Table 1); embryonic development was faster at 27° than at 24°C. No embryo could be seen through the chorion of 1-day old eggs obtained from field-collected females but, as the eggs aged, development of the embryo could be followed until the fully formed larvae was observed prior to eclosion. In contrast, eggs produced by females reared in the laboratory on *G. domesticus* contained well developed embryos at the time of oviposition and hatched within a few hours; most of the embryonic development had occurred within the female. The presence or absence of well developed embryos in eggs at the time of oviposition was associated with the mother's rate of oviposition; females that oviposited daily laid eggs with undeveloped embryos.

Table 1. Developmental time [2] for *Haemogamasus pontiger* with unrestricted food supply at two temperatures and 95 to 100% R.H.

Temp.	Eggs		Post embryonic			
			Males		Females	
(°C)	Number	Days	Number	Days	Number	Days
24	35	$3.2^{\pm}0.5$	18	$7.0^{\pm}0.7$	14	$7.9^{\pm}0.9$
27	23	$2.6^{\pm}0.5$	6	$6.3^{\pm}1.3$	13	$7.6^{\pm}1.2$

[2] Average $^{\pm}$ standard deviation.

As with most Mesostigmata, the developmental stages were egg, larva, protonymph, deutonymph and adult. Males tended to attain adulthood sooner than females, and to develop faster at 27 than at 24°C; there was no significant difference in the rates of development of females at 24 and 27°C. The larva, like those of most Mesostigmata, did not feed though the nymphs and adults readily consumed *G. domesticus.* Heparinized mouse blood as a food for *H. pontiger* (Furman 1959) was confirmed, and I have found that this species will also feed on heparinized human blood.

Females that fed on *G. domesticus* produced single offspring at irregular intervals that ranged from 5 to 15 days at 24°C and 95% r.h. Females of *H. pontiger* provided with *G. domesticus* and wounded *T. confusum* larvae that oozed lymph often produced one egg per day for as many as 10 consecutive days; occasionally two eggs were produced during a single day. Sometimes, however, females produced no offspring regardless of what food was available. The highest rate of oviposition observed for *H. pontiger* was less than the two eggs per day recorded for *H. liponyssoides* (Radovsky 1960) and greater than the one offspring every 2 days observed for *H. ambulans* (Furman 1959). Audy and Lavoipierre (1966) stated that little is known about factors such as quality of ambient air and substrate, circadian rhythmic fluctuations in activity, and physiological requirements that affect the bionomics of predatory mites. The factors that trigger optimal rates of oviposition in *H. pontiger* are not known though it is strongly suspected that availability and quality of food may be the most important of these. Similarly Barker (1968) suggested that food quality influenced the oviposition rates of *Androlaelaps casalis* (Berlese).

Since *H. pontiger* is a predator, it was expected to have a well developed capacity to search for prey. Evidence of this ability is the distance a predator can travel in a given time interval. Four *H. pontiger* that had been fed only on *G. domesticus* were allowed to walk freely on a glass plate for 5 minutes and the path of each carefully traced with ink. The

average distance travelled as measured with a map meter was 1.39 m; the range was 1.18 to 1.68 m. These are conservative estimates since the most minute turns taken by the mites could not be measured. The four mites were subsequently permitted to walk for half an hour; they walked for over 29 minutes of this time and travelled 8.3 m. Each *A. casalis* covered about 6 m in a similar period of time (Barker 1968). The fact that *H. pontiger* can walk farther per unit of time than can *A. casalis* suggests that the former species may be a more successful or a more selective predator.

Furman (1959, 1968) has stated that some species of the genus *Haemogamasus* will survive and reproduce when fed on blood from numerous different vertebrates. *H. pontiger,* however, cannot penetrate the skin of vertebrates (Furman 1959); in farm granaries then (Sinha 1963), it must be a predator on mites and on weakly sclerotized insect larvae.

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Received September 21, 1968.

EFFECT OF POTASSIUM CONCENTRATION ON UPTAKE OF CESIUM 137 BY *AEDES AEGYPTI*

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Suppression of Cesium ^{137} uptake by potassium has been reported for algae, higher plants, some vertebrates, but not for insects. The effect of potassium concentration on the uptake of Cesium ^{137} by the mosquito *Aedes aegypti* is reported. Radionuclide accumulation by larvae was markedly reduced by increasing the concentration of potassium in the rearing medium. The effect of potassium on radiocesium accumulation was augmented by increasing the ambient temperature.

Received 18 November, 1968

BOOK REVIEWS

Important Forest Protection Problems[1]

Publications providing quick access to information on forest pests are usually limited in their geographical coverage and rapidly become out-dated. As a result of the efforts of the Working Group on Forest Insects and Diseases of the North American Forestry Commission and the Department of Forestry and Rural Development of Canada, a timely and comprehensive report has been prepared on 65 insects and diseases regarded as being actual or potential threats to North American forests. Each report covers the distribution, hosts damage, life history and control measures for a single pest species. This information will be useful to practicing foresters and extension workers and also serves to reveal research areas where international cooperation is needed.

The style and format are remarkably uniform and the information given is clear, concise and quite complete. In some cases authorship of individual articles is by research personnel intimately involved in the problem but often a single author contributed to the articles on several species, without the benefit of close association with the problem. Some detail and useful new information thus may have been missed.

The distribution maps are generally adequate to the purpose of this publication but in two important cases, the Dutch Elm disease and the Smaller European Elm Beetle, the coincidence of distribution and political boundaries is very suspicious.

Illustrations are well chosen and generally excellently reproduced: these add greatly to the value of the booklet for extension purposes.

Although some of the information on control measures may be obsolete at the time of publication, many authors have indicated expected developments in control procedures. The comments on areas requiring research are welcome.

W. J. Turnock

[1] Important Forest Insects and Diseases of Mutual Concern to Canada, the United States and Mexico. Compiled and edited by A. G. Davidson and R. M. Prentice. 1967. Dept. of Forestry and Rural Development, Canada. Pub. No. 1180. 247 pages. Available from Queen's Printer and Controller of Stationery, Ottawa. Catalogue No. Fo47-1180.

PROGRAM OF ANNUAL MEETING

November 7 – Agriculture Auditorium

8:00 a.m. Registration

9:00 a.m. Address of Welcome, announcements

9:30 a.m. **Symposium Session A** (Chairman - C. H. Buckner)

Invitational Address
W. W. Mair, Deputy Minister,
Department of Mines and Natural Resources.
"Integrated resource management - a necessity not a luxury"

10:30 a.m. Coffee

11:00 a.m. **Invitational Papers**

1. A. J. Thorsteinson (Dept. of Entomology, U. of M.)
   "The husbandry of information for environmental management"
2. C. C. Thomson (Canada Dept. of Forestry, Winnipeg)
   "Research support for integrated environmental management"

12:00 p.m. LUNCH

1:30 p.m.

1. H. E. Welch (Dept. of Zoology, U. of M.)
   "Southern Indian Lake: A recent Manitoba example of conflicting interests in resource management"
2. M. A. Ashraff (Green Cross Products, Winnipeg)
   "Integrated approach to pest control"
3. L. B. Smith (Canada Dept. of Agriculture, Winnipeg)
   "Possible effects on grasshopper populations of changes in the environment"

3:00 p.m. Coffee

3:30 p.m. SUBMITTED PAPERS (Chairman - S. R. Loschiavo)

1. W. M. Hominick and H. E. Welch (Dept. of Zoology, U. of M.)
   "Synchronization of life cycles of three mermithids and three chironomids in the Delta Marsh"
2. S. Smith (Dept. of Entomology, U. of M.)
   "Autogeny of northern blood sucking Diptera"
3. B. Turner (Whiteshell Nuclear Research Establishment, Pinawa)
   "The effect of *Cuterebra* spp. on the weight and survival of *Microtus pennsylvanicus*"

November 8 – Agriculture Auditorium

9:00 a.m. **Symposium Session B** (Chairman - A. J. McGinnis)

Invitational Address
Dr. A. J. Mooradian, Managing Director
Whiteshell Nuclear Research Establishment
"Ecology of Science"

10:00 a.m. Coffee

10:30 a.m. **Invitational Papers**

1. J. M. Walker (Botany Dept., U. of M.)
   "The ecologist's approach"
2. J. R. Vallentyne (Freshwater Institute, Winnipeg)
   "Integrated approach to lake management"
3. W. J. Turnock (Canada Dept. of Forestry, Winnipeg)
   "Organization of a study of an ecological system"

12:00 p.m. LUNCH

1:30 p.m. SUBMITTED PAPERS (Chairman - W. J. Turnock)

1. J. M. Bergeron (Dept. of Zoology, U. of M.)
   "Goldenrod gall producers"
2. A. Campbell (Dept. of Entomology, U. of M.)
   "Predation of a larval dytiscid on immature mosquitoes"
3. A. J. McGinnis and S. R. Loschiavo (Canada Dept. of Agriculture, Winnipeg)
   "An insect repellent in wheat germ - fact or antifact"
4. J. Guthrie and A. Bruzynsky (Whiteshell Nuclear Research Establishment, Pinawa)
   "K+ and uptake of 137_{Cs} by *Aedes aegypti*"
5. J. H. Gee (Dept. of Zoology, U. of M.)
   "The effect of daily synchronization of sexual activity on the success in locating a mate in laboratory populations of *Dacus* (Diptera: Tethritidae)"
6. L. Tan (Dept. of Zoology, U. of M.)
   "A progress report on a new coccidian in carpet beetle larvae *(Trogoderma parabile)*"
7. P. S. Barker (Canada Dept. of Agriculture, Winnipeg)
   "Effect of food quality on multiplication of Mesostigmata mites"

6:30 p.m. Banquet and Social Evening

Champ's Motor Hotel, 160 Osborne Street, Winnipeg.
Guest Speaker: Professor L. B. Siemens,
Plant Science Department,
University of Manitoba.
"Life in Southeastern Asia"

ADDITIONS TO THE LIBRARY OF THE ENTOMOLOGICAL SOCIETY OF MANITOBA

Acridological Abstracts, no. 1-8, 1968. (Anti-Locust Research Centre, London.)

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1. The Manitoba Entomologist is printed annually and publishes articles on all phases of entomology. Each paper should contain the results of original research, or review in depth some aspect of entomology. While the primary aims are to publish material of regional interest, some papers of interest to other geographic areas or of general interest will be accepted.

2. Manuscripts should be prepared according to instructions described in the Style Manual for Biological Journals, published by the American Institute of Biological Sciences, 2000 P. St. N.W., Washington, D.C. 20036.

3. Manuscripts should be submitted in duplicate, including the original and one carbon copy on 8 1/2 x 11 paper, double spacing the entire manuscript. Each manuscript over two typescript pages should include an Abstract not exceeding 200 words.

4. Tables and illustrations should be clear and concise, kept within reasonable limits, and should not repeat material presented in the text. Notations identifying the author and title should be made lightly in pencil on the back of each illustration. Tables should be typed separately, one to a page at the end of the manuscript.

5. Each manuscript is reviewed by at least one referee, who will check for scientific content, originality, and clarity of presentation.