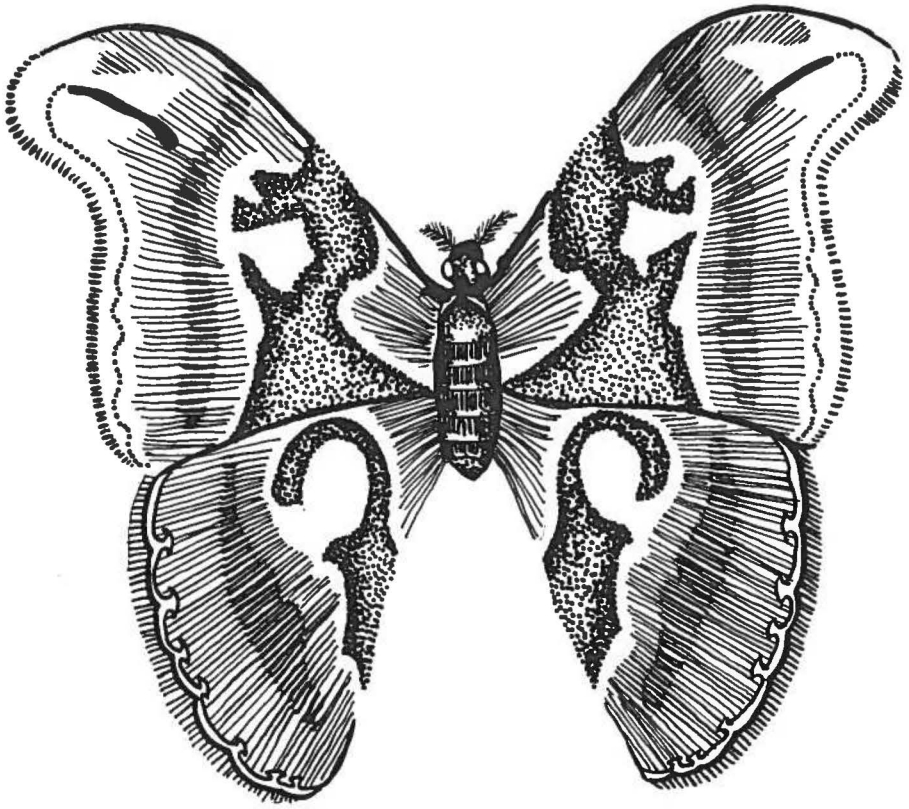
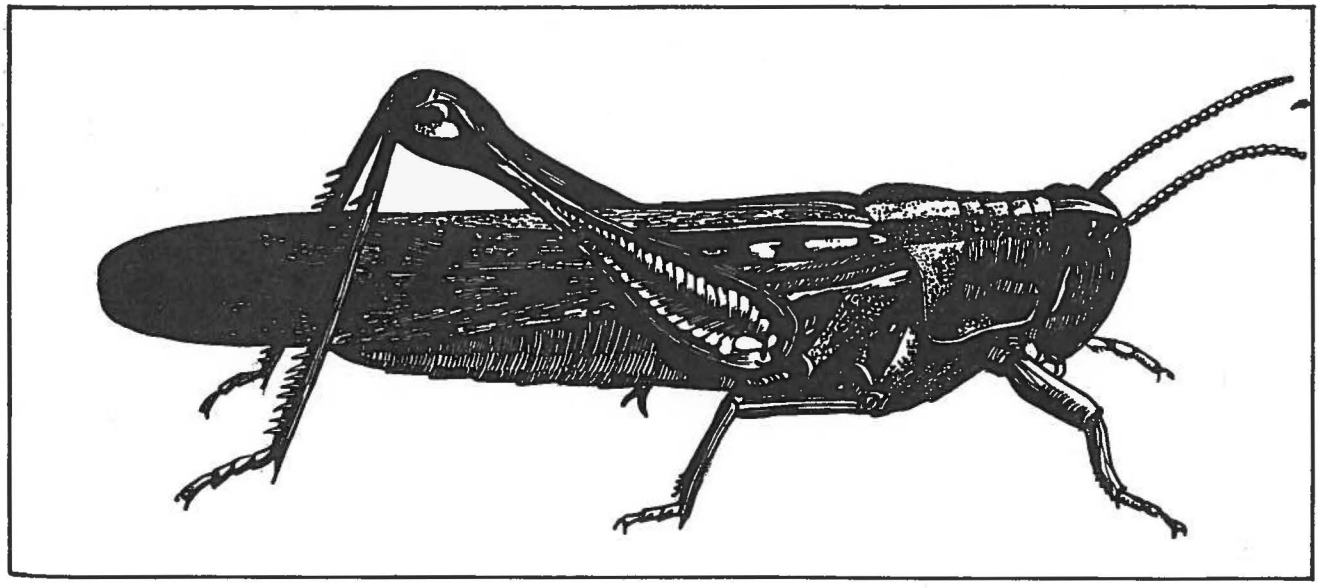
Vol. 8, 1974

ISSN 0076-3810



the manitoba ENTOMOLOGIST



ISSN 0076–3810

THE MANITOBA ENTOMOLOGIST

VOLUME 8

1974

An official publication of the Entomological Society of Manitoba published through the courtesy of the Manitoba Department of Agriculture.

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THE MANITOBA ENTOMOLOGIST

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

CONTENTS

THE CRIDDLES OF AWEME

ALMA CRIDDLE

Winnipeg, Manitoba

ABSTRACT: Norman Criddle was a distinguished pioneer naturalist and the first professional entomologist in the Canadian prairies. His father, Mr. Percy Criddle came from England in 1882 to settle at Aweme, Manitoba, bringing with him a classical education and an interest in nature. All of his four sons and four daughters were interested in natural history, and two of the sons, Stuart and Norman, achieved international reputation for their studies, although they received no formal schooling. Following Norman's appointment as Field Entomologist by the Federal Government, the first entomological laboratory in Manitoba was erected on the Criddle farmstead in 1913. Miss Alma Criddle, daughter of the youngest son, Talbot, presents some details of the life of this remarkable family, based on the diaries and correspondence of her grandfather and uncles.

Thank you, Mr. President — and gentlemen. I feel overwhelmingly outnumbered here. It would seem that even the most zealous Women's Libbers have agreed by mutual consent to leave the field of entomology to the men. Instead of protesting about discrimination, many members of the weaker sex still protest if anything with six legs or more touches them, and instead of a slogan, emit a Victorian scream — "Oo-o-oh! A bug! How horrid!"

The Criddle women were more tolerant of the insect world. Perhaps they had to be, since the men of the family were always bringing in specimens to identify or add to the family collection. But another reason was because they looked upon insects as a part of natural history, and an important part in the general scheme of things. An insect wasn't just a "horrid, creepy, crawly creature" — each had a name and a function, from being a source of food to nestling bluebirds, to disposing of a dead rodent or bird, as a form of sanitation department.

The Criddle children gained their first knowledge of entomology, and all other aspects of natural history, through first-hand observations and experience, and the teachings of their parents, rather than from the formal education of classrooms. None of the children attended school, for their father's opinion of the average "school-marm" available to small country schools was far from favorable. In the light of the standards shown by the letters of application from prospective teachers, his prejudice is understandable. As Trustee of Aweme School, Percy Criddle read all those letters, and deplored the quality of the contents.

"Aweme" was the name of the Postal district, and of the school the Criddles should have attended. It was situated about 17 miles south-east of Brandon (as the crow flies), but meant a 21-mile trip each way when the family went in for supplies. The name "Aweme" has long since vanished from the map — even its origin cannot be found, though the Post Office bestowed the name in 1884. One suggestion made by Vere Scott is that it originated from the Cree "Ah-way-nah" — meaning "Who is it?" When the Post Office closed in 1917, and the Criddle family began using nearby Treesbank as their mailing address, "Aweme" was still linked with Norman Criddle's name as an area for insect species, a bird migration list, and his field observations in regard to all natural history. It was still marked on a map in 1936 three years after his death. In a more intimate circle, the family were known as the "Criddles of St. Albans", for in British fashion, Percy Criddle gave a name to his home; first to the little long building, and in 1906 to the large, apple-green house which still stands on Section 32, Township 8, Range 16 in the Municipality of South Cypress, Percy's original homestead. Now, the house can be located for many by saying "St. Albans is about 9 miles south-east of Shilo military base", but in 1882, when the Criddles arrived by ox-team, there was no such place as Shilo. Chater, Currie's Landing, Onah, Milford, Two Rivers (or Souris Mouth), and Brandon were the surrounding centres for Percy Criddle and his neighbours of the settlement.

Their first months were spent under canvas, until the little log house, built chiefly by two neighbours more skillful in the art than Percy Criddle, was "habitable if not completely

weather-proof". Since they did not move into the house until December, the family had some chilly nights in the tents. Those first years, the little log house was not exactly weather-proof or warm. On many winter mornings, Percy recorded that the temperature in his bedroom was below 0°F. The family often found it necessary to sleep in their clothes for extra warmth. The cement filling between the logs kept falling out, so the winds whistled through the cracks, and frost built up on the inside walls. Percy Criddle could only guess at the temperatures at first, for the thermometers he brought with him were designed for British, not Manitoba winters. Specially made instruments were sent out to him by 1884, when he began keeping the official records.

There were 8 children in the family, 4 of each sex. All were expected to be alert and observant of their surroundings — an early training that became a habit to stay with them all their lives. With no labour-saving devices, and certainly no maids, the girls were kept busy in their roles as homemakers. Their Mother, Alice, set a good example for them all in her own efforts. Housekeeping was mixed with lessons to all the children (for Percy had not the patience to encourage them in the routine of studies), and an active participation in their study of the environment.

Even in those first months, the family showed a great interest in their environment, getting acquainted with all the unfamiliar plants, birds, mammals and insects — especially the mosquitoes, which plagued them all to distraction. According to Percy's diaries, these were the chief pests in his new-found Eden. He found species of birds and butterflies closely resembling their British "cousins" which were familiar to him. In the spring of 1883, he was intrigued by the arrival of the meadowlark, whose song he considered as its introduction, interpreting it as — "I am the great King, Chipple-a-bang". He refused to recognize our cheerful, little harbinger of spring, referring to them as "sundry, so-called robins". To him, that name belonged to the small, plump, tame little redbreast of Britain, not to our red-breasted thrushes. The diary pages were liberally sprinkled with descriptions of these discoveries, and his opinions of them all. Later, Norman made an effort at diary-keeping — a record consisting chiefly of natural history entries. He might dismiss the day's farm labours with a single sentence — "some ploughing and a few odd jobs done about the place". But if in ploughing, he had seen a new bird, or a different wildflower, he would devote several paragraphs to a detailed description. Norman's diary-keeping seemed to begin as a school exercise, perhaps at his Mother's suggestion, for several pages showed spelling corrections in her neat hand. It was good practice — to improve his education, and to increase his ability in descriptive writing, for the many articles he was later to write for such publications as The Auk, The Ottawa Naturalist, and the Canadian Entomologist.

Norman Criddle whose name is perhaps the best known to entomologists and naturalists, was only 7 when he came out with the family in August, 1882. Norman had inherited his grandmother's artistic talent. He painted the wildflowers of the area, and in his quest for accurate knowledge of them, sent the paintings to Ottawa with a request for correct identification of the plants he could not recognize. This brought his skill to the attention of Dr. James Fletcher — the genial "weed and bug man of Ottawa" as he called himself. He named the plants of Norman's paintings and returned them. When a grasshopper plague in 1900 brought Dr. Fletcher to Manitoba to investigate, he made sure he met Norman and the family, an acquaintance that soon became friendship, and he was a fairly regular visitor to St. Albans. On one visit, the boys decided a practical joke was in order. They created a "specimen" from pieces of dead insects — the hind legs of a grasshopper, perhaps; the elytrae of a June bug, the eyes of a dragonfly? The actual component parts are not remembered, but the result was an alarming entomological oddity. This the boys presented to Dr. Fletcher, with the explanation that they had found a new species and hoped he could identify it for them. Dr. Fletcher had his own sense of humour, so he inspected this specimen as though its proper identification was the most important part of his day. He scrutinized it carefully, studied it, and then raised his head to face the circle of gleefully waiting boys. With a twinkle in his eye belying his sober face, he announced most gravely — "That, gentlemen, is a HUMBUG!"

The acquaintance that matured to a lifelong friendship marked the beginning of Norman's work with the Department of Agriculture: as a "Grasshopper expert" in his own

area, where he developed the "Criddle mixture" of poison to combat the plagues; as Seed collector and analyst, as Field Entomologist and as artist to illustrate two books — "Farm Weeds" with text by Dr. Fletcher, and "Fodder and Pasture Plants" with George Clarke and M.O. Malte. He was commissioned to do a series of — I think it was about 175 — wildflower paintings for exhibition at the St. Louis World Fair in 1903. In 1913, a small laboratory was built on the farm, to be replaced in 1923 by a larger one, so he could more efficiently continue his work as Entomological Field Officer for Manitoba. From this centre, he could travel to Manitoba and Saskatchewan points to investigate insect infestations as reported. Surrounded by his familiar environment, he could also continue his research and study of Manitoba wildflowers, birds and mammals. His "Calendar of Wildflowers" was published as a checklist of all those he had identified in the area. "A Calendar of Bird Migration" covering the statistics of 25 years, was published in "The Auk" in 1922. The fact that he had seen Whooping Cranes for 8 of those 25 years now seems almost incredible.

In his earlier years of work with the Department of Agriculture, Norman kept his younger brothers and sisters involved in his efforts. While working in Ottawa, he sent back letters requesting specific weed seeds for the departmental collections. This increased their knowledge of the local weeds, kept them busy collecting enough seeds for the sample bottles, and gave them the first "pocket money" they had ever had. The family suffered such hardships and deprivations, including near-starvation, during their early years on the farm, that any money earned by any of them was turned over to the family household purse to help provide the bare necessities of life. Nothing was wasted, or used lavishly. Every scrap of paper was recycled. Norman often used the back of calendar pages for his paintings since he could not afford any real art paper. Opened-out envelopes served for lists, whist scores, or field notes — but they were not thrown out, unused, as soon as the contents had been extracted. In 1900, Norman confided to his diary that he was almost desperate for paper to continue his painting, and for money to purchase paints as well as other items for his "Naturalistic searches". He wrote that "the sum of one dollar would help me enormously. In fact the sum of two dollars would overcome all difficulties. Yet this small sum seems as far off as the moon".

When the weed seed collections were completed, the family were asked to collect insects — when Norman's work in Ottawa needed specimens. He had labels made up with the initial of each brother and sister, so all insects sent by them were meticulously identified as to the collector. "N. Criddle, Aweme", was not the only name on the labels — the initial might be S., E., or T., depending on who had collected and sent the insect to him. He always gave credit for any such help received. His letters specified what beetles he needed — and the requests were enhanced by his own pen-and-ink sketches. One showed a parade of beetles marching out of an overturned bottle onto his desk. (Thanks to Dad, this letter is now in my possession). Such requests continued the family's education, now in entomology, and made sure that alertness and attention to details were a daily part of "classes". Evelyn became the acknowledged champion as a Tiger Beetle collector. While the rest wandered in search of prey, his method was to locate a likely spot — and then stand, sit or kneel, motionless, eyes alert. So long as the searchers roamed, the Tiger Beetles froze, camouflaged against their background. But as Evelyn remained quiet — the beetles resumed their activity — his eye caught the movement — and another beetle was added to the bottle! Talbot (my father) copied his technique, and became just as successful. The method was as effective this last summer when he was asked to collect for someone in Minnesota. The 101 specimens sent as a result of his field trips earned him the distinction, at 84, of being the "oldest active Tiger Beetle collector in North America" (At least, it hasn't been contested yet). A field trip with two University students from the States in 1971 was written up by them as quite an event. I'll quote from their notes — "Tully Criddle, 81 this year, is the youngest brother of the late Norman Criddle. We were informed that Tully was playing tennis! When we reached him, he offered to take us on a collecting trip. The following day, the three of us collected for six hours in the Wawanesa area. After we returned to Brandon, Mr. Criddle went to the tennis court for a 'little more exercise'! We went to bed".

Stuart Criddle, the third brother, joined in the collecting of weed seeds and insects, but turned later to his preferred aspect of natural history — small mammals. He had numerous

papers published, in conjunction with Norman at first, then individually. The snakes of the Aweme area also interested him, an interest that resulted in a published article that is still quoted. At one time he had a small grass snake and a coral-bellied snake under observation. When he offered me a look, his wife hovered very close, almost terrified lest my then childish hands drop the glass jar in which they were confined — and turn the two reptiles loose in their living-room! Gardening was equally important to Stuart — he developed new strains of sunflowers and lilies, having one new lily named for him. In 1968, as a result of his work in natural history, Stuart received an honorary degree from the University of Brandon.

Maida became the "homemaker" taking her Mother's place after the death of both parents in 1918, keeping house for her brothers, and acting as hostess for Norman's guests and business associates. Such men as Dr. R. Bird, Dr. R. Handford, R.M. White, Dick Painter, Dr. Arthur Gibson came to stay for long or short periods in "The Big House" as St. Albans was known. J.B. Wallis was also a visitor and friend of many years' standing. He had become acquainted with the family while he was a school teacher in the district — and was a welcome guest immediately because he played a good game of cricket. He returned to visit regularly — and collected some of the Tiger Beetle specimens there that were later used in his book on the subject. "J.B." as he was known to most people, also joined the hunting parties of later years for bigger game — ducks or deer.

Maida continued the weather records begun by her father in 1884, carried on by Norman from 1918 until his work kept him away from home too much, and kept as a continuous weather log until the family moved to B.C. in 1960. The records were sent to Ottawa as official reports until 1942. For her efforts in this, Maida received a Centennial Award Plaque, when she returned on a visit to Manitoba in February, 1972.

Maida's ways with wild creatures had been noted in 1930 by Bert Cartwright in the Tribune's "Wild Wings" column. A picture showed her with redpolls perched on her shoulders and arms, clustered over a pail of seeds which she fed to them daily during the winter. Mr. Cartwright wrote that "she possesses that rare quality that wins the confidence of wild creatures, an influence that dissipates their fears and which engenders a trust which is never betrayed. Chickadees swarm over her. Redpolls do the same, as we see, and Canada Jays feed from her hand. I do not know of anyone else in Manitoba who has made friends with Redpolls so successfully". A prairie chicken found her a soft touch, and sat on the woodpile every morning, scolding fiercely if she did not appear quickly enough with his breakfast. A crow became a regular visitor later on — perching at the top of a tree to wait for Maida to come out to feed her chickens — and him! He could be equally impatient if she was late. She seemed to be the only one he trusted, and he showed no fear of her. Dr. Ralph Bird wanted to photograph her "pet" with her, so he settled himself in the best spot for pictures one morning, to be ready when Maida came out. But the crow would not come down while the stranger was present. He perched on the treetop, cawing and scolding, furious at this intruder who was keeping him from breakfast! Finally, Dr. Bird had to admit defeat — gathered up his equipment and retreated inside the house. Immediately the crow became quiet and flew down to join Maida — and to eat. Dr. Bird could see it all from the kitchen window — but not go near enough to take the pictures he wanted. This crow returned every summer for 8 years. He was easily recognized because of one missing toe. The bird was not banded, so the family never knew his fate, when he did not return the 9th summer.

In an unofficial capacity, Evelyn was the acknowledged weather expert for the district. In the days before radio became a regular household appliance, and when "weather outlooks" were still unheard of, the Criddle phone often rang early on winter mornings. On cold days, mothers wanted to know Maida's temperature reading, so they could decide whether to wrap an extra scarf around Junior's face for his walk to school. And Evelyn was sought out for his weather predictions. If someone wanted to know if it was going to be too windy for haying, or if a dust storm would spoil the weekly wash hung out — he or she asked Evelyn. If a blizzard was possible, Evelyn would know! Studying the clouds, the Aurora, hazes — many little signs indicated weather changes (to him) — Evelyn was right often enough that his word was respected.

This may sound as though the Criddle family were totally absorbed by natural history or the farm. Not so! Percy encouraged them in games and sports from the first, for they had to provide their own entertainment, and recreation was considered as necessary as hard work. Cricket, tennis, football, billiards, chess, cards, skating, hockey, baseball and golf, were all taken up with enthusiasm and increasing skill. The fact that the tennis court, the golf course, or the rink on river ice, were not of professional standard, did not spoil their enjoyment of games. Their first billiard tables were homemade by Percy and the older boys. Perhaps the uncertainties increased their skills as they had to compensate for the extra hazards. Around the turn of the century, the boys took up wood carving, using odd bits of wood to fashion inlaid cribbage boards and boxes. Ivory keys from an old organ were shaped and filed to add a contrast to the woods. And the boys found that the inner layer of clam shells from the Assiniboine River provided them with a source of mother-of-pearl from which they fashioned roses, hearts and diamond-shapes to insert for even greater beauty in their patterns. Some of their tools were hand-made first, so the chisel or knife would have just the right size or shape needed for the job.

My attention seems to have focused on those members of the family best known for their contributions to the science of natural history. The other daughters were homemakers. Two married and encouraged their children to an interest in nature, just as they had been taught. The youngest, Alma, died at 23, of cancer.

(Received 26 March 1975)

IMPACT OF FENITROTHION UPON JAPANESE QUAIL (*Coturnix Coturnix Japonica*) IN A FOREST ECOSYSTEM

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ABSTRACT: Fenitrothion residues and cholinesterase activities were measured in Japanese quail caged in a parkland area during aerial application of fenitrothion at 4 oz a.i. per acre. No fenitrothion related mortalities or fluctuations in body weight were recorded. Residues were detected in crop contents (0.06-1.9 ppm, wet weight) and carcasses (0.007-0.24 ppm, wet weight) of the quail at 8 hours after spraying. The residue levels declined by 2 days after spraying and by day 5 were undetectable. Quail in pens without any canopy protection exhibited a 62.5% suppression in the activity of serum cholinesterase at 8 hours after spraying. There was partial recovery of the enzyme activity by 2 days and complete recovery by 5 days postspray. This enzyme was not affected in birds caged under the spruce canopy. Birds in pens without canopy protection experienced a 13% suppression in brain cholinesterase activity, which did not completely return to normal 5 days postspray. In canopy pens brain cholinesterase was significantly suppressed in only 1 of 3 pens. Canopy protection reduces the impact of fenitrothion upon birds in a sprayed forest, but some residues will always reach them, be present for a short period of time and moderately reduce brain cholinesterase activity.

INTRODUCTION

Assessing the impact of pesticides used in our environment upon birds inhabiting spray areas is a difficult task, and frequently attempted by extrapolating laboratory results into field situations. Comprehensive studies with the mouse, rat and guinea pig have dealt with the absorption, distribution and excretion of fenitrothion (0,0-dimethyl-0-(4-nitro-m-tolyl) phosphorothioate). Following oral administration fenitrothion is rapdily absorbed (Douch *et. al.* 1968); residues rapidly disappear from blood and other tissues (Miyamoto 1964), with the result that an oral dose can be completely recovered in the urine and feces 3 days after administration (Hollingworth *et. al.* 1967). Since residues remain in the mammalian body for only a brief period, fenitrothion should not create a long-term or cumulative hazard for mammals following a single spray application. However, comparison of the acute oral LD_{50} values of fenitrothion for rats (570-740 mg/kg; Gaines 1969), with that of Bobwhite quail (27.4 mg/kg; Tucker and Crabtree 1969), indicates that the use of laboratory data for mammals to predict hazard to birds in the field is not justified.

In 1973, fenitrothion was used to control spruce budworm *(Choristoneura fumiferana* Clem.) in a parkland region of south central Manitoba. This is a report of field studies to assess the impact of fenitrothion upon Japanese quail caged in the sprayed area.

MATERIALS AND METHODS

The study site was an area of rolling topography along Pine Creek near Carberry, Manitoba consisting of a white spruce canopy and non-treed areas with numerous deciduous shrubs and grasses. Six pens, 13 feet long, 9 feet wide and 2 feet high, were built of 2 x 2 inch lumber and covered with chicken wire without disturbing the native shrubs and grasses. These pens were located along a 1000 foot transect perpendicular to the flight path of the spray plane. An additional control pen was located in an untreated area about one mile from the spray area.

Three treatment pens were placed in areas with no canopy. The quail in these pens would be exposed to the insecticide in the spray through dermal absorption, inhalation and

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Table 1. Weight (gm) of Japanese quail in control and treated pens (mean of 4 birds)

Pen location	Pen number	Prespray	Postspray (days) 0.33	2	5
Open	2	92.8	85.9	81.2	89.5
	5	86.4	90.4	85.1	84.9[a]
	6	91.7	93.0	86.8	80.8
Canopy	1	82.8	83.9	91.5	88.1
	3	88.0	89.1	90.4	95.5
	4	82.8	86.3	87.0	89.9
Control			84.7	82.3	87.1

[a] Value for one bird

Table 2. Residue level of fenitrothion (ppm, wet weight) in crop contents and carcasses of Japanese quail (mean measurements for 4 birds, except as noted). Fenitrothion residues were not detected in control birds

Pen location	Sample	Pen number	Prespray	Postspray (days) 0.33	2	5
Open	Crop	2	0	0.126	0.061	N.D.
		5	0	0.459	N.D.[a]	N.D.[b]
		6	0	0.110	N.D.	N.D.
			$\bar{x}$ =	0.232	0.020	
	Carcass	2	0	0.244	0.037	N.D.
		5	0	0.066	0.011	N.D.
		6	0	0.045	0.013	N.D.
			$\bar{x}$ =	0.118	0.020	
Canopy	Crop	1	0	0.386	0.204	N.D.
		3	0	1.894	N.D.	N.D.
		4	0	0.084	N.D.	N.D.
			$\bar{x}$ =	0.788	0.068	
	Carcass	1	0	N.D.	N.D.	N.D.
		3	0	0.019	0.007	N.D.
		4	0	0.039	0.009	N.D.
			$\bar{x}$ =	0.019	0.005	

[a] Non detected

[b] Value for one bird

via the food and water they consumed. The other three treatment pens were placed under the spruce canopy so that budworm killed by the spray would fall down into the pens where the quail could consume them. Birds in these pens would receive less exposure via the inhalation and dermal routes due to protection afforded by the tree canopy, but would conceivably receive a high oral exposure from the consumption of poisoned budworm.

Male Japanese quail, *(Coturnix coturnix japonica)* were pre-conditioned to a herbaceous diet in the laboratory. Two days before the spray was to be applied 22 quail, each 10 weeks old, were picked at random and placed in each pen to allow for further acclimation. They consumed grasses and broadleaf plants in the pen as well as insects including budworm falling from the spruce trees. This natural diet was supplemented with chick starter crumbles (Feed Rite, 21%) which were sprinkled in the pens each day to provide 50% of the birds daily dry matter requirement. Water from nearby Pine Creek was supplied in 2 gallon self-waterers.

Fenitrothion was applied by aircraft at 4 oz a.i. per acre at 0600 h on 7 June 1973, when the wind velocity was very low and spray cards indicated that the spray pattern was uniform throughout the treated area (Hildahl and DeBoo 1973).

Four birds were taken at random from each pen at each of 12 hours before and 8 hours, 2 and 5 days after spraying. Birds were weighed and then killed by decapitation. Blood was collected and allowed to clot before serum was separated by centrifugation. Brains and contents of the crops were removed and frozen at -40°C as were the remaining carcasses until analyses were performed.

Cholinesterase activity was measured in serum at 40°C by the method of Ellman *et al.* (1961) using prepared reagents from Boehringer Mannheim Corporation, and in brain tissue manometrically at 40°C using a Warburg apparatus (Knowles and Casida 1966, Hogan and Knowles 1968) with acetyl choline chloride as substrate. For residue analysis the bird carcasses were thawed, plucked and ground in a meat grinder. A 10 gm sample from each homogenized carcass was analyzed for fenitrothion (parent compound only) using the method of Grift and Lockhart (1974). Crop contents (0.3-0.6 gm) from the birds and collected insect samples were analyzed by the same technique. Standard errors and ANOV were calculated according to methods in Steel and Torrie (1960).

RESULTS AND DISCUSSION

During the two days prior to spray application the birds were actively searching for food and investigating their surroundings. Their activity was subdued the first day following spray application but by the second day their pretreatment activity had returned. The birds appeared to feed normally on the foliage and any insects falling into the pens (for example, spruce budworm) throughout the remainder of the study.

The body weights of birds, taken at each sampling, remained normal for all pens for 5 days following fenitrothion application, indicating that adequate food was ingested and that fenitrothion had not affected their feeding behaviour (Table 1). The only quail deaths recorded during this experiment were due to predation and not to the effects of fenitrothion.

Dead budworm larvae and dragonflies were collected 4-6 hours after spray application and analysis revealed 5 to 13.5 ppm fenitrothion (wet weight). Quail consuming these insects were therefore ingesting fenitrothion, and residue levels measured in crop contents and carcasses of the quail are presented in Table 2. Maximum fenitrothion residues were detected in contents of the crops and carcasses of all treatment birds at 0.33 days after spraying. Samples collected 2 days after spray application had lower residue levels and day 5 samples did not contain any detectable fenitrothion. This rapid decline of residue levels in the quail indicates that the environmental exposure to fenitrothion was rapidly decreasing under the conditions of this experiment. Rapid disappearance of fenitrothion from plant materials following spray application has been observed by Yule and Duffy (1972) who reported 50% disappearance of fenitrothion in 4 days following the spraying of a New Brunswick forest. Leuck and Bowman (1969) also reported 50% disappearance in 1 day and 90% disappearance in 7 days following application of fenitrothion to bermudagrass.

Table 3. Serum cholinesterase levels (mU/ml) of Japanese quail before and after fenitrothion spraying. [a] Values are means and standard errors of measurements for 4 birds except as noted

Pen location	Pen number	Prespray	Postspray (days) 0.33	2	5
Open	2	1918 ± 298	525[b] ± 84	808[b] ± 153	1378[b] ± 118
	5	1993 ± 245	634[b] ± 141	1534 ± 191	2450[c]
	6	1953 ± 205	1039[b] ± 254	1668 ± 188	1588 ± 299
Canopy	1	1796 ± 149	1430 ± 174	1540 ± 118	1993 ± 258
	3	1918 ± 97	1740 ± 116	1492 ± 207	1825 ± 81
	4	1850 ± 236	1481 ± 329	1731 ± 90	1690 ± 244
Control			1965 ± 131	1875 ± 225	1898 ± 122

[a] Acetyl cholinesterase activity is expressed as milli Units/ml of serum as in the method of Ellman *et al.* (1961).

[b] Significantly different (ANOV, $P \leq 0.05$) from the prespray value.

[c] Value for one bird.

Table 4. Brain cholinesterase levels of Japanese quail before and after fenitrothion spraying.[a] Values are means for 4 birds except as noted

Pen location	Pen number	Prespray	Postspray (days) 0.33	2	5
Open	2	6.19	5.87	5.20[b]	5.22[b]
	5	6.68	5.81[b]	5.42[b]	4.53[c]
	6	6.50	5.13[b]	5.56[b]	5.87[b]
Canopy	1	5.89	5.67	5.96	5.71
	3	6.24	5.64	5.46[b]	5.58[b]
	4	6.20	5.87	5.51	5.71
Control			6.32	6.09	6.19

[a] All values are activity expressed as micromoles acetylcholine hydrolized per hour per mg protein.

[b] Significantly different (ANOV, $P \leq 0.05$) from the prespray value.

[c] Value for one bird.

Birds in canopy pens had higher residue levels in the contents of their crops at 0.33 and 2 days after spraying than those in open pens, possibly the result of relatively high consumption of poisoned budworm by birds in the canopy pens. On the other hand, birds in open pens had the highest carcass residue levels at 0.33 and 2 days after spraying, possibly the result of relatively high inhalation and dermal exposure of these birds.

The measurements of serum cholinesterase activity presented in Table 3 clearly indicate a different response between the open and canopy covered pens. There was a significant (ANOV, $P<0.05$) reduction in the serum cholinesterase activity in the birds in all the open pens at 8 hours after spraying. On the average, the birds in these 3 pens experienced a 62.5% suppression in the activity of this enzyme. The birds in all the open pens exhibited some recovery in the activity of serum cholinesterase by 2 days after spraying. At 5 days after spraying the serum cholinesterase activity of the birds in pen 2 was still recovering; however, the activity remained significantly below the prespray value. At the same time birds in pens 5 and 6 were experiencing a stabilization of their enzyme activity at levels that were not significantly different from their prespray values. Only 1 bird was analyzed from pen 5 on day 5 since the other birds in the pen had disappeared, and cage damage indicated predatory animals. The birds in the canopy covered pens did not experience a significant change in their serum cholinesterase activity at any time following the application of the spray.

Comparing the results of Tables 2 and 3 it can be seen that at 0.33 days after spraying quail in the open pens which had the highest carcass residues concomitantly had a statistically significant depression in serum cholinesterase activity.

Brain cholinesterase measurements are presented in Table 4. Birds in all 3 of the open pens exhibited a significant reduction (ANOV, $P<0.05$) in the activity of brain cholinesterase following spray application. Similar reductions occurred in birds in only one of the 3 canopy pens. Thus the most consistent effect upon brain cholinesterase activity was experienced by birds in the open pens, which coincides with the serum cholinesterase results (Table 3). At 0.33 days after spraying quail in the open pens experienced a 62.5% reduction in serum cholinesterase but these same birds experienced only a 13% reduction in brain cholinesterase. Miyamoto (1969) reported a similar observation in mice; brain and blood cholinesterase were both suppressed by ingested or inhaled fenitrothion, but the suppression was much less for the brain enzyme than it was for the blood enzyme.

In 2 of the 3 open pens the reduction in serum cholinesterase activity was evident only at 0.33 days after spraying (Table 3). The effect upon brain cholinesterase lasted for at least 5 days in the same birds.

CONCLUSIONS

This study was conducted with Japanese quail to determine whether aerial application of fenitrothion to a forested area at 4 oz a.i. per acre, would or would not result in the accumulation of fenitrothion residues in bird tissues, and if so, whether the insecticide would produce measurable effects on the birds. Fenitrothion was detected in insects eaten by the birds, in the contents of their crops and in the carcasses of the birds. Detectable residues were present in the birds at 0.33 and 2 days after spraying but by day 5 residues were undetectable. Fenitrothion exposure in this study was insufficient to produce any mortality or cause any fluctuation in body weight of the quail.

Birds in open pens did receive sufficient fenitrothion intake to cause a brief suppression (<2 days) in the activity of serum cholinesterase, but brain cholinesterase activity was suppressed to a lesser degree for at least 5 days after fenitrothion application. Birds in pens located under the spruce canopy did not experience a suppression in the activity of serum cholinesterase but birds in 1 of the 3 pens encountered a significant suppression in brain cholinesterase activity.

Of the parameters measured in this study brain cholinesterase activity was probably the most important. Effects upon this enzyme were still evident 3 days after fenitrothion residues were no longer detectable in the bird tissues. The significance of this observation is being investigated in laboratory experiments.

Quail in pens under the spruce canopy were less effected by the fenitrothion spray than those in the open pens. If the birds in the canopy pens do simulate the exposure conditions of native birds, it is possible that the activity of their brain cholinesterase could be reduced when fenitrothion is applied to a parkland area at 4 oz a.i. per acre. The long term effect, if any, of this reduction in enzyme activity, is unknown.

ACKNOWLEDGEMENTS

This project was supported by a grant from the University of Manitoba Research Board. The work of Mr. D.A. Metner in doing the brain cholinesterase measurements and Mr. N. Grift in doing the fenitrothion chromatography is much appreciated.

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(Received 4 September 1974, Accepted 27 May 1975)

UPTAKE OF FENITROTHION BY CAGED CRAYFISH *Orconectes virilis*, IN PINE CREEK, MANITOBA, 1973

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ABSTRACT: Crayfish, *Orconectes virilis* (Hagen), were caged in a small permanent stream approximately 3.5 weeks before fenitrothion was applied by aircraft to the surrounding Spruce Forest at 279 g a.i./hectare (4 oz. a.i./acre). No mortality or behavioural changes followed this application. Fenitrothion was detected in samples of crushed whole crayfish at levels up to 1.37 µg/g (1.37 p.p.m.) and it persisted in some crayfish for periods up to one month.

INTRODUCTION

In 1973 fenitrothion was sprayed at a rate of 279 g a.i./hectare (4 oz. a.i./acre) over plots in the Spruce Woods Provincial Forest and several small test plots a few miles north of the forest (Hildahl and DeBoo 1973) for control of spruce budworm, *Choristoneura fumiferana* (Clemens). Pine Creek, a small permanent stream in one of the test plots mentioned above, was selected to assess the effects of fenitrothion on caged crayfish, *Orconectes virilis* (Hagen). This species, although it does not occur naturally in Pine Creek, is native to the Nelson River drainage in which Pine Creek is situated (Fedoruk 1970). It was used as a test animal because it is a food for some fish and mammals and had demonstrated concentration of some toxicants e.g. mercury, Hamilton (1972); DDT, Hopkins, *et. al.* (1966). This experiment was a preliminary attempt to see if crayfish would survive in the stream with or without "force-feeding", if they would accumulate fenitrothion and if so, if the fenitrothion would affect the survival and development during the thirty days following treatment.

MATERIALS AND METHODS

Crayfish cages (22 x 15 x 10 cm) were constructed from 0.6 cm wire mesh. On 14 May 1973, 6 animals were placed in each of 12 cages and 4 cages were anchored midstream with natural vegetation and driftwood at each of the 3 stations used by Flannagan (1973) in his drift studies: Station 1, the control station, approximately 1.6 km upstream from the test spray plot; Station 2, located in the centre of the test plot; and Station 3, nearly 0.4 km downstream from the test spray area.

The crayfish stock was 2-year old adults that had been reared in the laboratory from the eggs of a single "in berry" female which had been collected from the Rat River near St. Malo, Manitoba. Animals were tagged by clipping the pleurons with scissors as outlined by Dr. W. Momot, Ohio State University (personal communication). Inventory for each crayfish included records of sex, reproductive stage, body weight and length and indications of moulting.

At each station animals in two of the cages foraged for "drift" food available in the stream while animals in the remaining two cages were "force-fed" daily by squirting a suspension of tetramin B commercial fish food in stream water into the oral cavity with an eyedropper. All crayfish were monitored daily to ensure they were alive and disease free. Force-feeding was discontinued at the end of May since animals appeared to survive equally well on drift.

The date of fenitrothion treatment was 7 June 1973. At sampling times, prespray; 10, 19 and 30 days postspray, one cage of animals was removed from each station in the stream. Samples were to be taken on treatment day and during the week following if any crayfish died. Inventory data for the crayfish were recorded, then all the specimens from a site were

placed in a plastic bag, cooled on ice and transferred to a freezer as soon as possible. Two frozen crayfish which had not moulted were taken from each sample. Their whole bodies were crushed together and analyzed for fenitrothion residues using gas-liquid chromatography (Grift and Lockhart 1974).

RESULTS AND DISCUSSION

No crayfish died during the experiment. Development appeared normal for all animals throughout the study: copulation was observed in May, moulting began early in June and animals did not lose weight. Flannagan (1973) reported that fenitrothion was not detectable in sediments at any of the stations. It is possible that the crayfish survived the initial dosage of fenitrothion because they were shielded by the silt that accumulated in the cages between daily examinations. Further sublethal effects of the treatment on crayfish such as biochemical disturbances observed by Rorke *et. al.* (1974), in snails, might have been demonstrated by laboratory experiments.

The analyses (Table 1) show that fenitrothion was accumulated by crayfish at all three stations. Fenitrothion was probably ingested with water, vegetation and invertebrates contaminated by the spray. Sundaram (1973) and Lockhart (1973) have shown that fenitrothion is rapidly photodegradable. Since the highest level of fenitrothion in the stream water was 0.064 mg/l which dwindled to trace amounts (< 0.1 µg/l) a few hours after the spray, and the crayfish accumulated fenitrothion up to 1.37 µg/g 19 days after the spray; it appears crayfish accumulated fenitrothion above environmental levels and continued to do so long after the insecticide had disappeared from the surrounding silt and water.

Table 1. Concentration (µg/g) fenitrothion in crayfish. Pooled samples were prepared by crushing whole bodies of two frozen crayfish. Treatment was applied 7 June 1973. Levels of fenitrothion listed at <0.1 µg/g (in crayfish tissues) are interpreted as trace amounts.

Sampling sites	Prespray	Days after Spray 10	19	30
Station 1	0	<0.1	<0.1	0.15
Station 2	0	0.14	0.21	0.28
Station 3	0	0.84	1.37	0.1

It may be that accumulation was most rapid and reached the highest levels at Station 3 because those crayfish initially fed on invertebrates which were killed in the spray area and floated downstream. After the lethal effects of fenitrothion had passed, those crayfish presumably fed on surviving, less contaminated invertebrates and by the 30th day post spray the crayfish at Station 3 had eliminated most of their accumulated fenitrothion. The crayfish at Station 2, in the spray area, presumably continued to ingest surviving invertebrates contaminated by fenitrothion throughout the sampling period.

At Station 1, the recovery of fenitrothion residues 30 days post spray (Table 1) coincided with the sudden appearance of 0.5 µg/l fenitrothion in water samples (Flannagan 1973). This delayed contamination may reflect the dispersion of fenitrothion by aerial drift which eventually may have entered the stream with run-off water upstream of the spray area.

CONCLUSIONS

Although fenitrothion accumulated in the crayfish, neither mortality nor behavioural abnormality was observed within one month after spraying.

ACKNOWLEDGEMENTS

Thanks are due to the following people for their assistance: Mr. J.F. Flannagan kindly suggested the sampling stations and contributed valuable comments on all phases of this project. Mr. N. Grift provided the fenitrothion analyses and Mr. T. Mitchell constructed the sampling cages.

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(Submitted October 18, 1974
rewritten March 19, 1975.)

TESTS OF ARTIFICIAL SAMPLERS FOR COLLECTING STREAM MACROINVERTEBRATES IN MANITOBA

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ABSTRACT: The sampling efficiencies of four types of artificial samplers for macroinvertebrates were compared and the minimum period required to attain maximum stable colonization determined. The tray sampler ranked first in terms of sampling efficiency, the Hester-Dendy multiple plate sampler second, a chicken barbecue basket third and a pipe sampler fourth. When factors of cost and handling ease are considered with sampling efficiency, the Hester-Dendy ranked first. A 4-week period was adequate to achieve stable colonization and this period did occur between the last week in May and the first week in July.

INTRODUCTION

During the past 40 years artificial samplers have been widely used for qualitative and quantitative macroinvertebrate collections from lotic and lentic environments (Moon 1935, Moffet 1935, Surber 1939). Typically samplers have been employed where sediment types, water depths and current velocities have precluded the use of conventional dredge or bottom samplers.

Basket samplers have been utilized for water quality monitoring in Manitoba, and sampling efficiencies of the baskets and steel trays have been compared (Crowe 1969 and 1972a, b, and c). Many other sampler types exist, some designed for specific conditions and individual sampling requirements. In 1973, an experiment was designed to compare the relative efficiencies of four samplers; Hester-Dendy, basket, steel plate and pipe; using as criteria generic numbers and population densities. The minimum period required to attain maximum stable colonization and the most productive season in terms of diversity and densities were assessed.

The site chosen was the Whitemouth River within the Pineland Forest Nursery at Hadashville, Manitoba (Fig. 1). The Whitemouth River has a drainage of 3,509 km^2 in a region of mixed forest and farmland (Fedoruk 1970). At the site, the river is approximately 27 m wide. Water depths vary from 0.15 to 1.5 m and current flows from 0.09 to 1.67 cfs. Bottom sediments included boulders, cobble, gravel and sand.

METHODS AND MATERIALS

Sampler Details

The multiple plate sampler was similar to that described by Hester and Dendy (1962). Tempered hardboard plates provided a surface area of 0.9 m^2. The lead weights ensured that the sampler remained submerged (Fig. 2a). Cost of materials for one sampler was \$1.50[a].

The pipe sampler was designed and built by Research Branch[b] personnel to reduce the escape of organisms when retrieved (Fig. 2b). Cost of materials for this sampler was \$6.06[a] each. Galvanized sheet metal formed a cylinder 30 cm long and 12.5 cm in diameter. The

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[a] 1973 prices.

[b] Manitoba Department of Mines, Resources and Environmental Management.

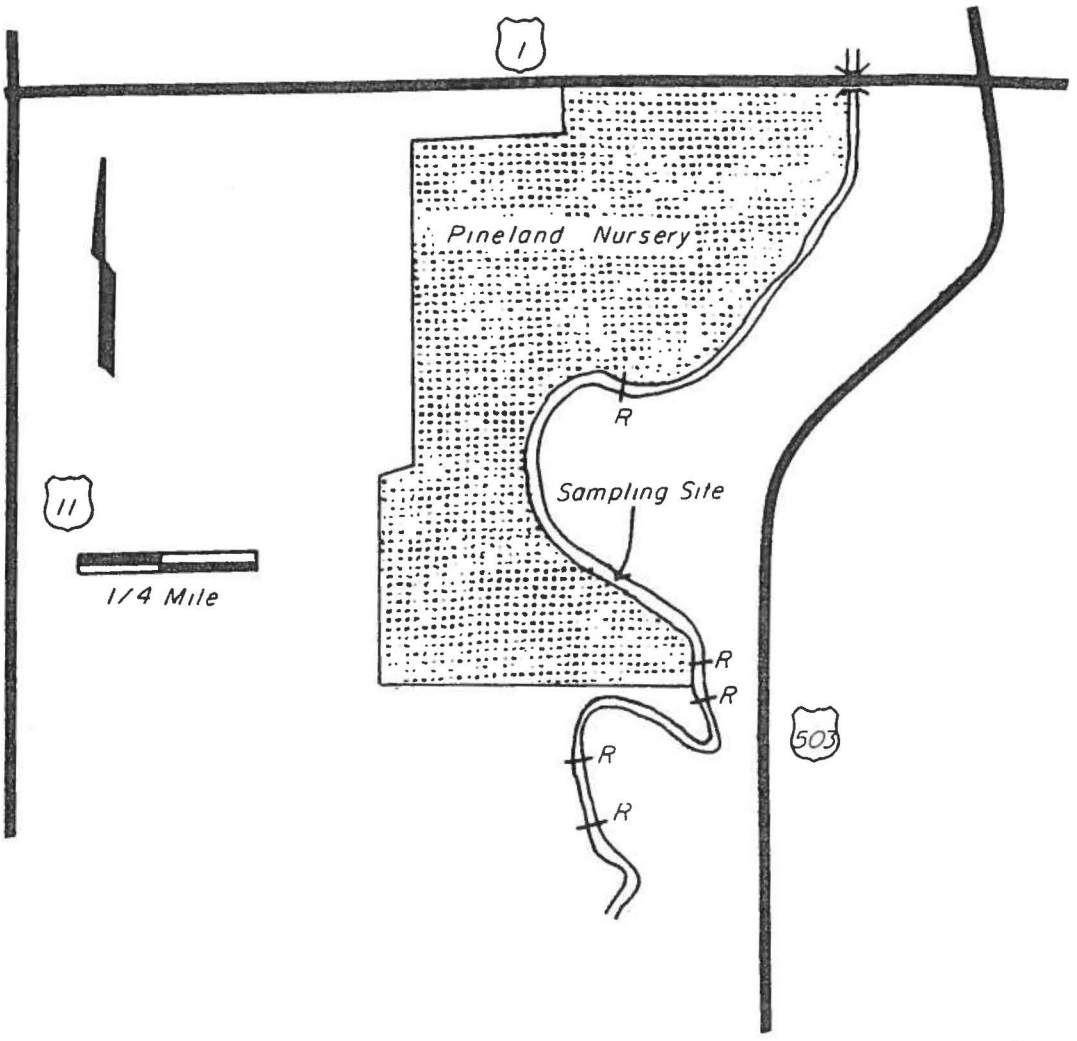

Figure 1. Artificial substrate sampling site, Whitemouth River, near Hadashville, Manitoba.

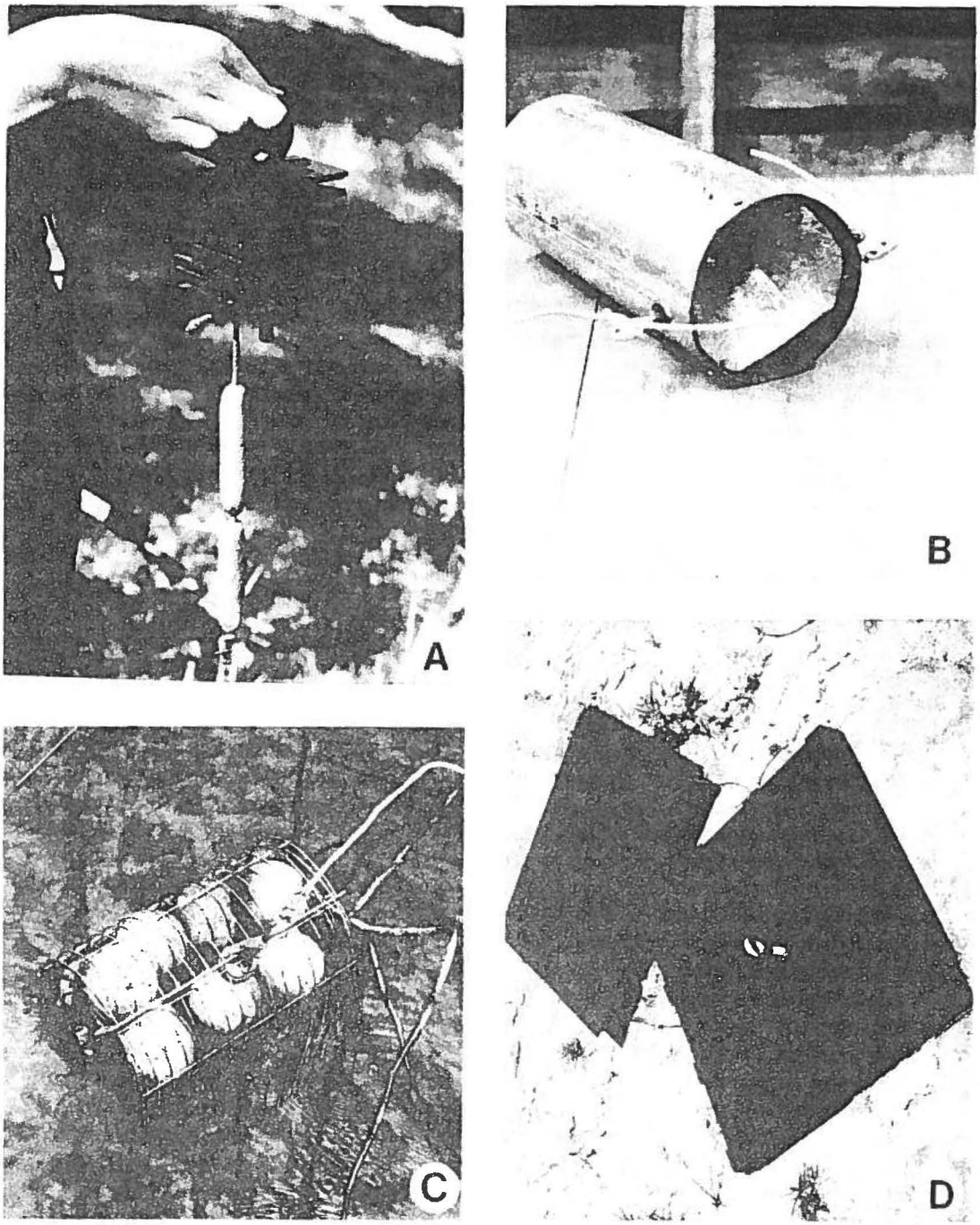

Figure 2. Types of sampler tested for efficiency: A. Hester-Dendy multiple plate sampler; B. Pipe sampler; C. Basket sampler; D. Tray sampler.

front was fitted with a recessed cone and ring bolts. The back was equipped with a #40 U.S. mesh screen. Colonization area was 0.165 m^2 provided by nine 7.5 cm styrofoam balls inside the cylinder. An 8-pound lead weight provided ballast.

The basket sampler was a commercial product, the chicken barbecue basket (Mason *et al* 1967). A surface area of 0.183 m^2 was provided by ten 7.5 cm styrofoam balls (Jacobi 1971). Each sampler cost \$6.74[a] (Fig. 2c).

The steel tray was 40 cm square and 3.1 cm deep. Two layers of expanded metal mesh plus the tray bottom provided 0.42 m^2 for colonization (Fig. 2d). Each sampler cost \$17.78[a] for materials and construction.

Sampling was carried out from 19 April to 13 September 1973. Six pairs of each type of sampler were set as shown in Figure 6. All samples rested on the bottom except the Hester-Dendy which were suspended from the float mechanism 1 m below the surface. The float consisted of a 14 ft. 2 x 4 inch board to which were attached six 1 foot styrofoam cubes. At weekly intervals over a six week period starting one week after all samplers had been initially set, two pairs of each sampler type were lifted, the organisms removed and the sampler reset. Individual samples were concentrated by washing through a conical nylon net having mesh openings of 0.49 mm. A vital stain, Rose Bengal with 95% alcohol was used as a preservative (Mason and Yevich 1967). In the laboratory the samples were further concentrated, and the organisms separated, enumerated and identified.

Statistical analyses included two-way analysis of variance and Duncan's multiple range test. The first test was performed to determine if there were significant differences between numbers of genera and densities versus sampler and time. The second test shows the sources of difference as indicated by a significant F value. The number of genera per sample were transformed using $\sqrt{x}$ and densities using log x.

RESULTS

Organisms collected by all samplers during the test periods included 61 genera from 14 taxonomic groups (Table 1). Most forms identified were of the order Diptera, particularly the Chironomidae, the Ephemeroptera and Trichoptera. No group was collected exclusively by one sampler.

Analysis of variance results are shown in Table 2. Duncan's multiple-range test was used to determine the sources of difference indicated by significant F results (Table 3). The pipe sampler was inferior to the other samplers in collecting numbers of genera. Samplers were ranked according to the values of the transformed taxa data (Table 4). The trays ranked first, the Hester-Dendy second, the baskets third and the pipe fourth. Fewer taxa and lower population densities were collected in traps set on 19 April, 26 July and 16 August, regardless of the length of the set period.

The maximum numbers of genera and maximum densities for most samplers tested increased up to the fourth week after which oscillations began to appear (Table 5). While some advantages should result from either an increase in generic composition or densities, the task of sorting, identifying and analyzing such masses negates the objective of water quality monitoring. Both generic numbers and densities were high from the end of May to the beginning of July.

Time and handling ease are factors to be considered. Handling time including retrieval, cleaning and resetting varied from 5 minutes for the multiple plate samplers, to 10 minutes for the baskets, to 20 minutes each for the trays and pipes. The trays are both awkward and heavy and it is difficult to prevent the escape of organisms during retrieval. The pipe samplers with galvanized construction and inward protruding metal screws were hazardous to handle.

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[a] 1973 prices.

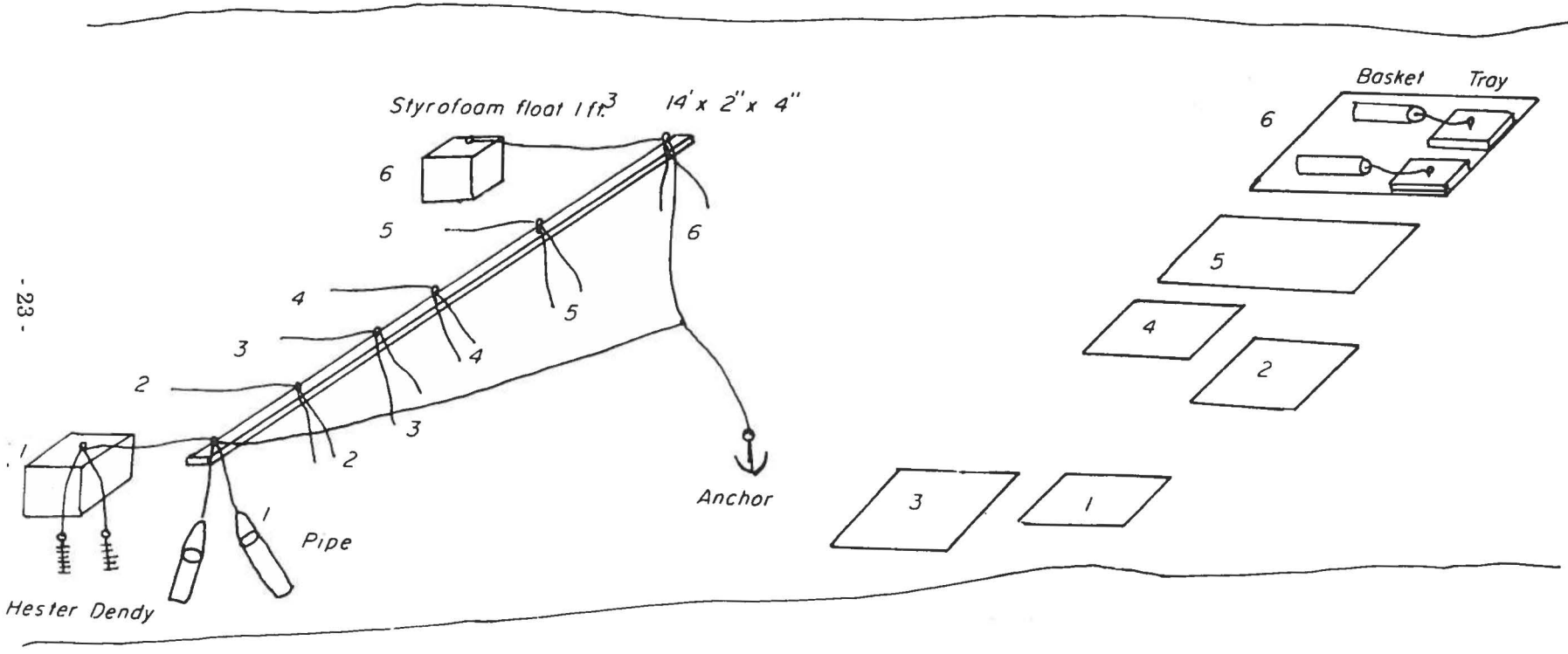

Figure 3. Experimental design for testing the samplers. Each number indicates the position of a pair of samplers of a particular type.

CONCLUSIONS

Artificial substrates can be placed and retrieved during varying weather and stream conditions, they can provide qualitative data on the occurrence of taxa and, if uniform substrates are used, they can provide quantitative population information (Coffman 1971). Their disadvantages are losses due to disturbance, predation and vandalism, disparity between collections and actual populations, variability of the stabilization period and positioning effects (Reising 1971). Nevertheless, they do provide a practical means of collecting macroinvertebrates under conditions which prevent the use of conventional dredge mechanisms such as an Ekman, Ponar or Peterson. The 1973 survey of the Whitemouth River was designed to select a sampler that was efficient, economical and easy to handle.

In terms of sampling efficiency the trays were the most effective. When the factors of cost and handling ease are added, the Hester-Dendy sampler would be the one selected.

The actual sampling period should include that time when the greatest variety of organisms can be collected. This is particularly crucial in water quality studies where the needs of communities must be assessed. This study indicated that the month of June was optimum for these requirements and that the limits should be from the last week in May to the first week in July.

Experimental test periods using artificial substrates have varied from four to nine weeks. Stable colonization is usually attained four weeks while diversity tends to increase up to nine weeks. Periods longer than six weeks are characterized by population fluctuations resulting from migration, emergence, predation and disturbance. This study indicated that a four week period was adequate to attain stable colonization.

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Table 1. Invertebrate fauna collected by artificial samplers.

Fauna	Type of Sampler			
	Hester-Dendy	Pipe	Basket	Tray
Diptera				
Chironomus		X	X	X
Chironomus (Einfeldia)				X
Chironomus (Tribelos)	X	X		X
Microtendipes	X	X	X	X
Paratendipes		X		
Glyptotendipes	X			X
Polypedilum	X	X	X	
Tanytarsus	X	X	X	X
Chironomus (Dicrotendipes)	X		X	X
Cryptochironomus			X	X
Chironomus (Cryptochironomus)		X	X	X
Para lauter borniella	X	X	X	X
Stictochironomus			X	X
Pentaneura	X	X	X	X
Procladius	X	X	X	X
Coelotanypus		X	X	X
Ablabesmyia		X		X
Tanypus	X	X	X	X
Orthocladius	X	X	X	X
Corynoneura	X	X	X	X
Cricotopus	X	X	X	X
Nanocladius				X
Metriocheus		X	X	X
Trichocladius	X	X	X	X
Brillia	X		X	X
Psectrocladius	X	X	X	X
Smittia	X			
Simuliidae	X	X	X	X
Ceratopogonidae		X		
Chaoborus	X	X	X	X
Ephemeroptera				
Choroterpes	X	X	X	X
Ameletus lineatus	X	X	X	X
Thraulodes	X		X	X
Hexagenia limbata	X	X	X	X
Baetisca obesa	X	X		X
Trichoptera				
Leptocella		X	X	X
Brachycentrus	X	X	X	
Hesperophylax	X	X	X	X
Hydropsyche	X		X	
Neureclipsis	X	X	X	X
Helicopsyche	X		X	
Astenophylax			X	X
Cheumatopsyche	X	X	X	X

Table 1 – Continued

Fauna	Type of Sampler			
	Hester-Dendy	Pipe	Basket	Tray
Odonata				
Agrion	X			
Octogomphus	X	X	X	X
Ophiogomphus		X		X
Gomphus			X	
Ischnura	X			X
Aeschna		X		X
Calopteryx		X		X
Coleoptera				
Ancyronyx	X	X	X	X
Hemiptera				
Belostoma		X		
Corixidae				X
Amphipoda				
Hyalella azteca	X	X	X	X
Decapoda				
Orconectes virilis	X	X		X
Plecoptera				
Pteronarcys	X		X	X
Isogenus	X	X	X	X
Acroneuria			X	X
Perlesta				X
Acanthocephala			X	
Nemertea				X
Mollusca				
Sphaerium				X
Pisidium			X	X
Physa	X	X	X	X
Amnicola	X	X	X	X
Ferrisia	X	X	X	
Oligochaeta	X			X
Hirudinea				
Helobdella stagnalis				X

Table 2. Two-way analysis of variance results

Factor tested	No. of Weeks	Source of variation	F valve	p
Taxa	1	Samplers	6.00	0.01
"	2	"	4.03	0.05
"	3	"	5.53	0.01
"	1	Time	6.72	0.01
"	3	"	3.92	0.01
"	6	"	8.68	0.005
Density	1	"	3.51	0.05
"	3	"	4.72	0.01
"	4	"	2.92	0.05
"	6	"	3.53	0.05

Table 3. Duncan's multiple range test results

Significant F tests	No. of weeks	Least significant difference		Significant means		Comments
		5%	1%	5%	1%	
Taxa vs. samplers	1	0.48	0.67	3.49	3.30	Significantly fewer taxa collected by pipe sampler.
Taxa vs. samplers	2	1.70	2.37	2.25	1.58	Significantly fewer taxa collected by pipe sampler.
Taxa vs. samplers	3	0.72	1.00	3.76	3.48	All samplers except tray collected significantly fewer taxa.
Taxa vs. time	1	0.48	0.67	3.55	3.36	Significantly fewer taxa collected from April 19, July 26 and September set dates.
Density vs. time	1	0.36	0.50	2.41	2.27	Significantly lower densities collected from April 19 and July 26 set dates.
Taxa vs. time	2	0.93	1.28	3.48	3.13	Significantly fewer taxa collected from April 19 and July 26 set dates.
Densities vs. time	3	0.63	0.87	2.66	2.42	Significantly lower densities collected from July 26 set date.
Taxa vs. time	3	0.93	1.28	3.48	3.13	Significantly fewer taxa collected from April 19 and July 26 set dates.
Densities vs. time	4	0.66	0.91	3.28	3.03	Significantly lower densities collected from July 26 set date.
Taxa vs. time	6	0.56	0.77	3.96	3.75	Significantly fewer taxa collected from April 19, July 26, and August 16 set dates.
Densities vs. time	6	0.76	1.05	2.25	1.96	Significantly lower densities collected from July 26 set date.

Table 4. Mean number of taxa collected in each type of sampler and exposure time. The relative efficiency of each type is shown by its rank within each exposure time (in parentheses).

Exposure Time Weeks	Number of taxa ($\sqrt{x}$)			
	Hester-Dendy	Pipe	Basket	Tray
1	3.60 (2)	3.10 (4)	3.48 (3)	3.97 (1)
2	3.23 (3)	3.07 (4)	3.25 (2)	3.95 (1)
3	3.45 (2)	3.32 (4)	3.40 (3)	4.48 (1)
4	3.53 (2)	3.22 (4)	3.51 (3)	3.96 (1)
5	3.36 (4)	3.42 (2)	3.41 (3)	4.00 (1)
6	3.36 (3)	3.27 (4)	3.81 (1)	3.74 (2)

Table 5. Mean number of taxa and organisms collected by each type of sampler during one to six week periods, April to September, 1973.

Date Set	Duration of Sampling (weeks)	Number of taxa and density[a] for each type of sampler			
		Hester-Dendy	Pipe	Basket	Tray
April 19	1	7 (128.4)	9 (185.6)	4 (70.2)	11 (267.9)
"	2	7 (353.1)	9 (288)	7 (122.8)	15 (403.6)
"	3	7 (449.8)	12 (358.4)	9 (342.9)	20 (584.9)
"	4	13 (695.5)	16 (854.4)	13 (266.8)	16 (677.8)
"	5	12 (700.3)	13 (368.0)	15 (832.6)	12 (629.1)
"	6	15 (1916.7)	11 (243.2)	12 (358.8)	13 (615.6)
April 27	6	14 (636.6)	12 (284.8)	15 (934.2)	20 (447.0)
May 3	5	8 (716.9)	12 (291.2)	13 (1007.1)	13 (91.2)
May 10	4	15 (786.4)	10 (192.0)	12 (1017.9)	14 (142.6)
May 17	3	10 (502.9)	9 (160.0)	18 (1262.7)	24 (292.1)
May 24	2	13 (727.6)	3 (54.4)	12 (253.8)	20 (281.7)
May 31	1	12 (818.2)	8 (144.0)	11 (183.6)	25 (285.2)
June 7	1	11 (535)	15 (364.8)	19 (1406.7)	18 (462.3)
"	2	10 (107.0)	19 (2038.4)	b	b
"	3	19 (2450.3)	20 (3769.6	11 (251.1)	29 (675.0)
"	4	15 (1609.9)	12 (675.2)	13 (353.7)	23 (1069.8)
"	5	13 (738.3)	21 (1110.4)	9 (318.6)	26 (1063.7)
"	6	20 (1963.4)	15 (422.4)	25 (1544.4)	22 (886.6)
June 14	6	7 (165.8)	7 (224.0)	7 (154.3)	6 (17.1)
June 21	5	12 (743.6)	13 (233.6)	9 (286.2)	12 (85.1)
June 28	4	7 (181.9)	6 (176.0)	9 (143.1)	4 (11.5)
July 5	3	8 (310.3)	6 (96.0)	12 (313.2)	10 (117.3)
July 12	2	9 (181.9)	8 (83.3)	8 (187.7)	12 (194.3)
July 19	1	8 (230.0)	8 (92.8)	10 (243.0)	12 (92.0)
July 26	1	17 (1294.7)	12 (377.6)	17 (669.6)	19 (221.9)
"	2	10 (374.5)	13 (261.6)	15 (810.0)	25 (446.2)
"	3	12 (353.4)	15 (371.2)	7 (113.4)	22 (392.1)
"	4	11 (957.6)	13 (352.0)	14 (666.9)	22 (416.3)
"	5	9 (304.9)	4 (182.4)	12 (40.5)	12 (334.6)
"	6	9 (337.0)	9 (220.8)	11 (378.0)	10 (207.0)
August 2	6	5 (304.9)	9 (185.6)	19 (979.6)	15 (561.1)
August 9	5	12 (492.2)	10 (262.4)	12 (199.3)	22 (874.0)
August 16	4	14 (850.6)	6 (227.2)	12 (286.2)	19 (454.2)
August 23	3	15 (160.46)	7 (166.4)	13 (664.2)	17 (419.7)
August 30	2	13 (609.9)	5 (112.0)	11 (275.4)	8 (158.7)
Sept. 6	1	9 (551.0)	6 (86.4)	13 (982.8)	15 (422.5)

[a] Organisms per m^2 in parentheses.

[b] No data collected due to flood conditions.

Table 6. Mean numbers of taxa, mean densities/m^2 and ranges (in parentheses) for samplers in each of one to six week sampling periods

Number of Weeks	Hester-Dendy		Pipe		Basket		Tray	
	Taxa	Densities	Taxa	Densities	Taxa	Densities	Taxa	Densities
1	11(5-18)	592.9 (128.4 - 1294.7)	8.6(7-15)	208.5 (86.4 - 377.6)	12(4-20)	55.9 (70.2 - 1406.7)	16(11-23)	258.6 (92 - 462.3)
2	11.2(6-19)	552.5 (181.9 - 107.0)	9.7(5-22)	462.6 (54.4 - 2038.4)	10.8(5-17)	329.9 (122.8 - 810.0)	16.2(11-27)	296.9 (158.7 - 446.2)
3	12.2(7-21)	961.9 (310.3 - 2450.3)	9.9(5-20)	698.5 (96.0 - 3038.4)	12.3(5-20)	657.9 (113.4 - 1262.7)	20.6(9-31)	351.8 (117.3 - 675.0)
4	12.7(6-16)	680.3 (181.9 - 957.6)	10.5(5-18)	412.8 (176 - 854.4)	12.5(7-21)	441.8 (143.1 - 1017.9)	16.6(1-24)	462.0 (11.5 - 1069.8)
	11.6(8-14)	646.3 (181.9 - 743.6)	12.4(3-22)	437.3 (176.0 - 1110.4)	11.7(6-18)	471.2 (40.5 - 1007.1)	18.1(10-26)	574.8 (11.5 - 1063.7)
6	13(6-21)	887.4 (304.9 - 1963.4)	10.7(5-18)	265.0 (185.6 - 422.4)	15.1(6-26)	724.9 (154.3 - 1544.4)	16.2(6-24)	455.7 (17.1 - 886.6)

A SAMPLING TECHNIQUE FOR ACTIVE SUBNIVIAN INVERTEBRATES IN SOUTHERN MANITOBA

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ABSTRACT: A technique for sampling subnivian invertebrates has been devised for Manitoba conditions based on a method used originally in Scandanavia. A pitfall trap containing a removable cylinder is set in the soil and covered with a ring holding a lid to keep out moisture and snow. To avoid excessive changes in the physical properties of the snow cover, two metal cylinders are inserted into the snow. The cylinder with the largest diameter is pushed to the top of the ring; the other with the slightly smaller diameter fits on the lid and allows the snow above the lid to be removed without compaction.

Among the invertebrates collected in the traps have been three new records for the fauna of Manitoba.

INTRODUCTION

Many researchers in the past have thought that insects and other invertebrates were not active during the winter, but Näsmark (1965) found otherwise. In the past twenty years techniques have been devised to study winter activity in the boreal regions (Heydemann 1956, Näsmark 1964, Breymeyer 1966). A modification of the method of sampling previously used in Scandanavia is discussed here. This modification was necessary because of the different snow characteristics in Central Canada. Apparently the properties of snow cover create an environment in which certain invertebrates can remain active throughout the winter.

Those conditions which favor invertebrate activity during winter are temperatures near 0°C and a high relative humidity. Snow cover, when at a certain thickness, insulates the ground from severe temperature changes and maintains a temperature near 0°C. Also under the snow the relative humidity is high (Coulianos and Johnels 1962, Näsmark 1964).

PROPERTIES OF SNOW COVER

Snow cover is really an ecotone between two very different environments: the dry, very cold, and sometimes rapidly moving atmospheric air, and the moist, relatively warm, and stable air of the microenvironment under the snow (Coulianos and Johnels 1962, Pruitt 1970). Formosov (1969) defined snow cover as "an emulsion of air and snow flakes . . .". A blanket of snow insulates the subnivian space (i.e. the space between the soil surface and snow cover (which may be 3 to 8 cm high, Coulianos and Johnels 1962), from the macroenvironment.

The first parameter which has a major effect on the insulation of snow cover is density. Snow with a low density provides greater insulation than snow with a high density (Rikhter 1954, Formosov 1969, Pruitt 1970). Due to the low thermal conductivity of snow, a temperature gradient develops in the snow cover between the source of heat in earth and the supranivian air (Formosov 1969). The movement of water vapor along the temperature gradient produces condensation on the colder crystals, changing their structure by making them larger and more rounded (Rikhter 1954, Geiger 1965). Metamorphorosis of snow crystals occurs with time, causing an increase in density. (Snow density may be defined as the ratio of the amount of ice in relation to the amount of air in a given volume, and snow hardness may be defined as the amount of force needed to collapse the intercrystalline bonds.) Furthermore, the snow cover may increase in both hardness and density (Rikhter 1954, Williams and Gold 1958). Snow density is also affected by air and snow temperatures. Williams and Gold (1958) found that higher snow densities were associated with shallow

snow cover and extremely variable wind and temperature conditions, such as those on the prairies and on the arctic tundra. In these conditions there is a maximum heat exchange from the ground to the air.

The second parameter which affects the insulation provided by snow cover is thickness. When snow thickness is 20 cm approximately or more, the subnivian environment is stable and independent of the macroenvironment (Williams and Gold 1958, Coulianos and Johnels 1962, Geiger 1965, Formosov 1969, Pruitt 1970). Pruitt (1970) has labelled this crucial thickness factor as the "hiemal threshold", i.e. the snow cover thickness at which the subnivian environment is insulated from the diel fluctuations in ambient temperatures. Snow thickness in excess of 20 cm does not increase the insulating power of the snow cover significantly, unless density decreases and thus decreases the heat loss from the ground (Coulianos and Johnels 1962, Geiger 1965, Pruitt 1970).

To quantify these data on snow cover in the present study, a National Research Council standard snow kit was used. The parameters of snow thickness, grain size, surface condition, wind speed, snow profiles with density, hardness and temperature readings from top to bottom in the snow cover are obtained.

CONSTRUCTION OF PITFALL TRAPS

Barber (1931) devised pitfall traps consisting of a jar filled with a non-repellent preservative for cave-inhabiting insects, and modified Barber traps were used in this project. Modified Barber traps were used by Näsmark (1964) and Breymeyer (1966), who fitted a small, inner, removable cup containing a small amount of preservative, inside an outer cup whose upper rim was level with the soil surface. Näsmark (1964) also placed a cover over the trap site to keep it free of snow. The cover consisted of a ring of plywood supported by three small legs (4 cm high), and a central masonite lid (see Figure 1). The preservative used in Manitoba was ethylene glycol, since it is non-repellent, does not freeze at -30°C (when pulled out of the outer cup to remove the specimens), and does not deteriorate over a long period of time.

During the winters of 1973-1974 and 1974-1975 invertebrates have been sampled using the method described above, at the fenced property of the Canada Cement Lafarge, Ltd. in Fort Whyte, Manitoba. Because snow conditions are very different in Manitoba than those in Scandanavia, modifications for removing the invertebrates from the traps were made in the winter of 1974-1975.

During the winter of 1973-1974, the disturbance of the snow on the lid of a trap at each sampling occasion led to a considerable increase in snow hardness at the trap site. This change in hardness probably resulted in heat loss. Hence each trap site was probably colder than the surrounding soil surface, and this may have affected the catch. Towards spring the snow cover was so dense and hard that it was necessary to saw out wedged-shaped blocks of snow to uncover the lids. Snow density was found to also have increased at the trap sites.

To minimize this change in snow hardness in the winter of 1974-1975, a pair of thin galvanised iron cylinders have been used. In very soft, friable snow both are used; the outer one whose diameter is slightly greater than that of the lid prevents the surrounding snow from falling into the trap, while the inner one whose diameter is less than that of the lid retains the soft snow immediately over the lid. A handle about 20 or 30 cm long has been fitted in the centre of the lid. By pulling it to remove the lid, the inner cylinder and the snow inside are removed with minimal disturbance. In hard spring snow, it is expected that only the inner cylinder, with saw-toothed edges, will be needed. In this way the hardness of the snow above the lid remains much the same as that of the surrounding snow cover. The only disturbed area is above the ring where the cylinders have penetrated.

In late winter and early spring, hoar frost accumulates on the underside of the lid, freezing the lid to the ring. The longer handles allow more leverage to be applied and thus make it easier to remove the lids than in the winter of 1973-1974.

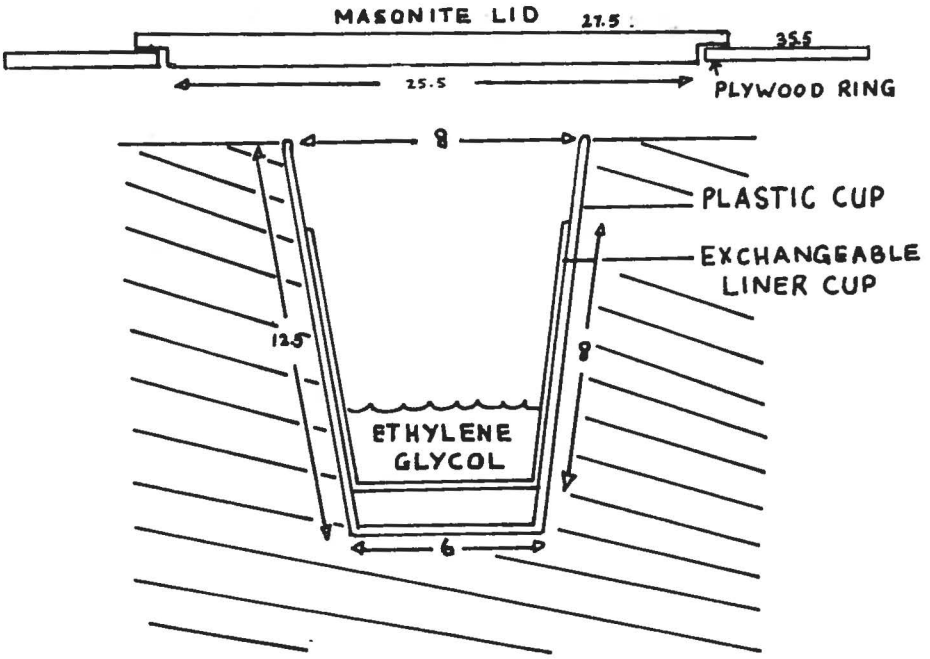

Figure 1: Transverse section through the trap. Measured in cm (after Näsmark 1964).

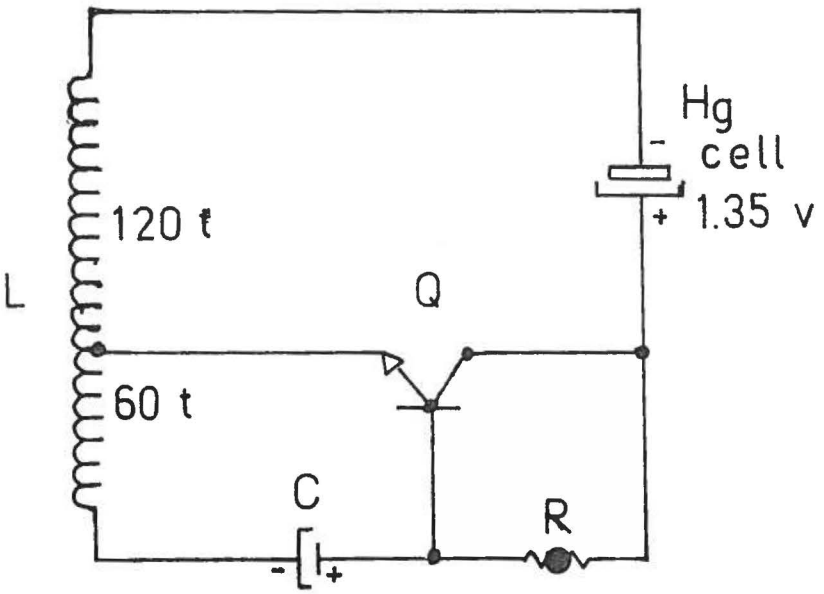

Figure 2: Circuit diagram of "clicker" telemetry transmitter component schedule:

- Q: MPS 3704 (Motorola) Silicon general purpose NPN transistor
- Cell: 1.35 volt mercury cell (one cell of type TR 133R battery, manufactured by Mallory).
- C: 1.5 microfarad tantalum electrolytic capacitor (15 W.V.D.C. rating)
- R: YSI #44014 (Yellow Springs Instruments) precision thermistor bead, 300 kohms at 25°C.
- L: Coil of 180 turns, single layer closely wound #32 wire, 0.5 cm diameter by 1.5 cm long. Approximately 2.2 millihenries.

TEMPERATURE MEASUREMENT

During the winter of 1973-1974, thermistor probes and an ohmmeter were used for temperature measurement. Since ohmmeters become inaccurate at temperatures below 4°C, they were replaced during the winter of 1974-1975 by a simple radiotelemetric device called a "clicker". It is an untuned simplification of the circuit used by Spencer (1968), (see Figure 2 for specifications). A transistor radio, tuning to 535 to 1605 kHz, makes a suitable receiver for the broad-beam AM radio frequency pulse emitted by the "clicker". The number of clicks emitted per minute varies directly with temperature (MacKay 1968). Each clicker has a range of about 60 cm, so that readings may be taken above the snow cover, without disturbing the snow.

INVERTEBRATES COLLECTED

The invertebrates collected in the traps have been mainly Collembola, Acarina, Araneae, and Staphylinidae in the mid-winter. Other groups were also caught in autumn and spring. The value of this method can be demonstrated by the fact that three new records for Manitoba have been recorded. They are as follows:

1) *Neanura muscorum* (Templeton), (Collembola: Poduridae), determined by W.R. Richards, Biosystematics Research Institute, Ottawa, taken 17 October 1973 from a ridge between 2 ponds.

2) *Stenamma diecki* (Emery) (Hymenoptera: Formicidae), determined by G.L. Ayre, Canada Agriculture Research Station, Winnipeg; taken 17 October 1973, from scrub oak-aspen woods.

and 3) *Lamycetes* sp. (Chilopoda: Henicopidae) determined by R.E. Crabill, Jr., Department of Entomology, Smithsonian Institute, Washington, D.C., U.S.A.; taken 24 October 1973, from a small meadow.

ACKNOWLEDGEMENTS

I extend my thanks to Dr. W.O. Pruitt, Jr., Department of Zoology, University of Manitoba, for proposing the project; to Canada Cement Lafarge Ltd. for use of their land; and to the Canada Agriculture Research Station, Winnipeg for making the cylinders. Critical analysis of the manuscript was provided by L.B. Smith, Canada Agriculture, Winnipeg. Financial support for the project was obtained from a National Research Council operating grant to Dr. H.E. Welch and from a research grant from the Museum of Natural Sciences of the National Museum of Canada.

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(Received 3 March 1975)

A BATTERY OPERATED TIME-SORT PITFALL TRAP[1]

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ABSTRACT: A time-sort pitfall trap is described which overcomes some of the limiting features of previously described traps. The trap operates from an internal power source of 6 flashlight batteries, will take 18 sequential samples at intervals adjustable between 1.5 and 24 h (total sampling sequence 1 to 18 days), and shuts itself off at the end of the sampling period. The unit is light weight and compact thus facilitating easy field installation and can operate without cover through rainfalls of up to 10 cm.

Pitfall traps have long been used to capture insects which are active on the soil surface. However, the collections obtained indicate little more than the fact that a species was present in the area and was active sometime during the period that the trap was in position. Information on the seasonal, weekly, daily or diurnal activity of the insects can be obtained if the traps are emptied or changed at regular intervals. This can be a laborious task and under certain field conditions may be impossible. To overcome these difficulties Williams (1958) designed a mechanical time-sort pitfall trap which automatically separated the daily captures into six periods. A modified but functionally similar trap was constructed by Nicholls (1970). Smith *et al.* (1973) designed a time-sort mechanism that operated electrically from 120 V line power. All of these traps operated on a 24-h basis, had preset timing cams, and had to be changed or reset daily. Although not normally a difficult task elsewhere, the daily change of traps in the heavy clay soils of the Red River Valley of southern Manitoba was undesirable and at times impossible. If moist, this heavy "gumbo" in cultivated areas compacts and cakes if walked upon; when wet it balls up on boots leaving holes and clods of clay scattered over the soil surface. The surface around the traps is thereby disturbed during servicing.

Traps to sample and monitor insect activity in the Red River Valley had to satisfy the following requirements:

1. Continuous operation for several days with an automatic shut down feature if the traps were not accessible at the end of the sampling period;
2. An independent and continuous power source to enable use distant from any external power supply;
3. Anti-flooding features without covering the top of the trap and thus interfering with the immediate micro-climate;
4. Adjustable time periods so that not only the periods during the day but also the number of days sampled could be altered;
5. Economy in both initial construction and in operation.

The trap described herein possesses all these features and is therefore considered to be an improvement over any previously reported time-sort trap and should be of value in many circumstances outside the conditions found in the Red River Valley.

The trap contains 19 collection vials and will operate for 18 continuous days at one sample per day, 9 days at 2 samples per day, etc., to 18 samples per day for one day. The 19th vial functions as a "catch-all" between the end of the total sampling period and the time the traps can be emptied. Theoretically the traps will function for one year on one set of six 1.5 V batteries; in fact, 10 traps have now each been used approximately 2500 h and none show any appreciable loss in battery charge. They will continue to function through rainfalls of up to 10 cm during the sample period, although collections made during the rain are lost. The traps are of readily available materials and excluding assembly time were built for approximately $60 Canadian each.

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[1] Contribution No. 660, Canada Agriculture, Research Station, Winnipeg, Manitoba.

DESCRIPTION OF TRAP
(Figure 1A)

The basic principle of the trap is similar to that described by Williams (1958) in that it consists of a rotatable disc of vials set under a collection cone with the whole assembly placed in a container in the ground. The main differences are that the number of vials have been increased and the mechanical timing and drive mechanisms have been replaced with an electric DC power source.

Timing assembly – The timing assembly is built from a 365-day, battery-operated clock. The hour hand was replaced with a gear giving a 2:1 ratio with a geared plastic disc providing the basis of a 24-h time clock. The timer was calibrated by cementing photo copies of the face plate of a 24-h clock to the surface of the disc. Small spring-backed paper clips were used as cams to trip the miniature snap switch which activated the turntable.

Drive assembly – The basis for the drive for the turntable is a small 1.5 to 6.0 V DC motor of the type used in many hobby models. Accurate alignment of the vials on the turntable and the collection funnel is achieved by running the motor at a relatively low speed (i.e. on 1.5 V) and by a large gear reduction between the motor and turntable, thus largely eliminating inertial drift when the motor is turned off. In these traps a gear reduction of 150:1 is achieved through a worm gear and a series of pinion gears plus a further 12:1 reduction in the friction drive to the turntable.

Vial and funnel alignment – Although the alignment of vials and funnel is accomplished through the drive motor, the power supply to the motor is controlled through a pegged disc on the same shaft as the turntable. Nineteen pegs correspond to the 19 vials on the turntable and a 20th peg is offset but on the same radius as the 19th peg. The circuit to the motor is closed through a microswitch activated by the cams on the time clock. Through the pegs on the disc a second switch opens the circuit to stop the turntable with the appropriate vial under the funnel. The 20th peg actuates a third switch which opens the circuit to the motor thus shutting down the whole system until the turntable is reset on peg 1 to commence a new sampling sequence.

Electrical circuit and power source – Ignoring the timing and shut down features of the trap the principle of operation is simply that of a two-way switch — the circuit is closed at one location (the clock) and opened at another (the peg switch). A relay in the system holds the motor circuit open until the timing cam has passed through the clock switch allowing it to return to its normal open position. This is essential for the next vial change.

A circuit diagram is shown in figure 1B. The sequence of operation is as follows:

The timer closes the clock switch (C_s) and current for the motor is through the relay arm and the contact N_c. The turntable rotates and the trip-peg on the disc closes switch S_1 thus energizing the relay and transferring relay arm to contact N_o. Diodes D_1 and D_2 provide circuit paths for the motor and relay when the relay arm is between contacts. As the trip-peg passes S_1 the circuit is opened leaving the next vial under the funnel opening. The relay continues to hold in the N_o position until the timer cam is past the clock switch (approximately 5 min.) and then returns to the N_c position leaving the system ready for the next sequence. The 20th peg on the trip-peg disc opens switch S_2 thus cutting the power to the motor and preventing the collection plate from moving past the 19th vial.

The system is operated on a compliment of six 1.5 V flashlight batteries. Four "D" cells supply the current required by the relay coil, one "D" cell supplies the motor and one "C" cell is used in the timing clock.

General considerations – No dimensions or materials list are given for this trap as individual needs and resources may vary. In these particular units the funnel is fabricated from fibre glass and the main support brace from sheet galvanized iron. A standard 1.5 V electric clock movement available from any jeweler or watch maker is used for the timer. The gear arrangements are designed to utilize the gears obtained in a "Meccano" gear set available at hobby shops. Gear boxes and discs are made of 3.2 mm acrylic plastic, the

trip-peg disc being fitted with a rubber 0-ring for the friction drive. The turntable is fitted with 19 permanently cemented plastic vials into which smaller screw cap vials (approximately 50 ml) partially filled with glycol are placed for receiving trapped material. The whole assembly fits into a 10 gal. plastic garbage pail allowing approximately 10 cm clearance at the bottom for rain.

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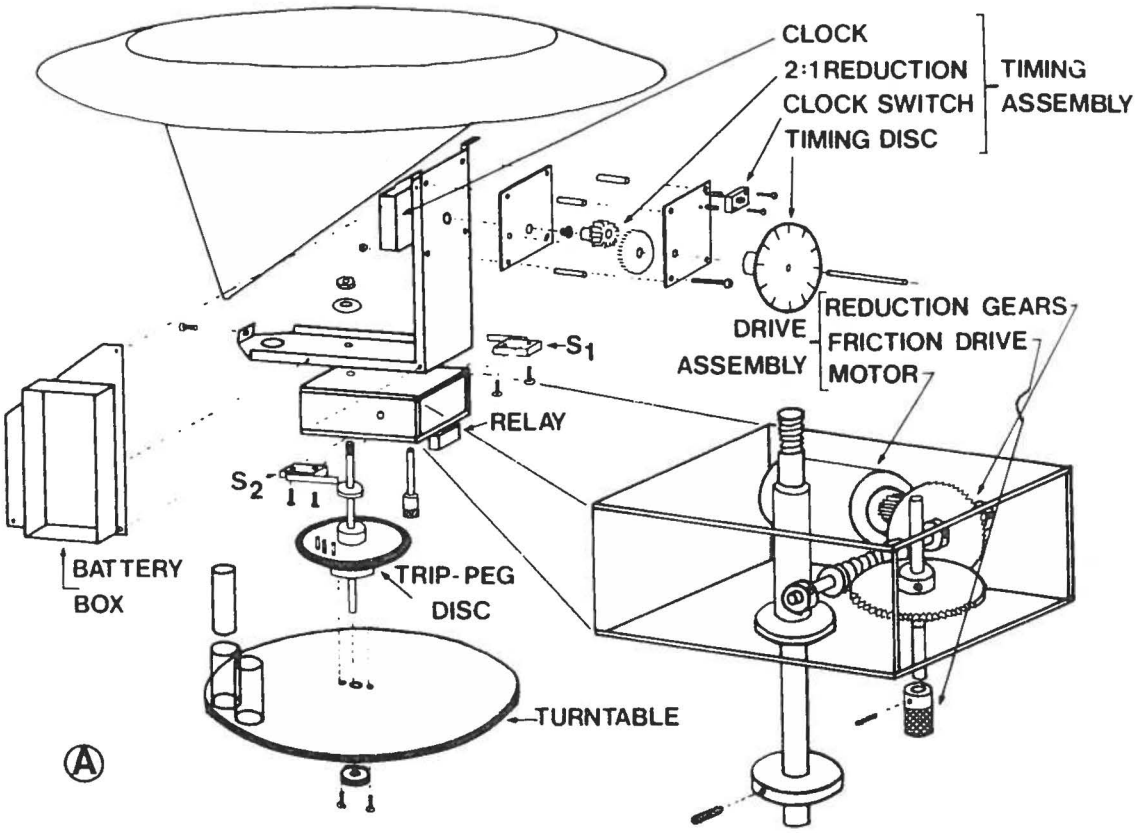

RY_1 - 6 VOLT, 500 OHM COIL SPDT CONTACTS

D_1D_2 - SILICON DIODES, 1AMP. 50PRV.

M - 1.5 VOLT MOTOR

C_S, S_1, S_2 - SWITCHES

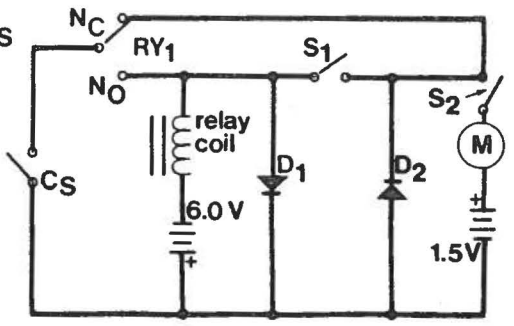

Figure 1. A. Basic construction of trap.
B. Schematic wiring diagram of trap.

BIONOMICS OF *Caloglyphus anomalus* NESBITT (Acarina:Acaridae)[1]

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ABSTRACT: The life history of *Caloglyphus anomalus* Nesbitt was studied at 15.6, 18.9, 22.2, 22.8, 24.4, 27.8 and 30.0°C. This species has polymorphic males. The optimal temperature for egg development was 30°C where 3.2 ± 0.4 days were required for development. Post embryonic development was most rapid at 27.8°C where 6.2 ± 1.2 days were required for development. The greatest average number of eggs per female (619 ± 265) was produced at 18.9°C. At 27.8°C *C. anomalus* had its greatest finite rate of increase which was 1.31 female offspring per female per day.

INTRODUCTION

The genus *Caloglyphus* is widely distributed geographically and some species such as *Caloglyphus berlesei* (Mich) are probably cosmopolitan. *Caloglyphus* spp. are found in diverse habitats and they may be occasionally regarded as pests. Some species have been found in bat guano (Hughes 1959) and *C. berlesei* and *Caloglyphus mycophagus* (Megnin) have been collected from poultry manure (Evans *et al.* 1961, Rhode 1959). Hughes (1959) mentions that *Caloglyphus spinitarsus* (Hermann) can be a pest of cultivated mushrooms. *C. mycophagus* was found infesting asparagus and *Caloglyphus redikorzevi* (Zachvatkin) has been collected from rice bran (Hughes 1961). *Caloglyphus birgophilus* (Vitzthum) was taken from the respiratory chamber of the land crab and *Caloglyphus viduus* (Berl.) was collected from termite nests.

C. anomalus (Nesbitt) was first collected from partially destroyed lily bulbs in Ottawa (Nesbitt 1944) and Woodring (1969) found it on barn-stored navy beans in Louisiana. Wireworm larvae *(Limonious* sp.) collected at Chatham, Ontario, and reared in the laboratory, often became covered with the hypopi of *C. anomalus* (Smith 1955). The strain of *C. anomalus* used here was found near Pilot Mound, Manitoba, where it was feeding inside kernels of Manitou wheat that had been planted during the wet spring of 1968; though germination was poor and many plants were too weak to emerge, it was not clear that the mites were responsible.

Some work has been done on the life histories of *C. mycophagus* (Rhode 1959), *C. berlesei* (Hughes 1961), and *C. anomalus* (Woodring 1969, Pillai and Winston 1969). The present study extends the earlier work on *C. anomalus.*

MATERIALS AND METHODS

Cultures of *Caloglyphus anomalus* were maintained in cages made from tissue culture slides covered with 1 mm thick glass; the concavity of the slide was 36 mm in diameter and 5 mm deep. The mites were fed on dried brewer's yeast and kept at 15.6°C and 95 - 100% R H in desiccators.

The rearing cells used in the life history study consisted of "hanging drop" microscope slides, 0.8 mm deep, and coverslips. A few grains of dried brewer's yeast were dusted onto the floor of each cell before the coverslips were attached to the slides by shortened bobby pins. The cells were held in desiccators containing tap water (95 - 100% R H).

Egg hatchability, development of the immature stages and oviposition were observed at 15.6, 18.9, 22.8, 24.4, 27.8, and 30.0°C. A few adult females were placed in each of a number of cells and left overnight to lay eggs. The eggs were observed daily until eclosion.

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Single eggs of undetermined age were placed in each of a number of cells, and were examined daily until the mites, which hatched from these eggs, had become adults. Adult females were placed in rearing cells immediately after they emerged from the quiescent deutonymph stage. An adult male was placed with each female. The eggs produced were counted and removed each day until the female died; if the male died first, it was replaced.

RESULTS AND DISCUSSION

C. anomalus egg development was fastest at 30°C (Table 1), a temperature slightly less than optimal for egg development of *Tyrophagus putrescentiae* (Schrank) (Barker 1967). Eggs of *C. anomalus* laid and held for one week at 32°C did not hatch.

The relationship between temperature and the time required for development of an organism has often been expressed mathematically and the data presented in Table 1 fit Janisch's (1932) catenary equation closely (Fig. 1). It was assumed that only one curve could possibly pass through more than six points at once, and the equation described here comes close to fulfilling this requirement. Howe (1967), however, suggests that at least 10 points should be used. In Janisch's (1932) formula:

$$D = \frac{m}{2}(a^{T} + a^{-T})$$

where: m = the minimum time of 3.2 days required by the eggs for embryonic development;

T = obtained by subtracting a temperature t_2, at which we wish to know the developmental time, from the temperature t_1 (=29°C) at which the minimum developmental time m occurs;

a = a constant determined by trial and error in the present study to be 1.14, and which represents the slope of the curve.

D = the time for development at the temperature t_2 .

One advantage of the use of an equation to describe the relationship between developmental time and temperature is that the investigator can easily detect data that do not fit the expected pattern.

The data presented by Pillai and Winston (1969) for egg development of *C. anomalus* do not fit this curve. Thus, there may be strain difference. The maximum egg mortality in my experiments was 15.4% (Table 3); the reason for the high mortalities (22.5 to 50%) observed by Pillai and Winston (*op. cit.*) is not clear. Mites of the strain used in this work were compared with the type specimens by Dr. E.E. Lindquist and were found to match them completely.

At the lowest temperatures used in these experiments, it was possible to observe all the stages of post-embryonic development between eclosion and emergence of the adults. On eclosion, the eggs produce a six-legged larva that moults after passing through a quiescent stage to an eight-legged protonymph. Michael (1901) called the moulting process ecdysis, though more recently Cutcher and Woodring (1969) refer to this process as apolysis.

The hypopi produced in this species are mobile and have a well-developed sucker plate. As in other species of *Caloglyphus* which I have observed, these hypopi can attach themselves to beetles and be transported elsewhere. At 15.6°C a great percentage of the protonymphs became hypopi (=heteromorphic deutonymphs). These hypopi became nymphs upon return of favorable temperature and food conditions. There is, in the literature, considerable confusion on the correct naming of the stage of development subsequent to the protonymph. According to Michael (1901), the larval stage is followed by the first nymphal period which is then followed by the second nymphal period; he states the hypopial stage occupies the period between the first and second nymphal periods in the development of some individual mites. Zakhvatkin (1959) refers to the post-embryonic stages of development as larva, first nymph or protonymph, and telonymph; he points out that the hypopus is an additional stage which resembles the telonymph in some features,

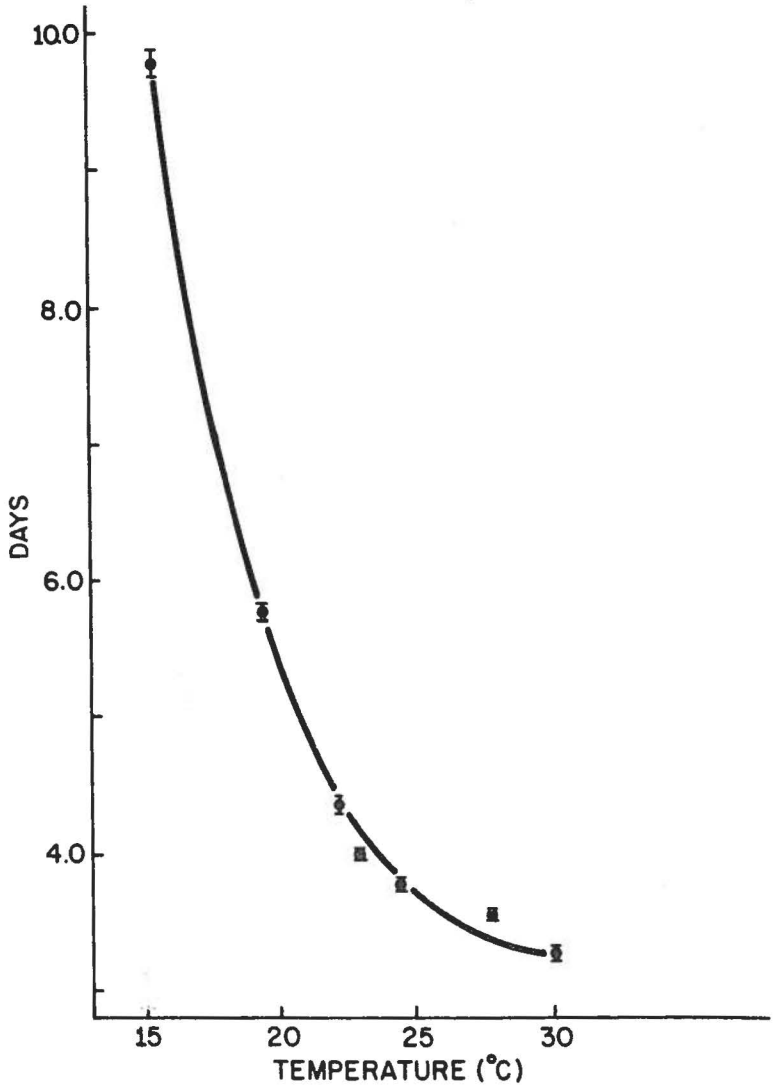

Figure 1. The effect of temperature on the incubation time of eggs of *Caloglyphus anomalus* Nesbitt.

Table 1. Developmental time for viable eggs of *Caloglyphus anomalus* at various temperatures

Temp. (°C)	N	Days to Eclosion		
		Mean	Standard Deviation	Range
15.6	65	9.8	±1.34	8 - 14
18.9	28	5.8	±0.49	5 - 7
22.2	57	4.3	±0.53	3 - 6
22.8	43	4.0	±0.14	3 - 4
24.4	28	3.7	±0.43	3 - 7
27.8	27	3.5	±0.57	3 - 5
30.0	41	3.2	±0.40	3 - 4

Table 2. Duration of the post-embryonic period of *Caloglyphus anomalus*

Temp. (°C)	No. adults emerging	Eclosion to Adult Emergence (Days)		
		Mean	Standard Deviation	Range
15.6	20	22.6	±3.73	16 - 31
18.9	28	14.7	±4.67	9 - 24
22.2	40	10.2	±2.39	7 - 15
22.8	39	9.3	±2.38	7 - 20
24.4	40	6.3	±1.26	5 - 12
27.8	23	6.2	±1.20	5 - 8
30.0	32	7.9	±5.50	5 - 13

Table 3. Percentage mortality of eggs and immature stages and formation of hypopi of *Caloglyphus anomalus*

Temp. (°C)	Mortality (%)		Hypopi formed (% of hatchlings)	Total mortality plus hypopi (%)
	Eggs	Immatures		
15.6	12.5	19.0	46.6	70.0
18.9	6.6	34.1	2.3	40.6
22.2	15.4	15.1	0.0	28.2
22.8	0.0	4.8	0.0	4.9
24.4	7.2	4.8	0.0	11.6
27.8	6.6	11.1	0.0	17.0
30.0	8.9	22.0	0.0	28.9

particularly the two pairs of "genital suckers". Hughes (1961, p. 22) suggests, through analogy with the Oribatei, that the hypopus might be regarded as a deutonymph and the following stage as a tritonymph; she adds, however, that the hypopus might as easily be regarded as a heteromorphic tritonymph because of the possession of the two genital sense organs which are similar to those found in the tritonymph. In their discussion of the Glycyphagidae, Baker and Wharton (1952) state as does Hora (1934) that the nymph which precedes the adult is the deutonymph. Chmielewsky (1967) studied the genitalia of *Caloglyphus* sp. and concluded that the hypopus should be called a heteromorphic deutonymph and the nymph which immediately precedes the adult should be called deutonymph. Thus, the development of *C. anomalus* can follow two paths: one in which the protonymph becomes, in turn, a heteromorphic deutonymph (hypopus), deutonymph and adult and a second path in which the protonymph becomes a deutonymph and ultimately an adult. Chmielewsky's (1967) scheme is followed in this paper.

The most rapid development, with least variability, of the immature post embryonic stages occurred at 27.8°C (Table 2). At the three highest temperatures, development occurred so rapidly that it was not possible to record all of the stages of development for each individual and consequently only the total developmental period was measured. Mortalities of eggs and immature mites are shown in Table 3. Since the hypopi usually survive much longer than one generation, and often last longer than many generations, hypopi were considered to be the equivalent of dead mites for the calculation of the net reproductive rates. Hypopi were only produced at the two lowest temperatures and it is therefore suspected that low temperatures may favor formation of this stage, though Barker (1968) showed that formation of hypopi in *Glycyphagus domesticus* was correlated with low humidity and high temperature. Griffiths (1966) has also shown that nutrition was a significant factor in the production of hypopi, thus it is possible that many factors may cause hypopi formation.

A sex ratio of 1:1 was obtained from the adults that emerged during the experiments designed to determine the longevity of the immature stages.

Oviposition data was obtained at five temperatures (Table 4). The oviposition period was longest at the lowest temperatures used. The greatest number of eggs per female per day was obtained at 27.8°C, whereas the greatest number of eggs produced per female per lifetime was obtained at 15.6 and 18.9°C. Oviposition was low at 30°C, a temperature that was also unfavorable for the development of the immature stages. At 22 to 24° C oviposition was lower in these experiments than that obtained by Woodring (1969), though oviposition at 15.6 and 18.9°C (Table 4) was comparable to that found by Woodring *(op. cit).* The observation by Lipa and Chmielewsky (1966) that aparity (development of progeny in the body of a dead female) occurs in *Caloglyphus* sp. was verified on two occasions for *C. anomalus.*

The net reproductive rates (Table 5) of *C. anomalus* were similar to those found for *T. putrescentiae* (Barker 1967). *T. putrescentiae*, however, can prosper at temperatures of 32 to 33°C, whereas *C. anomalus* cannot. The mean generation time (T) of *C. anomalus* was longer, and consequently the finite rate of increase (λ) was smaller than that of *T. putrescentiae.*

Woodring's *(op.cit.)* statement that the pleomorphic males appear to fight was verified. According to Woodring there are four kinds of males and of these the most common are the pleomorphic males with a thickened third pair of legs and not the heteromorphic males as would seem to be the case from Hughes' (1961) discussion of the genus *Caloglyphus.* The advantage of this fighting behaviour to the species is far from clear, though the definite reduction of the male population, as a result of fighting, may reduce the competition for food and space.

It is concluded that *C. anomalus* can prosper and rapidly infest a food substrate at temperatures between 15 and 30°C. The species can survive adverse conditions as a mobile hypopus that can be disseminated by attaching itself to other hosts.

Table 4. Mean number of eggs laid (±standard deviation) and oviposition period (mean ± standard deviation) of *Caloglyphus anomalus*

	Temperature (°C)				
	15.6	18.9	22.2	27.8	30.0
Oviposition period (days)	42.76±16.5	41.28±14.7	25.20±9.6	17.33±5.62	13.07±3.28
Average number of eggs per day per female	11.87±2.9	15.24±4.5	15.00±4.0	20.77±4.5	11.92±4.7
Average number of eggs per female	516.23±227.5	619.50±265.0	397.15±209.0	368.31±195.3	162.50±77.4
Maximum number of eggs per female	785	1164	680	698	258
Number of females	13	21	20	9	13

Table 5. Net reproductive rates (R_o), innate capacities for increase (r_m), finite rates of increase (λ), females per female per day), and mean lengths of generations (T, days) of *Caloglyphus anomalus* at various temperatures

	Factors			
Temp. (°C)	R_o	r_m	λ	T
15.6	75.49	0.07787	1.081	55.52
18.9	183.95	0.12745	1.130	40.91
22.2	188.98	0.18079	1.200	28.99
27.8	152.65	0.27259	1.310	18.43
30.0	57.71	0.22141	1.250	18.31

ACKNOWLEDGEMENTS

Thanks are due to Mr. D. Kurtz for his technical assistance. The author is grateful to Dr.E.E. Lindquist, Entomology Research Institute, Canada Department of Agriculture, Ottawa, for identification of *C. anomalus.*

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(Received 13 March 1975)

A COMPARISON OF FORAGING ACTIVITY OF HONEY BEE COLONIES WITH LARGE AND SMALL POPULATIONS

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ABSTRACT: Foraging activity and pollen collection was compared throughout the day using "standard" and "small" colonies of honey bees from 30 July to 19 August 1971. This was done with devices that separate incoming from outgoing foragers, or collect pollen at the hive entrance. No significant differences in the proportions of incoming foragers, or the weights of pollen collected, occurred in the two types of colonies. The possible uses for small over standard colonies are discussed.

INTRODUCTION

Experiments involving honey bee drifting activity, nectar and pollen foraging, pollen collection, etc., frequently require counts of bees at the hive entrance or on combs, and/or pollen trap collections at hive entrances. Congestion at the entrance can occur making it difficult to obtain accurate data. This is particularly true when large colonies, such as occur during mid and late summer, are used. Experiments were designed to determine if colonies with low and high populations provide data about foraging activity at the hive entrance, and pollen collection, which is relative to their populations; if this is true, these data could be more easily (and probably more accurately) collected from colonies with low populations.

Experiment I

All experiments were conducted on the University of Manitoba campus in 10-frame Langstroth hive boxes in 1971 using honey bees of a yellow strain. On 30 July, four hives with two brood chambers (Group I, "Standard Colony" and containing 32,000-35,000 bees) and two hives with one brood chamber (Group II, "Small Colony" and containing 12,000-15,000 bees) were selected to compare incoming forager frequencies. Prior to the experiment, adult populations and stores of honey and pollen, in each group, were equalized as far as possible.

An apparatus was designed (Figure 1) to separate incoming from outgoing bees at the colony entrance so that returning foragers could be counted as they passed through a narrow passage. Using a stop watch and a hand counter, an observer at each hive made three, 30-second counts, each hour between 900 and 1600, of the total number of incoming foragers as well as the total number of incoming pollen and non-pollen carrying foragers.

The three 30-second hourly counts, of all incoming foragers (as well as incoming pollen foragers), were averaged for each experimental colony. These hourly means were then totalled for all hives of a group and averaged to give a "group hourly mean". A "group mean total" was obtained by summing all of the "group hourly means" and by dividing each "group hourly mean" into the "group mean total" a "group hourly proportion" was obtained. A Chi-square test was used to ascertain if there was a significant difference between the "group hourly proportions" of incoming foragers (and incoming pollen foragers) of "standard" and "small" colonies.

In addition to the above tests, three standard colonies and one small colony, had Ontario Agricultural College pollen traps fitted to their entrances; each hour from 1000 to 1600 h the pollen collected in the traps of each hive was weighed. The hourly weights of pollen were converted to "group hourly proportions" and analyzed statistically as outlined above.

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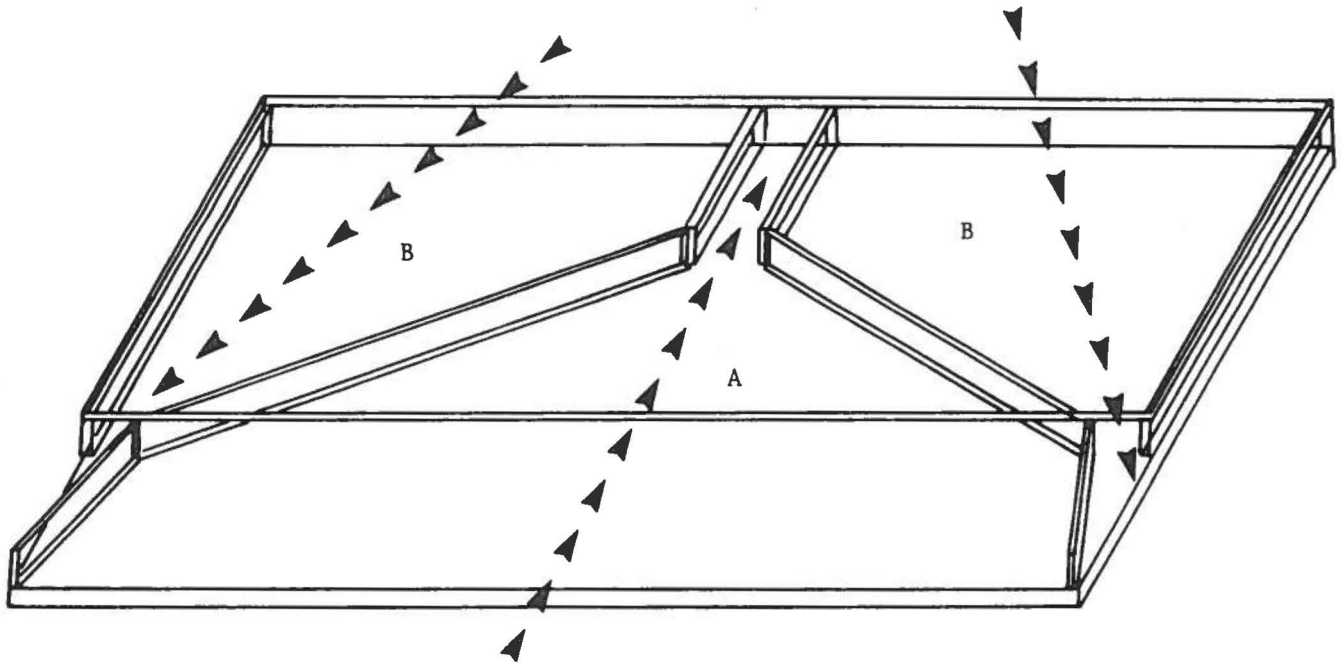

Figure 1. Glass topped entrance device.

A. Incoming Honey Bees.

B. Outgoing Honey Bees.

Specifications:

Width: 5 1/2 inches.

Length: 15 1/8 inches.

Height : 7/8 inches.

Materials:

Top: 1/8" Glass.

Funnel and Sidewalls: 1/8" Plexiglass or 1/4" Plywood

Bottom: 1/4" Plywood.

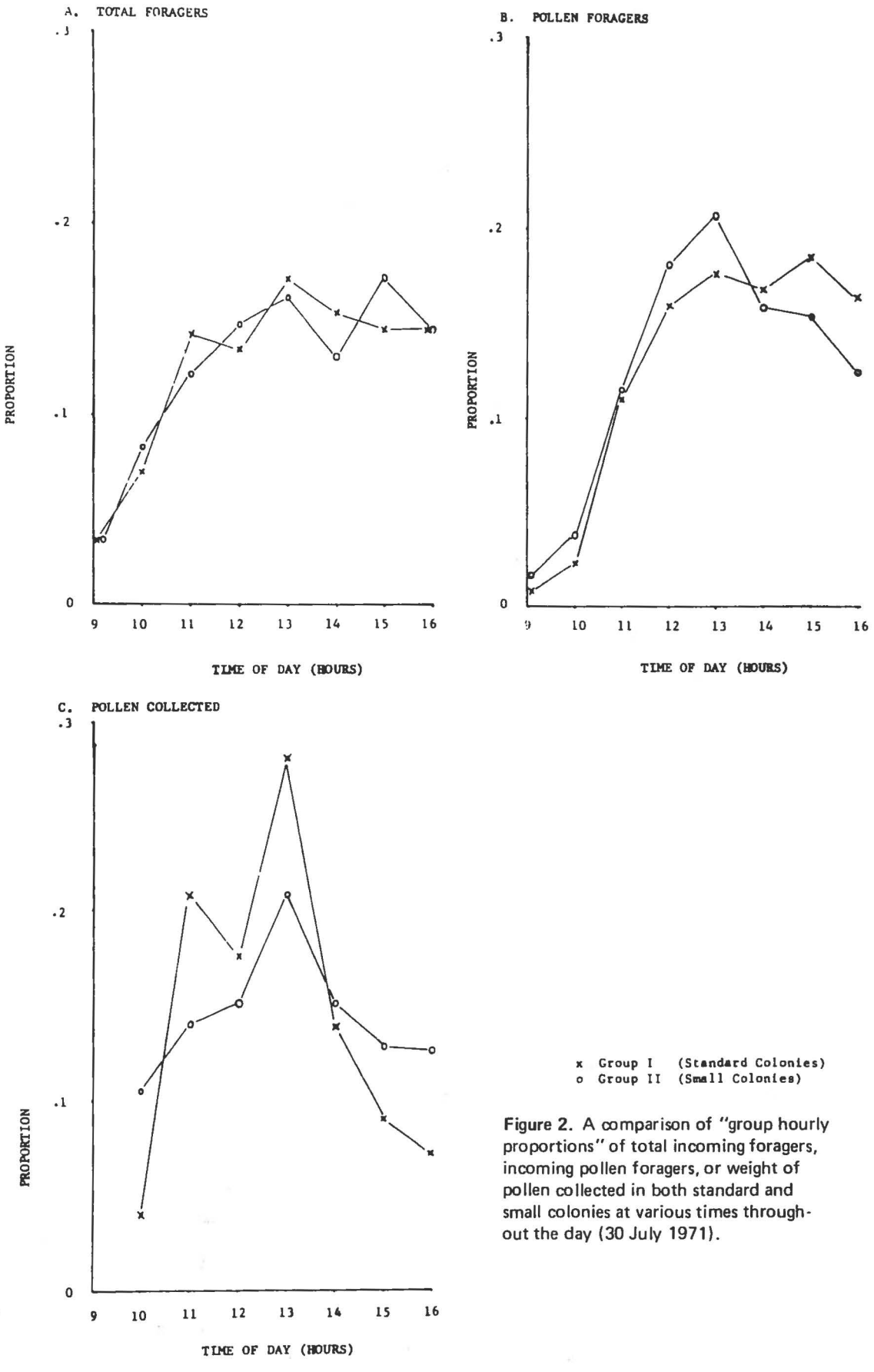

Figure 2. A comparison of "group hourly proportions" of total incoming foragers, incoming pollen foragers, or weight of pollen collected in both standard and small colonies at various times throughout the day (30 July 1971).

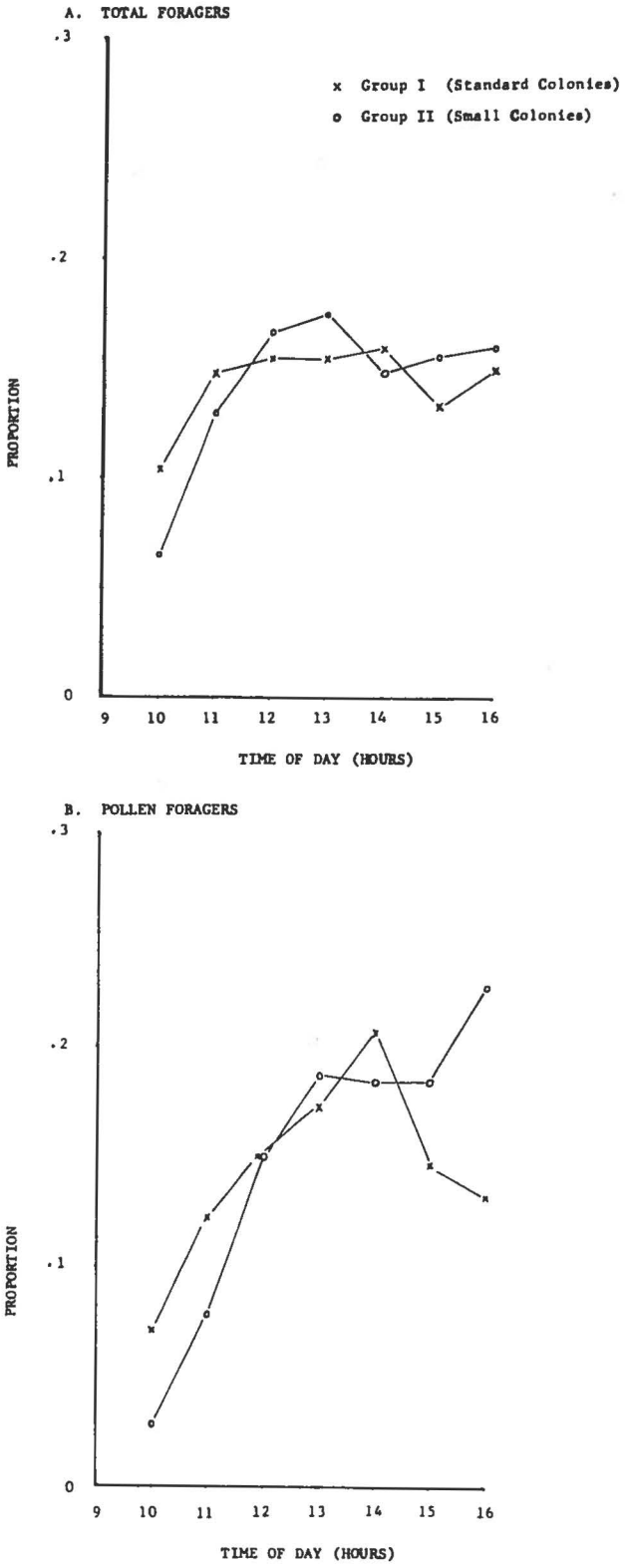

Figure 3. A comparison of "group hourly proportions" of total incoming foragers or incoming pollen foragers collected in both standard and small colonies at various times throughout three days (5, 6 and 9 August 1971)

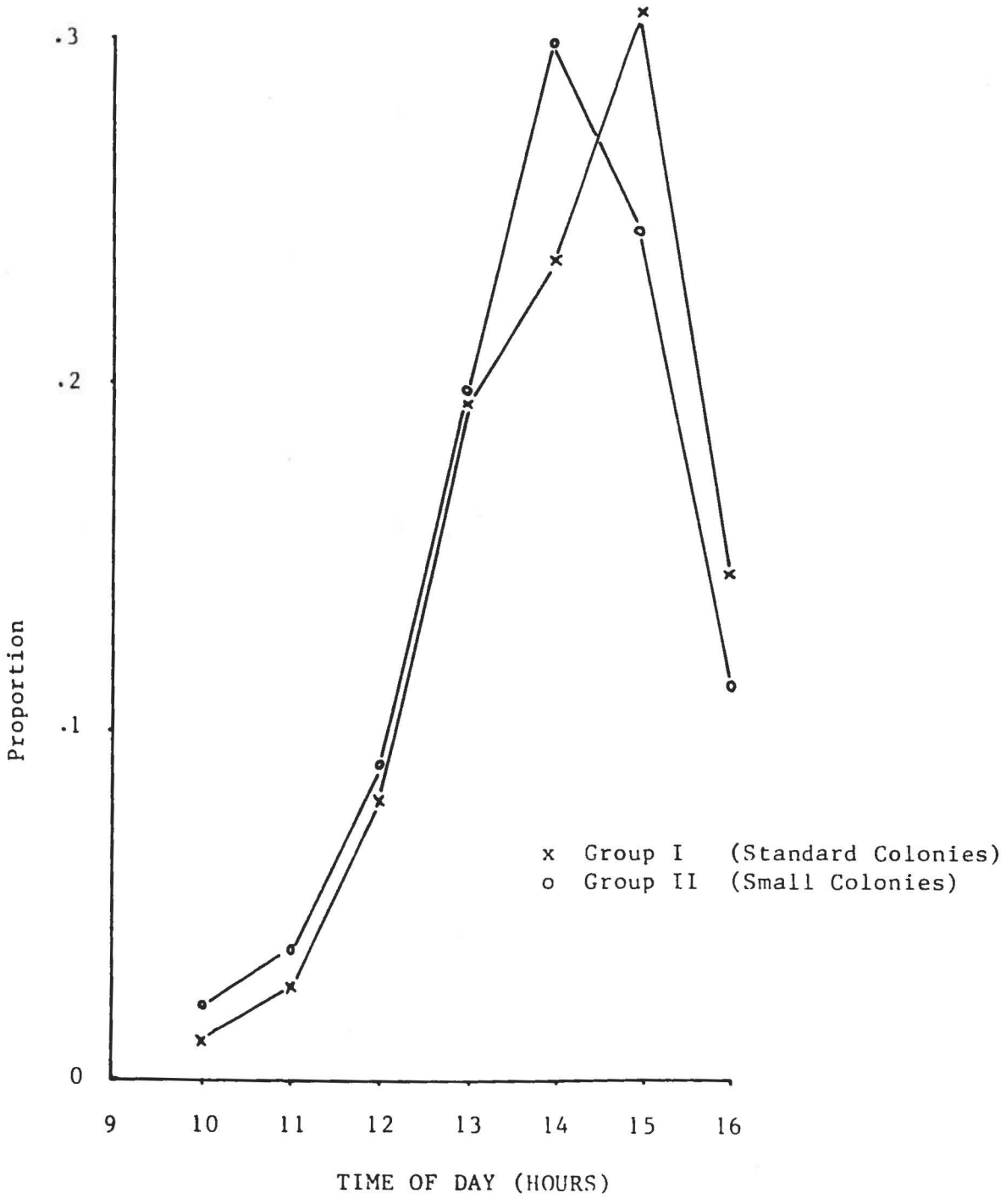

Figure 4. A comparison of "group hourly proportions" of weight of pollen collected in both standard and small colonies at various times throughout three days. (19, 20 and 23 August 1971).

The results are shown in Figure 2, a, b, c. No significant differences occurred between standard and small colonies in the proportion of incoming foragers, pollen foragers, or weight of pollen collected each hour during the test period.

Experiment II

On 5 August three standard colonies and three small colonies were selected and entrance counts of total numbers of incoming foragers and total numbers of incoming pollen foragers were made between 1000 and 1600 h on 5, 6, and 9 August as outlined in Experiment I. The results are shown in Figure 3, a, b. No significant differences occurred between standard and small colonies in the proportion of incoming foragers or incoming pollen foragers each hour during the test period.

Experiment III

On 19 August three standard colonies (40,000-45,000 bees) and three small colonies (15,000-19,000 bees) were fitted with Ontario Agricultural College pollen traps and each hour from 1000 to 1600 h on 19, 20 and 23 August the pollen in the traps of each hive was weighed. The results are shown in Figure 4. Analyses were done as outlined in Experiment I. Comparison of the hourly proportions of pollen collected during the day showed no significant differences between the two groups of colonies.

DISCUSSION AND CONCLUSIONS

In all experiments the proportion of total incoming foragers, incoming pollen foragers, or the weight of pollen collected each hour throughout the day in standard relative to small colonies, was not significantly different. It is important to note that this study was done during a 20-day period when major nectar flows occur in Manitoba and when bee populations are at or approaching their maxima (Jay 1974, Smirl and Jay 1972). Thus it may be convenient, because of the lower bee populations, to use small colonies in certain studies conducted during this time where entrance counts of honey bees are required. Before small colonies, rather than standard ones, can be used at times other than during the main honey flow, additional comparative entrance count and pollen weight data, from the two types of colonies, must be obtained.

Jay (1966, 1968) used small colonies throughout the season in his "drifting" studies and significantly reduced the amount of equipment and the amount of work required to obtain the data. This latter was especially important because bee counts had to be done on large numbers of colonies early in the morning before the bees flew and therefore time schedules had to be strictly adhered to.

Other studies of honey bees which could utilize small colonies, either wholly or in conjunction with standard colonies, and in which entrance counts are important are listed below: alteration of brood (eg. Free 1967), presence or absence of a queen or rearing of a queen (eg. Ribbands 1951, Free 1967), use of pollen traps (eg. Lindauer 1952, Rashad and Parker 1958, Lavie 1967), population and brood/bee ratio studies (eg. Farrar 1931, Moellar 1961), honey production studies (eg. Farrar 1937, Sharma and Sharma 1950), feeding sugar syrup or honey to stimulate foraging (Free and Spencer-Booth 1961, Barker 1973), package bee comparisons when hived on different dates (Nelson and Jay 1972, Smirl and Jay 1972), and pollination studies including directing bees to crops (Free 1970).

Although in most of the above studies, a saving in beekeeping equipment (and perhaps food used to produce the higher populations in standard colonies) may be important, another advantage of smaller colonies is the ease with which an observer can obtain entrance counts of foragers. This method also permits modification of the entrance apparatus to obtain counts of outgoing foragers, should these data be required.

ACKNOWLEDGEMENTS

The authors thank the National Research Council of Canada for funds necessary to conduct this study.

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(Received 3 March 1975)

THE WATER MITES OF RIDING MOUNTAIN NATIONAL PARK, WITH A DESCRIPTION OF *FORELIA BISPINOSA* n.sp. (ACARI: PIONIDAE)

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ABSTRACT: Eighty-six species of water mite were found in the study area. One of these species, *Forelia bispinosa* n.sp., is described. *Arrenurus (Megaluracarus) membranator* Thor is reported from North America for the first time and a further 16 species are first records from Canada. Examination of specimens of *Hygrobates decaporus* Koenike suggest that *H. dodecaporus* Nordenskiöld may be a junior synonym of this species. The synonymy by Prasad and Cook (1972) of North American specimens of *Pionopsis lutescens* (Hermann) with *P. paludis* (Habeeb) is rejected. I believe that these are two separate species in North America.

INTRODUCTION

This paper discusses collections of water mites from Riding Mountain National Park and its surrounding district in Manitoba. The collections were made in July 1964, August-September 1967, August 1970, and from June to August 1973 (Saunders). Conroy (1968) reported on some of the material but most of it is discussed for the first time.

Riding Mountain National Park is located 280 kms north-west of Winnipeg, Manitoba. The area is an ecological "island" formed as part of an erosion plateau by pre-glacial erosion. The 763 m high mountain is part of the Manitoba escarpment that was cut off from the Duck Mountains (to the north) and from the Turtle Mountains (to the south) by erosion caused by rivers. The area rises 300 m above the surrounding prairie.

The surface geological deposits are moranic boulder till. Evidence of glacial movement is seen in the many depressions filled by small lakes found all over the Park. To the north and east of the area are the beaches of the pre-glacial Lake Agassiz. The remnants of this lake can be seen today as the great lakes of the Province of Manitoba (Winnipeg, Manitoba, Winnipegosis and Dauphin).

The Park lies in the Aspen Parkland ecotone bordering the Boreal Forest. Areas of treeless prairie are found throughout the Park. Bird (1961) suggested that many of these areas were caused by either repeated fires or by overgrazing by wapiti *(Cervus canadensis).* The dominant trees in the Park include white spruce *(Picea glauca* (Moench) Voss), black spruce *(P. mariana* (Mill.)), jack pine *(Pinus banksiana* Lamb), trembling aspen *(Populus tremuloides* Michx.), white birch *(Betula papyrifera* Marsh.), larch *(Larix lariciana* (DuRoi) K. Koch), balsam fir *(Abies balsamea* (L.), Mill.), green ash *(Fraxinus pennsylvanica* March. var. *subintegerrima* (Vahl) Fern.), elm *(Ulmus americana* L.) and Manitoba maple *(Acer negundo* L. var. *interius* (Britt.) Sarg.).

The aim of the study was to learn more about the taxonomy and ecology of water mites in Riding Mountain National Park as part of a resource inventory of the park. Mites from 95 collections (73 from within the park boundaries and 22 from the surrounding district) were examined. A complete list of all the stations sampled is included as Appendix I.

The district visited during this survey may be found on the Canada National Topographical series maps-sheets 62J (Neepawa), 62K (Riding Mountain) and 62N (Duck Mountain).

METHODS

A variety of trapping methods was used to collect water mites including hand-nets, Surber sampler and Ekman dredge. The water mites were preserved in Koenike's fluid (five parts Glycerine, three parts distilled water and two parts Glacial Acetic Acid). Permanent slide mounts were made using either Glycerine jelly or CMC-10 non-resinous mounting medium (Turtox-Cambosco).

In the species list, the stations where the species were recorded are indicated by a number corresponding to the station number listed in Appendix I. All measurements cited are in microns (μ). The anatomical terms used follow those of Mitchell (1967). The classification used follows that of Cook (1974).

RESULTS

In the collections 86 species of water mite, representing sixteen families and twenty-seven genera, occurred. One of these species, *Forelia (Forelia) bispinosa* n.sp., is described. A second species, *Arrenurus (Megaluracarus) membranator* Thor is a first record from North America. The species was previously known from Norway, Sweden, England, Germany, Färöes Islands, Switzerland, Austria, Roumania, and USSR (Viets 1956). Sixteen species *(Thyas bruzelli* Lundblad, *Oxus intermedius* Marshall, *Limnesia puteorum* Stoll, *Hygrobates textor* Habeeb, *Unionicola figuralis* (Koch), *Neumania fragilis* Marshall, *N. hickmani* Marshall, *N. pubescens* Marshall, *Forelia cursor* Habeeb, *P. flatheadensis* Cook, *P. loda* Cook, *P. socialis* Marshall, *Arrenurus americanus mucronatus* Lavers, *A. morrisoni* Marshall, *A. laticornis* Marshall and *A. scutuliformis* Marshall) are new to Canada.

Twenty-two of the eighty-six species included in this paper were reported from the Riding Mountain National Park and district by Conroy (1968). Ten of these species were not found in subsequent collections and are included here for the sake of completeness. These species were: *Eylais abitibiensis, E. rimosa, E. robusta, Eylais as Ghost River form A, Eylais as Winnipeg no. 62, Limnesia columbica, P. pugilis, Arrenurus cascadensis, A. lautus,* and *A. krameri.* The twelve species reported by Conroy (1968) from the study area and recollected in later samples included: *Hydrachna cruenta, Eylais extendens, Hydrodroma despiciens, Limnesia cornuta, L. maculata, L. undulata, Unionicola crassipes, Piona carnea, P. conglobata, P. rotunda* (as *P. reighardi), P. neumani* (as *P. circularis* and as *P. setiger),* and *Mideopsis americanus.*

Family : **HYDRACHNIDAE**

Genus : *Hydrachna* Müller *s. str.*

1. *H. cruenta cruenta* Müller

   Sta.: 7 (five males, 16 females, 14 nymphs, two teleiochrysallids), 13 (two males), 15 (two males, two females, three nymphs), 18 (one male), 19 (one male, six females, 22 nymphs), 20 (one female), 23 (Conroy 1968, one male), 26 (Conroy 1968, three males, one female), 29 (one female, 14 nymphophans on Corixids).

2. *H. magniscutata magniscutata* Marshall

   Sta.: 10 (two males).

Family : **LIMNOCHARIDAE**

Genus : *Limnochares* Latreille

3. *L. aquatica* (Linne)

   Sta.: 15 (seven adults, one larva).

Family : **EYLAIDAE**

Genus : *Eylais* Leach

The adult characteristics of the Genus *Eylais* are extremely variable which makes accurate identification of the adults difficult. Lanciani (1969, 1970a, 1970b) pointed

out that the larval characteristics are more stable and identification of the larvae should be used to identify the adult species. Cook (1974) suggested that by associating larvae with known adults it might be possible to produce a better adult identification system. Since all the species of *Eylais* listed in this survey were based on adults only, their exact status is difficult to assess accurately.

4. *E. abitibiensis* Marshall

   Sta.: 23 (Conroy 1968, one male).

5. *E. extendens extendens* (Müller)

   Sta.: 3 (Conroy 1968, 1 adult), 7 (8 adults), 10 (one female), 12 (one adult), 15 (Conroy 1968, one adult, one nymph), 17 (two adults), 23 (Conroy 1968, four males, two females), 25 (one adult, three nymphs).

6. *E. rimosa* Piersig

   Sta.: 13 (Conroy 1968, one male).

7. *E. robusta* Marshall

   Sta.: 11 (Conroy 1968, one male).

8. *Eylais as Ghost River form A* Marshall

   Sta.: 11 (Conroy 1968, one female).

9. *Eylais as Winnipeg no. 62* Marshall

   Sta.: 8 (Conroy, one adult), 11 (Conroy 1968, one male).

Family : **HYDRYPHANTIDAE**

Genus : *Hydryphantes* Koch

10. *H. ruber* Geer

    Sta.: 28 (one female).

Genus : *Thyas* Koch

11. *T. bruzelli* Lundblad

    Sta.: 12 (three adults).

    Distribution: New to Canada. Previously known from Michigan, Maine, Sweden and Siberia (Crowell 1961).

Family : **HYDRODROMIDAE**

Genus : *Hydrodroma* Koch

12. *H. despiciens despiciens* (Müller)

    Sta.: 13 (Conroy 1968, one nymph), 13 (one female), 16 (one male), 18 (five adults), 19 (five adults, one nymph), 20 (eight adults), 20 (one male), 29 (one female), 32 (Conroy 1968, one female, four nymphs, one larva).

Family : **SPERCHONTIDAE**

Genus : *Sperchon* Kramer

13. *S. glandulosus* Koenike

    Sta.: 4 (one male).

Family : **LEBERTIIDAE**

Genus : *Lebertia* Neuman

14. *L. ontarioensis* Marshall

    Sta.: 4 (three males, two females).

15. *L. porosa porosa* Thor

Sta.: 3 (two females), 7 (one male), 14 (three males, five females), 18 (20 females).

16. *L. tyrrelli* Koenike

Sta.: 14 (one female).

Family : **OXIDAE**

Genus : *Oxus* Kramer

17. *O. connatus* Marshall

Sta.: 18 (four adults, one nymph).

18. *O. intermedius* Marshall

Sta.: 14 (11 adults).

Distribution: New to Canada. Previously known from Minnesota, Wisconsin, New Jersey, and Tennessee (Crowell 1961).

Genus : *Frontipoda* Koenike

19. *F. americana* Marshall

Sta.: 18 (two adults), 19 (eight adults), 20 (one adult).

Family : **LIMNESIIDAE**

Genus : *Tyrrellia* Koenike

20. *T. circularis* Koenike

Sta.: 14 (one male, one female, one nymph).

Genus : *Limnesia* Koch *s. str.*

21. *L. columbica* Marshall

Sta.: 13 (Conroy 1968, one female), 31 (Conroy 1968, one female).

22. *L. cornuta* Wolcott

Sta.: 2 (Conroy 1968, one female), 14 (20 males, 21 females, one nymph).

23. *L. fulgida fulgida* Koch

Sta.: 14 (one male).

24. *L. maculata maculata* (Müller)

Sta.: 9 (Conroy 1968, three females), 12 (one male, two females), 17 (two females, one nymph), 20 (one male, two females), 21 (one male, 11 females).

25. *L. paucispina* Wolcott

Sta.: 10 (two females), 20 (one female), 24 (one male, two nymphs), 31 (one female).

26. *L. puteorum* Stoll

Sta.: 18 (two females), 22 (two males, four females, three nymphs).
Distribution. New to Canada. Previously known from Guatemala and Mexico (Crowell 1961).

27. *L. undulata undulata* (Müller)

Remarks: Common throughout the Riding Mountain area.

28. *L. anomala* Koenike

Sta.: 17 (two females), 21 (one male, three females).

Family : **HYGROBATIDAE**

Genus : *Atractides* Koch

29. *A. nodipalpis americanus* (Marshall)

Sta.: 9 (one male), 14 (one male, one female).

Genus : *Hygrobates* Koch *s. str.*

30. *H. occidentalis* Marshall

Sta.: 2 (one female).

31. *H. textor* Habeeb

Sta.: 7 (one female).

Distribution: New to Canada. Previously known only from New York (Habeeb 1968).

Subgenus : *Dekabates* Thor

32. *H. decaporus* Koenike

Sta.: 4 (one male), 16 (two males, two females) (Figures: 1, 2, 3.)

Remarks: Cook (1974) synonymized *Dodekabates* Viets 1926 with *Dekabates* basing his findings on two specimens of *Hygrobates angelieri* Cook from Liberia (Cook 1966). He pointed out that "in most water mite groups, when the pairs of acetabula reach more than four, the number becomes unstable and the difference between five and six pairs is meaningless" (Cook 1974, p. 197). Of the two specimens of *H. angelieri*, one had five pairs of acetabula; the other had six pairs.

The four specimens of *H. decaporus* examined from the Whirlpool River showed—

male (mount RMNP-8-01) — five acetabula on right, six on left (Plate 1: 1, 2)

male (mount RMNP-8-06) — five acetabula on each side (Plate 1: 3a)

female (mount RMNP-8-04) — six acetabula on each side (Plate 1: 3b)

female (mount RMNP-8-05) — five acetabula on each side (Plate 1: 3d).

The male examined from the seepage into Clear Lake (near the Wishing Well) (mount RMNP-3-02) had six acetabula on each side (Plate 1: 3c). The palps, coxal plates and genital areas were similar in all cases with the above differences the only ones noted. In view of this, I believe *H. dodecaporus* Nordenskiöld may be a junior synonym for *H. decaporus* Koenike.

Family : **UNIONICOLIDAE**

Genus : *Unionicola* Haldeman *s. str.*

33. *U. crassipes crassipes* (Müller)

Sta.: 8 (Conroy 1968, one nymph), 8 (32 males, 37 females, two nymphs), 9 (Conroy 1968, one nymph), 13 (fourteen males, five females, one nymph), 15 (two males), 16 (four males, three females, two nymphs), 18 (four males, 14 females), 20 (six females), 34 (nine males, 39 females).

34. *U. gracilipalpis gracilipalpis* (Viets)

Sta.: 18 (four females), 20 (two females).

35. *U. pectinata* (Wolcott)

Sta.: 18 (two females).

Subgenus : *Pentatax* Thor

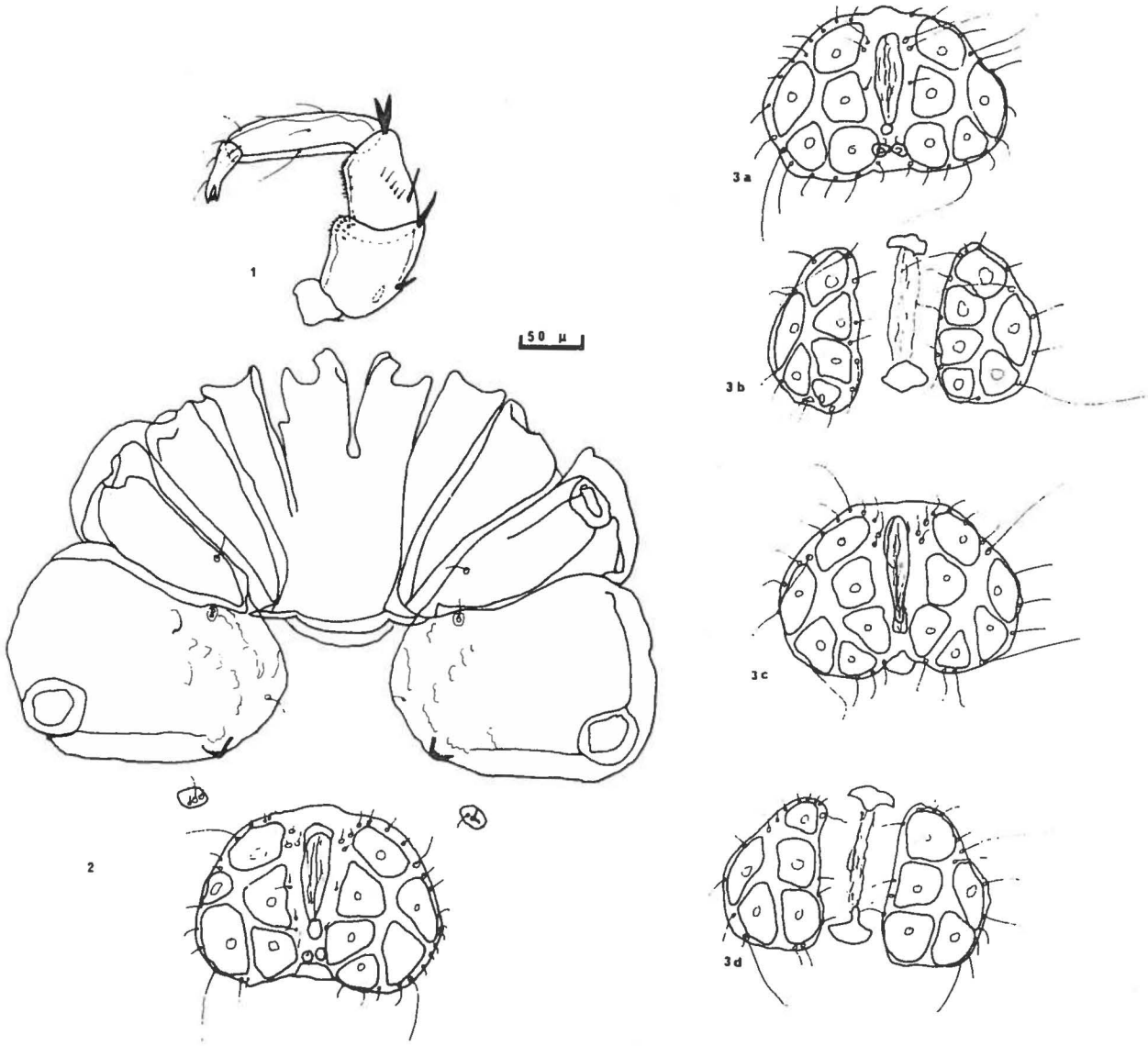

Plate 1 *Hygrobates decaporus* Koenike 1. Palp, male (mount RMNP-8-01) 2. Ventral view, male (mount RMNP-8-01)
3. (a) genital area, male (mount RMNP-8-06) (b) genital area, female (mount RMNP-8-04)
(c) genital area, male (mount RMNP-3-02) (d) genital area, female (mount RMNP-8-05)

36. *U. figuralis* (Koch)

Sta.: 13 (one male, three females).

Distribution: New to Canada. Previously known from Wisconsin (Crowell 1961). Two females, however, were found in Kinowa Lake, Prince Albert National Park, Saskatchewan, in August 1967 (unpublished record).

37. *U. aculeata* (Koenike)

Sta.: 18 (two females).

Genus : *Neumania* Lebert

38. *N. fragilis* Marshall

Sta.: 14 (one female).

Distribution: New to Canada. Previously known from Illinois, Michigan and Wisconsin (Crowell 1961).

39. *N. hickmani* Marshall

Sta.: 7 (one female), 20 (one female).

Distribution: New to Canada. Previously known only from Wisconsin (Crowell 1961).

40. *N. ovata* Marshall

Sta.: 11 (three females).

41. *N. pubescens* Marshall

Sta.: 11 (one male).

Distribution: New to Canada. Previously known from Colorado, Indiana, Iowa and Wisconsin (Crowell 1961).

42. *N. semicircularis* Marshall

Sta.: 3 (two females), 14 (one male, two females, five nymphs), 17 (five males, one nymph), 21 (one female).

Genus : *Koenikea* Wolcott *s. str.*

43. *K. concava* Wolcott

Sta.: 14 (three females).

Family : **PIONIDAE**

Genus : *Wettina* Piersig

44. *W. podagrica* (Koch)

Sta.: 16 (two females)

Genus : *Hydrochoreutes* Koch

45. *H. intermedius* Cook

Sta.: 3 (four females).

Distribution: Previously recorded from Montana (Cook 1970). Conroy and Scudder (1975) have recorded *H. intermedius* from Marion Lake, British Columbia and I have further unpublished records from Knight's Lake, Waterton National Park, Alberta (August 1967); and from a creek by 57 Trail, Prince Albert National Park, Saskatchewan (August 1967).

Genus : *Tiphys* Koch *s. str.*

46. *T. ornatus* Koch

Sta.: 19 (two egg-bearing females, one nymph).

Distribution: This is the second record for Canada. Conroy and Scudder (1975) reported the species from British Columbia. Previously known from Africa, Asia, Europe and from New Jersey, Alaska, Michigan, and Wisconsin (Cook 1955).

47. *T. simulans* (Marshall)

Sta.: 13 (one female).

Genus : *Pionopsis* Piersig *s. str.*

48. *P. lutescens* (Hermann)

Sta.: 3 (one female), 28 (one female).

Remarks: I compared the above two females with others from Marion Lake, British Columbia (one female), from Galwey Creek, near Waterton National Park, Alberta (one female), and with specimens given to me by Dr. L. Halik, Prague, Czechoslovakia. I found no differences between the North American and European forms. All of the above specimens agree closely with the figures in Cook (1956) and with a specimen loaned to me by Dr. Cook. Prasad and Cook (1972) considered all North American records of *P. lutescens* to be of *P. paludis* Habeeb 1954. I consider *P. lutescens* and *P. paludis* as different species in North America.

Genus : *Forelia* Haller *s. str.*

49. *F. cursor* Habeeb

Sta.: 14 (three egg-bearing females).

Distribution: New to Canada. Previously known from Michigan and New Jersey (Crowell 1961).

50. *F. siegasiana* Habeeb

Sta.: 12 (one male, one female).

51. *F. bispinosa* nov. sp.

Figures: 4, 5, 6, 7, 8, 9.

Type locality: Clear Lake, Riding Mountain National Park, Manitoba.
Specimens studied: six males, fourteen females, one nymph.

Type specimens:

Holotype: Male, mount number RMNP-02, 67-01 (deposited with the National Museum of Canada, Natural History Branch, Ottawa). Specimen found on September 1, 1967 at 22 cms in sand and gravel, in Clear Lake, Manitoba, near the "Wishing Well".

Allotype: Female, mount number RMNP-02, 67-04 (deposited with the National Museum of Canada, Natural History Branch, Ottawa). Same location and data as holotype.

Paratypes: In the collection of the author. Two males, eight females from Clear Lake, Manitoba (September 1, 1967) same data as holotype; one male from Falcon Lake, Manitoba (June 8, 1964) at point of entry of Hamilton Creek, at 10 cms and 16.5° C — reported erroneously as *F. ligulifera* (Piersig) in Conroy (1968); one male, one female, from Lake Dauphin at Dauphin Beach (August 24, 1964) at 12.5 cms and 18° C; one male from Lake Winnipegosis (one mile north of 53°) on August 20, 1964, at 15 cms and 18.5° C; one female from the seepage into Clear Lake near the type locality (September 1, 1967) at 3 cms; one female from Katherine Lake (September 2, 1967) at 12 cms; one egg-bearing female in an Ekman dredge sample from Moon Lake (June 22, 1973) (Saunders collection 1218-D-2) and one female and one nymph from an Ekman dredge sample from Clear Lake (August 6, 1973) (Saunders collection 134-D-2).

Diagnosis: The new species can be readily separated from all other members of the genus by the presence of two large spines on the IV-leg-4 of the male (Plate 2: 4); the

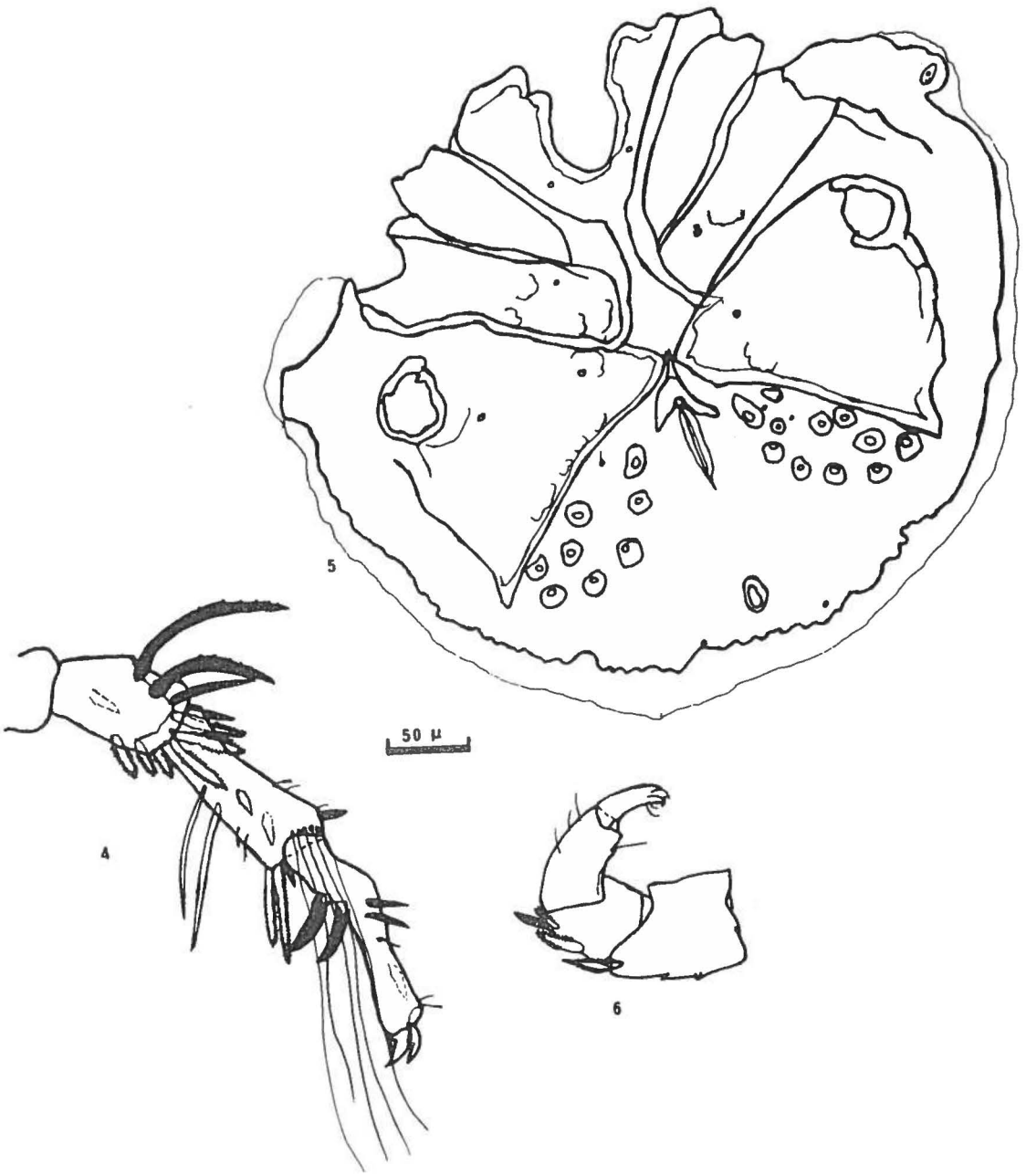

Plate 2 *Forelia bispinosa* n.sp. male 4. IV-leg-4 5. ventral view 6. palp

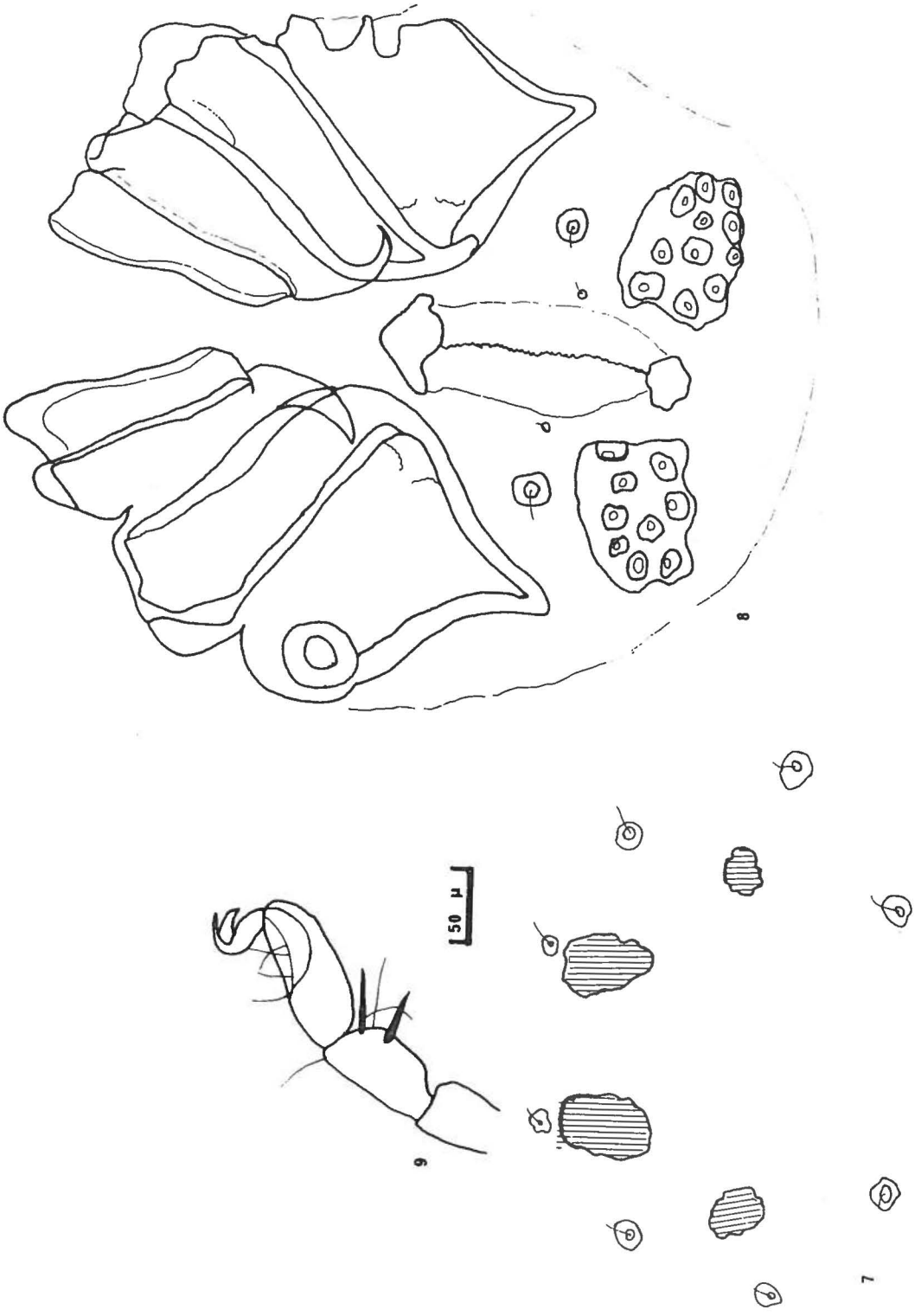

Plate 3 *Forelia bispinosa* n.sp. female 7. dorsal plates 8. ventral view 9. I-leg-5 and I-leg-6

dorsal shield in the male is large; the genital acetabula number 8-10, are indistinct and are carried on the secondary sclerotization on the ventral side.

Zoogeographic range: Nearctic.

Male: Length of body 399-411; width of body 411-472; body globular; heavy sclerotization of both dorsal and ventral surfaces; dorsal plate 430-441 long, 231-326 wide; inner margins of CP-IV touching each other; posterior corners of CP-IV acute; acetabular plates incorporated into the secondary sclerotization; 8 - 12 genital acetabula on each side (Plate 2: 5).

Length of III-leg-5 130-154; length of III-leg-6 124-135; claws of third leg normal; IV-leg-4 length 88-96, carrying a pair of large spines with small nodules dorsally, distally carried seven feathered bristles (Plate 2: 4); IV-leg-5 106-117 long, carrying two long hairs ventrally and four smaller feathered spines laterally, five long swimming hairs distally (subequal to IV-leg-6) and two long feathered spines distoventrally; IV-leg-6 135-156 long, with two large, peg-like spines mid-ventrally and two smaller spines dorsally, one small, feathered spine distally; two claws inserted at tip. Dorsal lengths of palpal segments: P-I 26-31; P-II 80-88; P-III 44-52; P-IV 67-75; P-V 41-49 (Plate 2: 6).

Female: Length of body 430-557; width of body 399-504; body globular, integument soft; dorsum with one pair of sclerotized plates, 59-75 long by 33-42 wide flanked by a second, smaller pair, 31-39 long by 31-34 wide (Plate 3: 7); acetabular plates separate, longer than wide, with 8-11 genital acetabula on each plate (Plate 3: 8); I-leg-6 expanded distally, 81-107 long (Plate 3: 9).

Subgenus : *Madawaska* (Habeeb)

52. *F. borealis* (Habeeb)

Sta.: 3 (three females).

Remarks: This species was also recorded by the author from Marion Lake, British Columbia (numerous occasions) (Conroy and Scudder 1975) and from Knight's Lake, Waterton National Park, Alberta (August 1967) (Conroy unpublished record). Since the species was previously recorded from Ontario (Cook 1955), it would appear to have a very wide distribution across Canada.

Genus : *Piona* Koch

53. *P. alpicola* (Neuman) = *P. uncata* (Koenike).

Sta.: 1 (one male), 12 (one male), 13 (one male, one nymph), 41 (one male).

54. *P. carnea* (Koch)

Sta.: 8 (one female), 15 (one male), 16 (one male, ten nymphs), 19 (80 males, 33 females, six nymphs), 20 (one female), 25 (five males, two females), 26 (Conroy 1968, 15 males, one female, 89 nymphs), 34 (three males), 37 (one female).

55. *P. coccinea americana* (Marshall)

Sta.: 11 (five males, one female), 17 (six males, ten females, two nymphs), 41 (one male, one female).

56. *P. conglobata* (Koch)

Sta.: 13 (Conroy 1968, one male, one female), 21 (one female), 22 (one male, one nymph).

57. *P. constricta* (Wolcott)

Sta.: 12 (three females), 20 (three females), 22 (seven nymphs).

58. *P. exilis* (Wolcott)

Sta.: 21 (one female).

59. *P. flatheadensis* Cook

Sta.: 3 (one male, three females), 7 (two females), 22 (three females).

Distribution: New to Canada. Previously known only from Montana (Cook 1960, Crowell 1961).

60. *P. interrupta* Marshall

Sta.: 17 (26 males).

61. *P. loda* Cook

Sta.: 15 (two males, two females, 24 nymphs).

Distribution: New to Canada. Previously known from Montana and Washington (Crowell 1961).

62. *P. neumani* (Koenike).

Sta.: 20 (two females), 28 (Conroy 1968, as *P. setiger* (Wolcott), four males), 38 (Conroy 1968, as *P. circularis* (Piersig), one female).

63. *P. pugilis* (Wolcott)

Sta.: 13 (Conroy 1968, one nymph).

64. *P. rotunda rotunda* (Kramer)

Sta.: 14 (four males, two females, four nymphs), 15 (one female), 20 (five males), 24 (Conroy 1968, as *P. reighardi* (Wolcott), one male, one female, one nymph), 38 (Conroy 1968, one male, two females as *P. rotunda* one female as *P. reighardi).*

65. *P. socialis* Marshall

Sta.: 7 (three females).

Distribution: New to Canada. Previously recorded from Minneosta and Montana (Crowell 1961).

66. *P. spinulosa* (Wolcott)

Sta.: 14 (one female).

67. *P. variabilis* (Koch)

Sta.: 19 (eight females).

Family : **MIDEOPSIDAE**

Genus : *Mideopsis* Neuman *s. str.*

68. *M. orbicularis* (Muller)

Sta.: 4 (one adult), 7 (two adults), 8 (one adult), 14 (one adult), 19 (one adult).

69. *M. americanus* Marshall

Sta.: 3 (one male, one female), 9 (Conroy 1968, two males), 14 (nine adults), 16 (one adult).

Family : **ARRENURIDAE**

Genus : *Arrenurus* Duges *s. str.*

70. *A. americanus* Marshall

Sta.: 31 (one male, one female).

71. *A. americanus mucronatus* Lavers

Sta.: 11 (one male), 18 (one male).

Distribution: New to Canada. Previously found in Michigan and Washington (Crowell 1961).

72. *A. cascadensis* Lavers

Sta.: 9 (Conroy 1968, one female).

73. *A. laticornis* Marshall

Sta.: 13 (one male), 15 (one female), 19 (six males, 12 females).

Distribution: New to Canada. Previously known from Illinois, Iowa, Michigan, Missouri, Tennessee, and Wyoming (Crowell 1961).

74. *A. lautus* Koenike

Sta.: 39 (Conroy 1968, one male).

75. *A. major* Marshall

Sta.: 13 (one male).

76. *A reflexus* Marshall

Sta.: 18 (two males).

77. *A. serratus* Marshall

Sta.: 7 (one male).

Subgenus : *Megaluracarus* Thon

78. *A. invaginatus* Lavers

Sta.: 31 (four males, eight females).

79. *A. krameri* Koenike

Sta.: 29 (Conroy 1968, one female).

80. *A. membranator* Thor

Sta.: 29 (one male).

Distribution: New to North America. Previously known from Norway, Sweden, England, Germany, Färöes Islands, Switzerland, Austria, Roumania, and USSR (Viets 1956).

81. *A. morrisoni* Marshall

Sta.: 15 (one female), 19 (two males, six females).

Distribution: New to Canada. Previously recorded from Michigan, Washington and Wisconsin (Crowell 1961).

82. *A. scutuliformis* Marshall

Sta.: 3 (one male, one female).

Distribution: New to Canada. Previously known from Maine, Michigan, and Wisconsin (Crowell 1961).

Subgenus : *Micruracarus* Thon

83. *A. crenellatus* (Marshall)

Sta.: 9 (one male), 16 (one male).

Family : **HOMOCALIGIDAE**

Genus : *Homocaligus* Berlese

Subgenus : *Paludocaligus* Habeeb

84. *H. muscorum* (Habeeb)

Sta.: 25 (one male).

Family : **ORIBATIDAE**

Genus : *Hydrozetes* Berlese

85. *H. lacustris* (Michael)

Sta.: 14 (two adults), 15 (five adults), 18 (three adults), 19 (one adult), 20 (11 adults), 28 (one female).

Genus : *Trimalaconothrus* (Berlese)

86. *Trimalaconothrus* sp.

Sta.: 14 (one adult, unidentified to species).

ACKNOWLEDGEMENTS

Sincere thanks are extended to the Natural History Branch of the National Museum of Canada, Ottawa, to the Canadian Wildlife Service, and to the University of Winnipeg, whose financial help made this survey possible; thanks are also due to the Department of Indian Affairs and Northern Resources, National Parks Branch, for permission to collect in the Park; to R. Saunders, Canadian Wildlife Service, for collections made in 1973; and to L. Forman and D. Forman and the members of my family who assisted in collecting.

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(Received 25 March 1975)

APPENDIX I : List of Stations

After the station name will be found the year(s) in parentheses in which the stations were sampled.

(a) **Riding Mountain National Park**

1. Ditch near Park south gate (1964).
2. Clear Lake at Audy Lake Road junction (1964, 1967).
3. Clear Lake near the Golf Course (1964, 1967).
4. Clear Lake near the *Wishing Well* (1967 twice).
5. Clear Lake at point of entry of small stream (1967).
6. Clear Lake shore, near Station 5 (1967).
7. Clear Lake (Saunders 1973 - 10 collections).
8. Jackfish Creek (1964, 1967).
9. Audy Lake (1964, 1967).
10. Grayling Lake (1964, 1967, Saunders 1973 — one collection).
11. Edward's Creek (1964, 1967).
12. Edwards Lake (Saunders 1973 — 4 collections).
13. Slough near Junction of Audy Lake Road and Highway 10 (1964, 1967).
14. Katherine Lake (1964, 1967, Saunders 1973 — 6 collections).
15. Whirlpool Lake (1964, Saunders 1973 — 5 collections).
16. Whirlpool River (1964, 1967 — twice).
17. Muskrat Lake (Saunders 1973 — 5 collections).
18. Pudge Lake (Saunders 1973 — 2 collections).
19. South Lake (Saunders 1973 — 8 collections).
20. Kinosas Lake (Saunders 1973 — 3 collections).
21. Moon Lake (Saunders 1973 — 3 collections).

(b) **Environs of Riding Mountain National Park**

22. Lake across the road from Octopus Lake (1964).
23. Hawk Lake (1964).
24. Sandy Lake (1964).
25. Slough on Sandy Lake Road (1970).
26. Shoal Lake (1964).
27. Alfretta Lake (1964).
28. Slough near Shoal Lake Town (1964).
29. Salt Lake near Salt Lake Beach (1964, 1970).
30. Salt Lake (East Shore) (1964).
31. Slough near Salt Lake east shore (1964, 1970).
32. Beau Lake (1964).
33. Crawford Lake (1964).
34. Lake north of Sandy Lake (1970).
35. Jackfish Lake (1970).
36. Minnedosa River at the Dam (1964).
37. Minnedosa River on the Sandy Lake-Newdale Road (1970).
38. Park Lake, Neepawa (1964).
39. Slough near Stoney Creek (1964).
40. Gravel Pit near Rivers (1970).
41. Rivers Lake (1970).

BOREAL FOREST CANOPY COVER CHANGES AFTER EIGHTEEN MONTHS OF CHRONIC GAMMA IRRADIATION

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ABSTRACT: The effects of chronic gamma radiation on the canopy cover of a mixed boreal forest in southeastern Manitoba are presented. Pre-irradiation (1971-2) canopy cover results were compared to those obtained after 18 months of irradiation. Canopy cover decreased significantly within 50 m of the irradiator due primarily to the death of trees and shrubs. Beyond 50 m some significant increases were observed. Changes in per cent cover of the individual species which comprise the canopy show similar trends.

INTRODUCTION

Changes in the forest canopy cover may cause alterations in the species composition of the understory. Therefore, if an environmental stress is applied which changes the amount of canopy cover, secondary effects on the rest of the biota can be expected. The causes of such change could be physical: drought, wind, flood, cold, heat, logging or fire, or biological such as forest tent caterpillar outbreaks. The controlled stress applied to the Field Irradiator — Gamma (FIG) forest is ionizing radiation.

The FIG area, 1000 m in diameter, is located in a mixed boreal forest about 120 kilometers NE of Winnipeg, at Atomic Energy of Canada's Whiteshell Nuclear Research Establishment. After several years of ecological studies, a 10,000 effective Ci ^{137}Cs source was placed in the center of the area on a 20 m tower (Dugle 1969, Dugle and Thibault 1972, 1974). Chronic irradiation began 2 March 1973 and continued for an average of 19 h/day since that time. The effect of the local climate on the forest is the subject of a separate study (A. Reimer, Meteorologist, WNRE). This paper describes the changes taking place in the canopy cover of the area during the first 18 months of irradiation, consisting of two growing seasons and one winter.

METHODS

Within the study area, 15 x 25 m quadrats representing as many different plant associations as possible were permanently located prior to the start of irradiation. Each 15 x 25 m quadrat is subdivided into five 5 x 15 m macroplots. Twenty stations in each quadrat (four per macroplot) were selected using a stratified random design, and marked with a permanent stake. Before chronic irradiation began (1971-2) the tree and tall shrub canopy was determined at each stake with a "moosehorn" (Robinson 1947, Dugle and Thibault 1974). The species comprising the canopy at each station were recorded. During the summer of 1974, following 18 months of chronic irradiation, the measurements were repeated at the same locations, which included a transect of quadrats extending 500 m north of the irradiator. The pre-irradiation (1971-2) canopy results were compared to those after 18 months of irradiation (1974) using a paired t test.

The dose received at each station was determined from several thermoluminescent lithium fluoride dosimeters (Dugle and Thibault 1974). Dose readings from several stations were averaged to obtain each dose rate presented.

At the end of each growing season, leaves were sampled from the broad-leafed species in the canopy (Dugle and Thibault 1974). The leaves were measured (length and width in mm) and qualitatively assessed for insect damage. Insect damaged leaves were placed into one of four categories: none, little, medium or severe.

RESULTS AND DISCUSSION

All quadrats with significant canopy decreases after 18 months of irradiation were found within 50 m of the tower while those with increases were beyond that distance (Figure 1). Results of a qualitative estimate of insect damage, using leaf samples from marked trees and shrubs, showed that the number of leaves in the severely damaged category was variable. There was no evident correlation with year (Table 1) nor were there unusual numbers of phytophagous insects in either 1972 or 1974 (J.E. Guthrie, personal communication). Thus, none of the decreases or increases in canopy can be attributed to an abnormal amount of insect damage.

One of the main causes for loss of canopy cover during chronic irradiation was the death of trees and shrubs. Between 1971-2 and 1974 there was a significant increase in the number of tree and shrub deaths within 50 m of the irradiator (Figure 2). The per cent dead ($< 10\%$) in the canopy of each quadrat beyond 50 m is similar to that observed in this forest prior to irradiation. In some cases the cover was so dense that even though the trees over the stake were dead, their branches were so thick and overlapping that the cover was still 100%. In such cases, several years would be required to reduce the canopy.

On the north transect of the irradiated area, changes in mean canopy cover varied from a significant decrease at 2550 mrad/h to a significant increase at 670 mrad/h (Figure 3). When macroplots, rather than quadrats were examined (Figure 4), the region between 25 m and 40 m showed a statistically significant decrease in canopy cover, while beyond 55 m some statistically significant increases were evident. Even though the degrees of freedom were very low ($n = 4$ or 8), the statistical significance of the differences was maintained.

Although the response of various species appears similar (Figures 5 and 6), changes in certain species have a much greater impact on the increase or decrease in canopy cover than do changes in others. Much of the loss of canopy near the irradiator was due to the absence of *Alnus rugosa* leaves during 1974, within 40 m of the irradiator (Figure 5). Also, since irradiation began the mean leaf size has decreased significantly beyond the 40 m point (unpublished data). *Populus tremuloides* (Figure 5) and *Betula papyrifera* (Figure 6) were also important in the loss of canopy close to the irradiator. The reduction attributed to *Salix* spp. (Figure 6) was unusual. Many of the branches were killed, and produced no leaves during 1974. However, on the lower half of the main stems, new branches sprouted, grew rapidly and formed extra large leaves. This effect produced a smaller but very dense shrub which could either increase or decrease canopy cover, depending on the relationship of the sampling point and the shrubs. This probably explains the results found in Figure 6, where both increases and decreases in *Salix* spp. canopy can be seen within 25 m of the irradiator. Although nearly all *Picea* spp. close to the irradiator were killed, the occurrence of *Picea* in the canopy is sparse at this distance, so the changes seen in the per cent canopy were not large. Also, a loss of needles from a thick growth of *Picea* does not produce a large change in per cent canopy cover.

There are several probable reasons for the increase in canopy at 50 - 500 m from the tower. Some of this forest is still young and canopy is increasing rapidly. This is especially true at 450 - 500 m N (Figure 1). Significant increases in size of individual leaves of some species with lower doses of radiation of about 1000 mrad/h (unpublished data) may also be important since the increase in individual leaf size results in an effective increase in per cent canopy cover. Thus the relative importance of certain species in the canopy, and their individual radiation responses, cause the changes in canopy cover after 18 months of chronic irradiation.

ACKNOWLEDGEMENTS

We wish to thank D. Thibault, D. Morgan and the several summer students who collected the canopy cover data.

Table 1. Relative significance of insect damage 1972-1974 on leaves of canopy trees and shrubs

Species and dose (mrad/h)	Distance from tower (m)	Year	n	Insect damage on leaves (%) None	Little	Medium	Severe
Alnus rugosa	45	72	57	0	54	26	20
1557.0		74	56	0	48	46	5
Alnus rugosa	84	72	62	0	61	23	16
413.95		74	55	0	16	56	27
Populus tremuloides	39	72	68	0	87	13	0
2173.25		74	45	0	56	40	4
Populus tremuloides	42	72	301	0	75	11	14
2331.2		74	52	0	17	71	12
Populus tremuloides	46	72	103	0	39	21	40
1456.95		74	86	0	36	61	4
Betula papyrifera	41	72	197	0	94	6	1
2010.75		74	81	5	46	47	2
Betula papyrifera	73	72	53	0	67	23	10
309.40		74	68	0	6	90	5
Betula papyrifera	109	72	96	0	78	22	0
119.15		74	151	0	64	33	4
Betula papyrifera	111	72	50	0	65	29	6
103.84		74	118	0	1	74	25

The dose listed is that measured on the tree or shrub described.

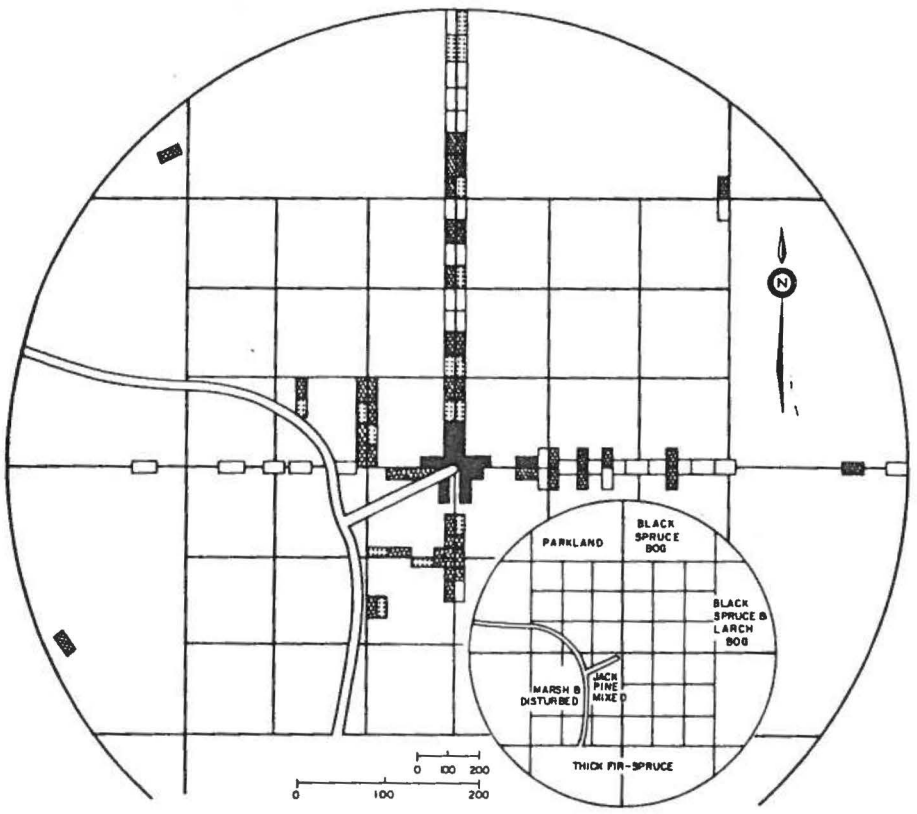

Figure 1. Significance of canopy cover changes in quadrats and their location within FIG.

Statistically significant decrease in canopy cover from 1971-2 to 1974 ($t > 2.093$, $n = 20$, $p < 0.05$).

No change in canopy cover.

Statistically significant increase in canopy cover from 1971-2 to 1974 ($t > 2.093$, $n = 20$, $p < 0.05$).

Quadrats not studied.

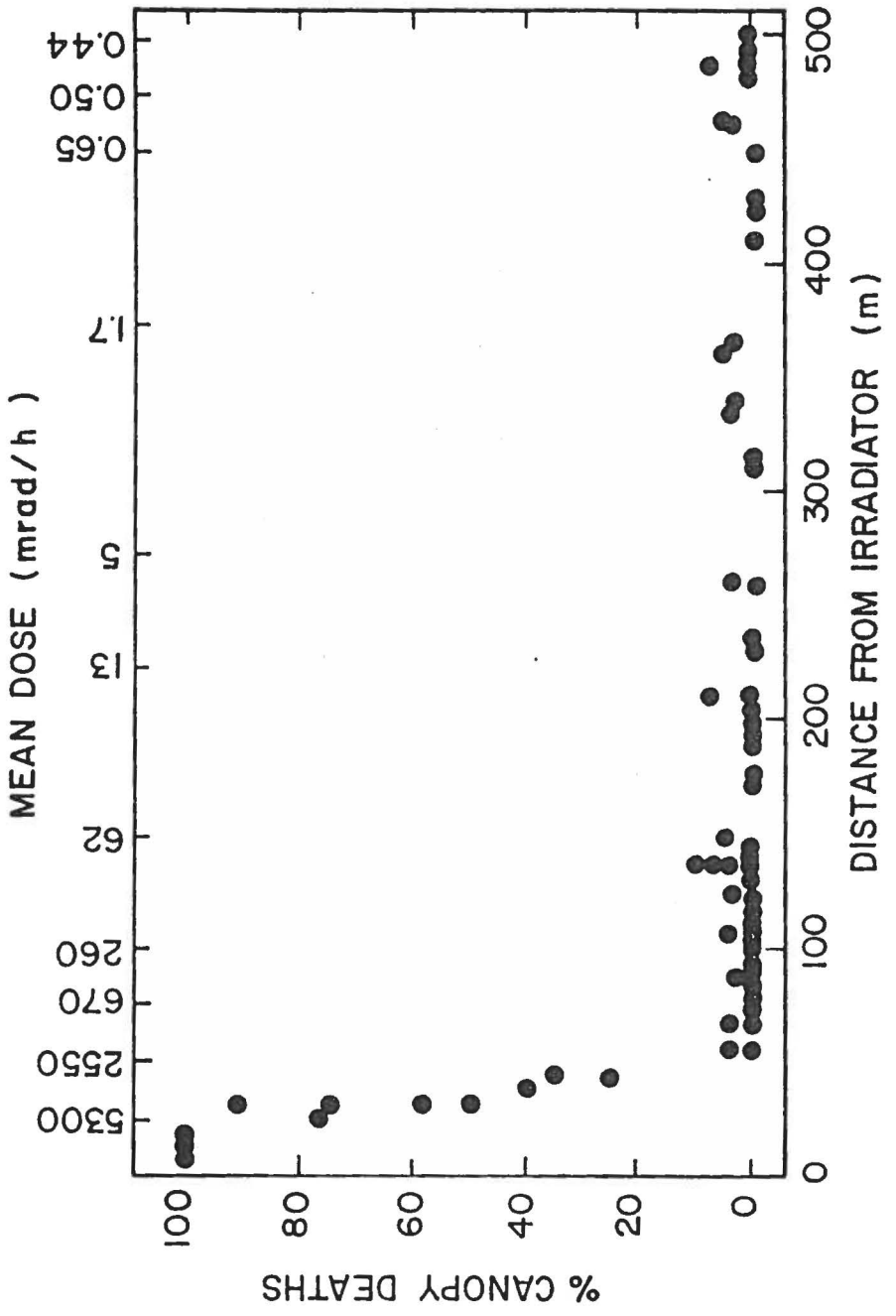

Figure 2. Accumulated deaths in canopy trees and shrubs by 1974.

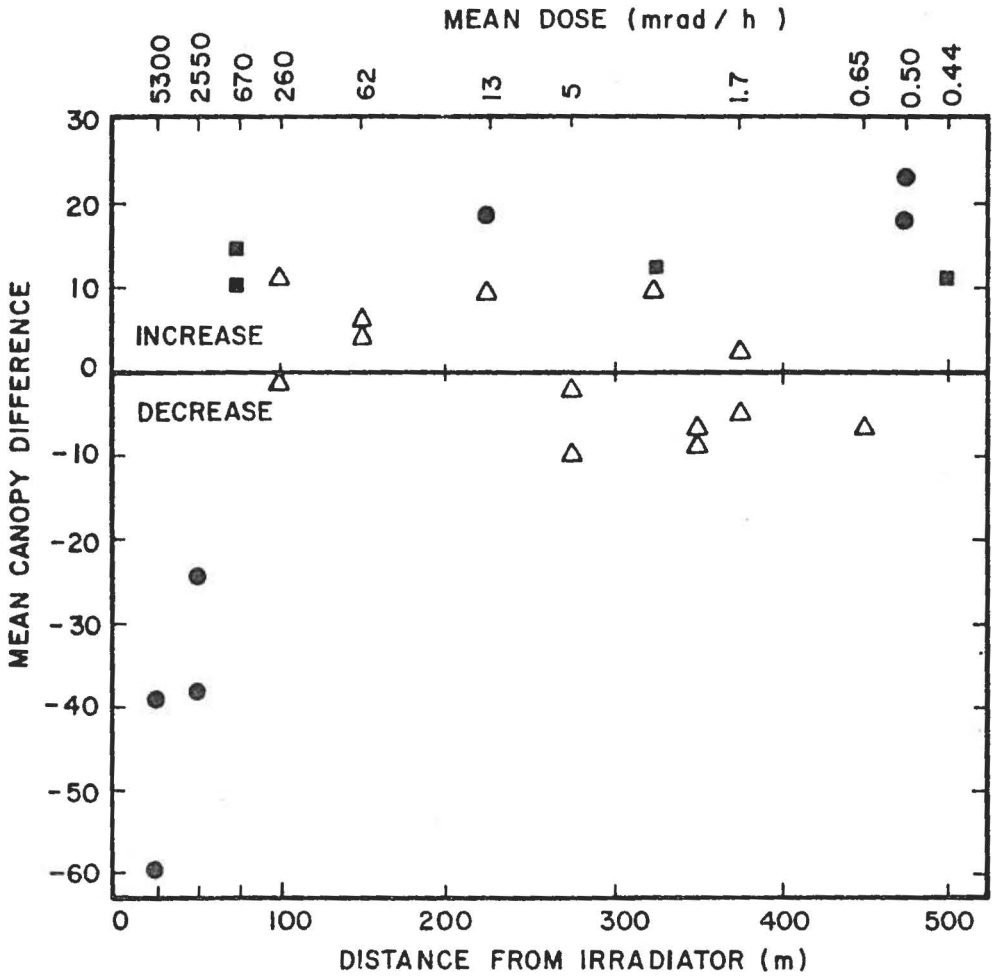

Figure 3. Canopy cover difference (mean per cent 1974 minus mean per cent 1971-2) for quadrats along the north transect between 0 and 500 m.

● Significant at the 99% confidence level ($t > 2.861$, $n = 20$).

■ Significant at the 95% confidence level ($t > 2.093$, $n = 20$).

△ Means not significantly different.

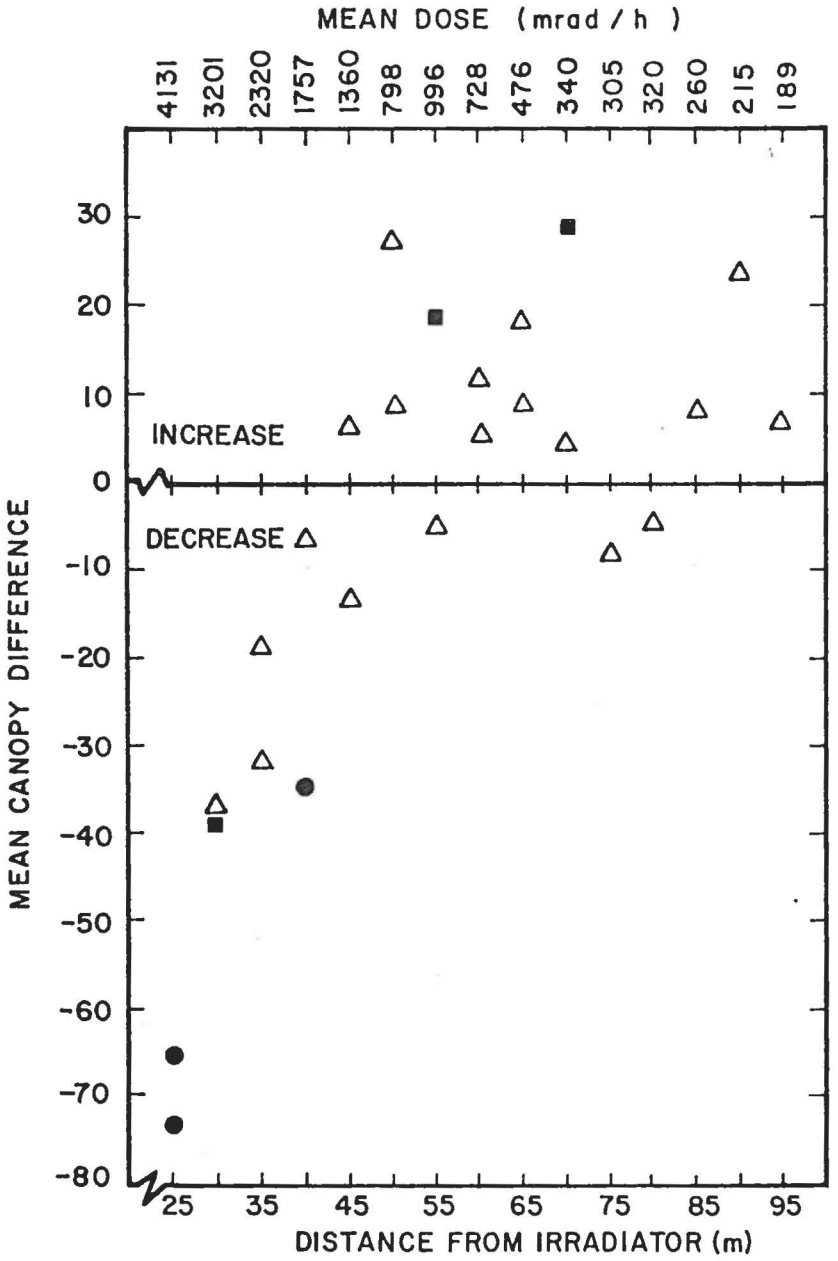

Figure 4. Canopy cover difference (mean per cent 1974 minus mean per cent 1971-2) for macroplots on north transect between 25 and 100 m.

● Significant at the 99% confidence level (25-75 m $t > 5.841$, $n = 4$; 75-100 m $t > 3.499$, $n = 8$).

■ Significant at the 95% confidence level (25-75 m $t > 3.182$, $n = 4$; 75-100 m $t > 2.365$, $n = 8$).

△ Means not significantly different.

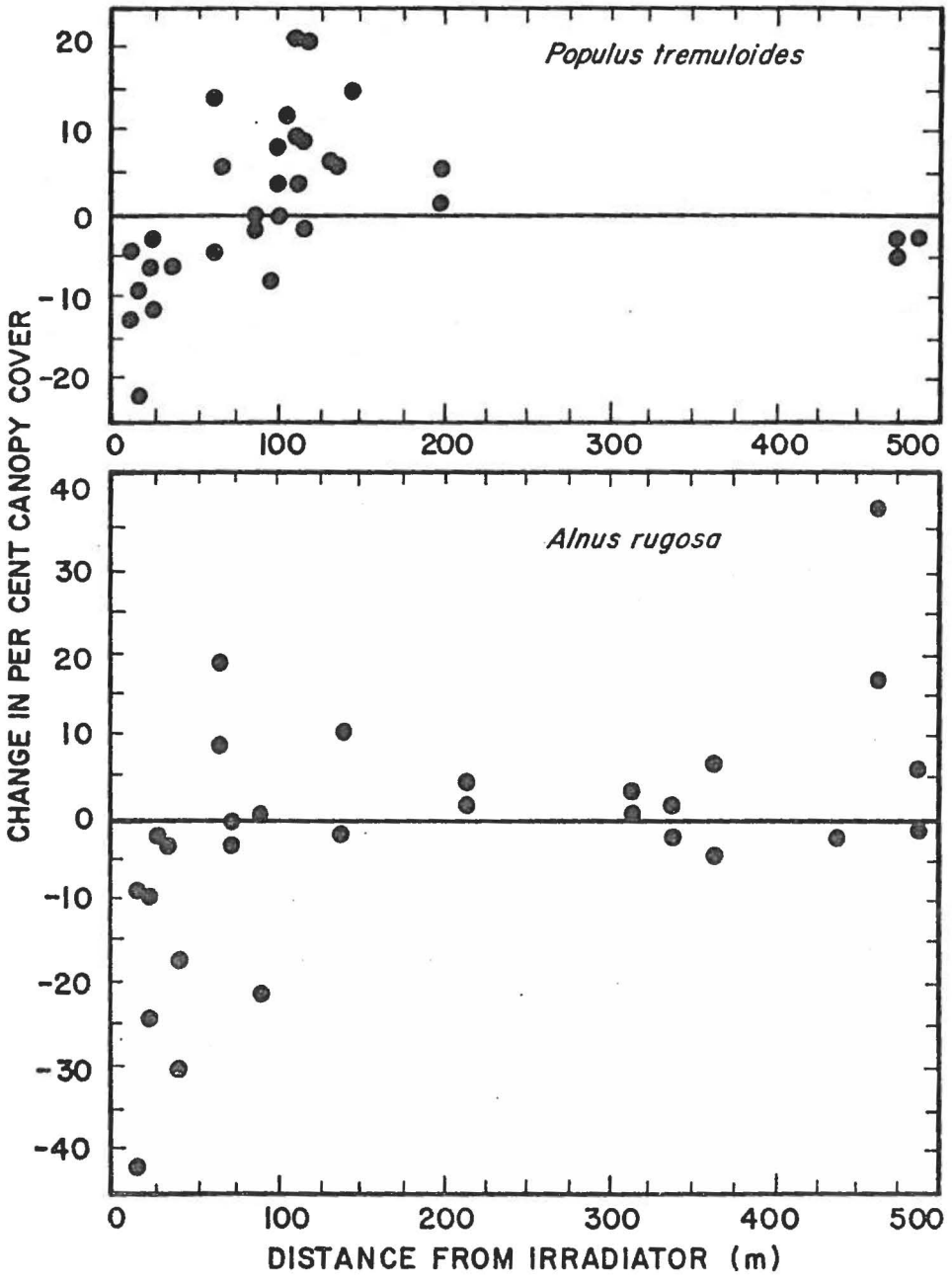

Figure 5. Changes in per cent canopy cover of *Populus tremuloides* (a), and *Alnus rugosa* (b).

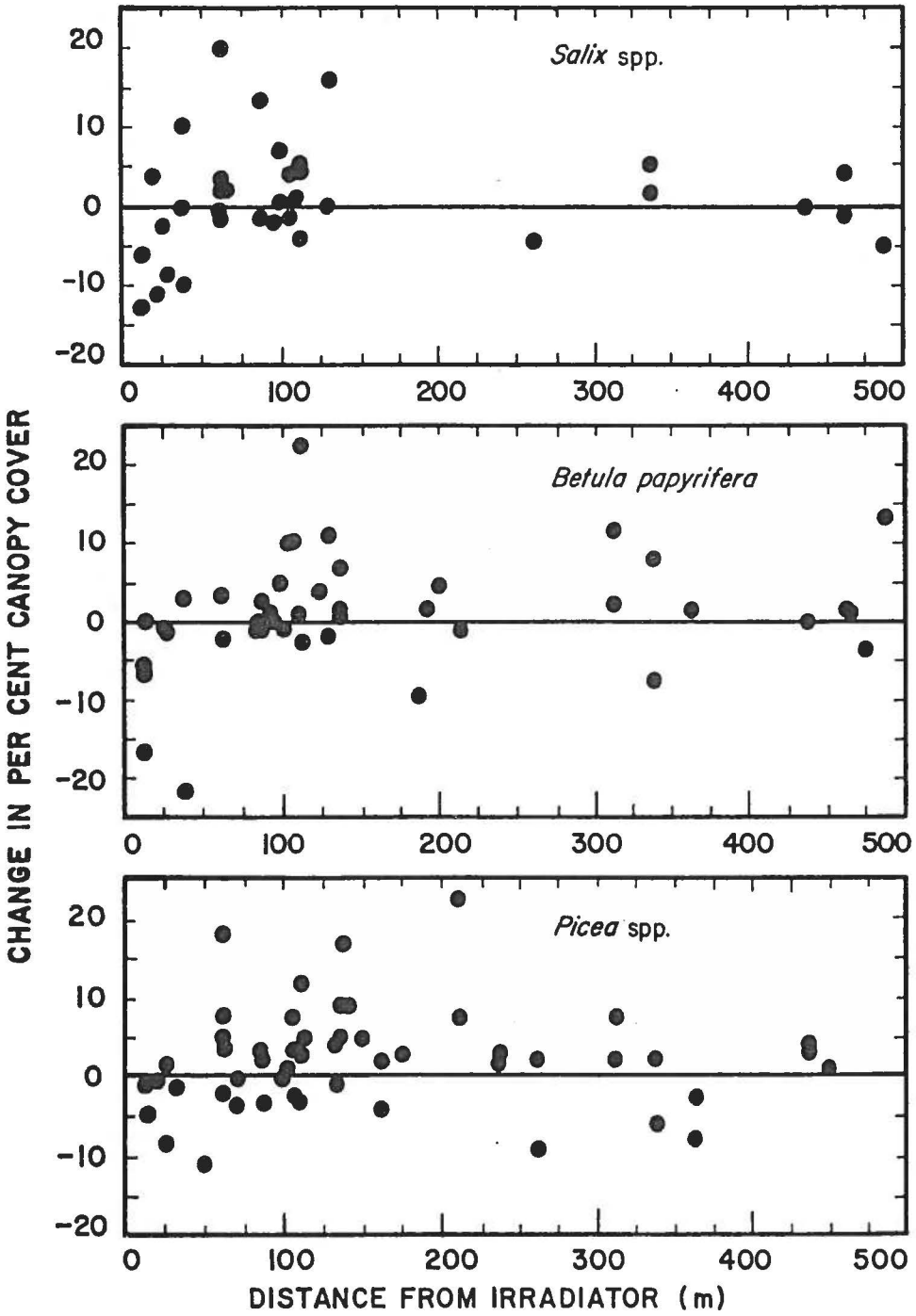

Figure 6. Changes in per cent canopy cover of *Salix* spp. (a), *Betula papyrifera* (b), and *Picea* spp. (c).

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(Received 13 February 1975)

A THEORETICAL CONSIDERATION OF THE BEHAVIOUR OF AIR-FUMIGANT MIXTURES IN STORED GRAINS IN RELATION TO THE LAWS OF GASES[1]

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ABSTRACT: The effects of fluctuations of ambient air temperature and barometric pressure on air and fumigant gases in bulks of grain were calculated. A granary of 411 bushels (approximately 15m^3) of wheat would absorb 35 liters of air when ambient temperatures declined from 20 to 10°C. A drop of barometric pressure of 18.52 mm of mercury would cause 8000 bushels (291 m^3) of wheat to lose 3.34 m^3 of air. The rate of diffusion and velocity of diffusion of hydrogen phosphide were calculated to be 0.0491 cm^2/second and 0.491 cm/minute. The velocity of diffusion of hydrogen phosphide was found to be 0.51 cm/minute when measured experimentally.

INTRODUCTION

Parkes and Mellor (1940) have discussed methods of using the laws of gases for calculation of the effects of fluctuations of temperature and of barometric pressure on the magnitudes of volumes of gases. Oxley (1948: 14) has briefly considered the "aspiration" of air by bulks of grain when barometric pressure rises. In addition, he noted that the intergranular atmosphere of a grain bulk expands with a rise in grain temperature.

Parkes and Mellor (*op. cit.*) have discussed principles of diffusion of gases and suggested a method for the calculation of the rates of diffusion of gases relative to hydrogen. The rates at which hydrogen and carbon dioxide diffuse through air have been measured (Anonymous 1962). The rate of diffusion of carbon dioxide through masses of wheat was measured by Henderson and Oxley (1944) and Robertson (1948). Bailey (1959) measured the rate of diffusion of oxygen through wheat. There is, therefore, background information to enable reckoning of actual rates of diffusion of fumigant gases through wheat.

Goring (1962) in a review on fumigation of soils, concluded that fumigant gases moved through soils by diffusion rather than by air currents. He discussed the influence of air space, moisture, texture, organic matter, and temperature. Keen (1931) also considered that fluctuations of barometric pressure and irrigation exerted a greater effect on interchanges of gases between soils and above-soil air than fluctuations of ambient temperature. Intergranular air spaces are larger in masses of wheat than in soils and it has been shown that air currents exist in masses of grain (Oxley 1948).

These phenomena of diffusion, and the expansion and contraction of intergranular atmospheres, are governed by the laws of gases. It is the aim of this paper to use the laws of gases to calculate the amounts of gas moved in and out of granaries in response to fluctuations of ambient temperature and pressure, and through the action of diffusion.

I. VOLUMES OF AIR IN MASSES OF CEREAL GRAINS

Before we can discuss the behaviour of the air in a mass of grain, some information must be obtained on the proportion of the mass that is represented by interstitial air. The total volume of a mass of grain can be calculated from the dimensions of the bulk. The proportion of air space in a grain mass can be obtained by a manometric method (Jones 1943) or by means of an Air Comparison Pycnometer (Simons 1965).

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[1] Contribution No. 654, Agriculture Canada, Research Station, Winnipeg.

Jones *(op. cit.)* found that the percent air space in a mass of Manitoba No. 1 Northern wheat varied from 36.2 to 49.5% according to the kind of packing and moisture content. Most samples of grain contain some chaff and other dockage so that the actual air spaces in grain may vary from those found in clean grain samples. For example, the air space in five samples of wheat of 12.5% moisture content and containing 5% dockage, by weight, was 45.1% of the sample volumes as determined with a Model 930 Beckman Air Comparison Pycnometer.

II. INFLUENCE OF TEMPERATURE ON THE VOLUME OF AIR IN MASSES OF CEREALS

Essentially, the effect of temperature on gas volumes is summarized in Charles' (Gay-Lussac) law which states that "*the same rise of temperature produces in equal volumes of all gases the same increase in volume, provided the pressure be kept constant.*" For each degree Celsius of temperature change, the volume of a gas will exhibit a variation of 1/273.15 of its volume (Parkes and Mellor *op. cit.).*

If the metric system of measurement is used, the relationship can be expressed most easily as:

$$\frac{V_1}{V_2} = \frac{(273.15 + T_1)}{(273.15 + T_2)} \qquad (1)$$

in which V_1 and V_2 are volumes in liters, and T_1 and T_2 are temperatures in degrees Celsius.

To illustrate how Charles' law may be used to determine the air exchange in a granary, let it be assumed that the granary is full of wheat, circular, 2.44 m in diameter, 3.66 m tall, and that during a night the temperature at the periphery dropped from 20 to 10°C, and further, that at 0.15 m from the outside surface the grain temperature was not affected (Oxley *op. cit.*). Calculating the peripheral volume of the grain mass and using 45.1% as the volume of air in the interstitial spaces, it may be seen from equation (1) that the granary would absorb 35 liters of air from the outside. This volume was equivalent to 0.45% of the total volume of air in the wheat or 3.4% of the air in the peripheral 0.15 m of grain.

This example illustrates the daily rhythm of air change in a granary. As the air in the peripheral grain warms from 10 to 20°C during the day there would be a net outflor of air equivalent to 3.4% of the air in the peripheral 0.5 ft (0.15 m) shell of grain; as the air in this part of the grain bulk cools from 20 to 10°C during the night there would be an equivalent inflow of air.

With this sort of daily air exchange the air closest to the points of leakage, along with any fumigant or other gases it might contain would be largely exchanged for fresh air in a granary in a short time.

III. INFLUENCE OF ATMOSPHERIC PRESSURE ON THE VOLUME OF AIR IN MASSES OF CEREALS

The influence of pressure on volumes of gases has been described in Boyle's (Mariotte's) Law which relates the volume of a gas to the pressure to which it is subjected.

According to this law, "*the volume of a fixed mass of a gas kept at one uniform temperature varies inversely as the pressure to which it is subjected*" (Parkes and Mellor, *op. cit.).*

The arithmetical expression of this law is:

$$V_1 P_1 = V_2 P_2 \qquad (2)$$

One unit of atmospheric pressure is defined as that which can support a 76 cm column of mercury at 0°C.

During early May 1974, atmospheric air pressure at Portage la Prairie, Manitoba, varied from a high of 74.52 cm Hg to a low of 72.67 cm Hg during four consecutive days. Calculating as before, the amount of air lost from 8000 bushels (290.9 m^3) of wheat stored in that locality would have been about 3343.7 liters or about 2.54% of the interstitial air volume. Thus, as with temperature, fluctuations in atmospheric pressure would lead to air exchange in a granary.

IV. THE GENERAL LAW OF GASES

The two previous laws can be combined into what is known as the General Law of Gases, in which the effects of pressure and temperature on a volume of a gas are described by a simple equation (Parkes and Mellor, *op. cit.*).

$$\frac{P_1 V_1}{(273.15 + T_1)} = \frac{P_2 V_2}{(273.15 + T_2)} \qquad (3)$$

There are changes of pressure and temperature from one part of a day to another. Afternoons are usually warmer than early mornings so the density of the ambient air in the afternoon is usually less than in the early morning (as a given volume of gas expands with temperature, its density is reduced). Consequently, there is usually a net overflow of air from granaries during the day and a net inflow of air after sunset. A natural consequence of this continuous exchange of air is the translocation, throughout a bin, of moisture and calories as well as of fumigant gases. During the sampling of gases in a bin, caution must be exercised in the interpretation of results because the sample may contain outside air that has just entered the bin.

V. GRAHAM'S LAW ON THE DIFFUSION OF GASES

Graham's Law states that under comparable conditions, the "*relative speeds of diffusion of gases are inversely proportional to the square roots of their relative densities*" (Parkes and Mellor *op. cit.*).

According to Jost (1960), diffusion is "the flow or current of a substance which passes perpendicularly through a reference plane of unit area during a unit of time." The unit chosen for the quantity of substance is not specified since it can be moles, grams, cubic centimeters of gas, etc. Thus, all tables which list rates of diffusion use the units cm^2/sec.

The relative diffusion rates of various gases can be calculated quite easily from their molecular weights (Graham's Law) and the numbers obtained can then be modified according to the media through which the diffusion takes place. Thus, the relative density of hydrogen phosphide is 17.02 (=mol. wt/2) and that of sulfur hexafluoride is 73.03; the relative rates of diffusion of these two compounds are 0.2424 and 0.1170 cm^2/sec, respectively. However, these speeds of diffusion are relative to hydrogen. Hydrogen has a measured rate of diffusion in air of 0.634 cm^2/sec (Anonymous 1962) so that the rates of diffusion of hydrogen phosphide and of sulfur hexafluoride in air are 0.15369 and 0.07417 cm^2/sec, respectively.

Once the rate of diffusion of these two gases in air is known, their rate of diffusion in wheat can be calculated. Bailey (1959) measured the diffusion of oxygen through wheat and found that it diffused through wheat at 32% of the rate through air. Similarly, Robertson (1948) found that the rate of diffusion of carbon dioxide through wheat was nearly 30% of the rate in air.

Assuming that wheat retards diffusion of gases to about 32% of the rate in air, it is probable that hydrogen phosphide diffuses through wheat at a rate of 0.0491 cm^2/sec and sulfur hexafluoride at 0.0237 cm^2/sec. Thus, 0.0491 cm^3 of hydrogen phosphide will go through a 1 cm^2 plane in 1 sec.

These figures require further transformation to discover how far the gases will diffuse in a given unit of time. For this transformation the following equation may be used:

$$\text{distance per minute} = \frac{\text{Rate X 60}}{6} \qquad (4)$$

The rate of diffusion (cm^2/sec) X 60 is the rate of diffusion per minute (cm^2/min). However, after a molecule has traversed the reference plane, its direction of movement can be reduced to a combination of any of six directions (up and down, forwards and backwards, left and right) so that only one-sixth of the number of molecules which traverse one reference plane immediately traverse the next plane.

Thus, for hydrogen phosphide, the velocity is 0.491 cm per minute and for sulfur hexafluoride, the velocity of diffusion is 0.237 cm per minute.

In practical terms hydrogen phosphide will diffuse from the point of application to the nearest leak at a speed of 0.49 cm per minute: once the leak is reached the gas will exit at a rate of 0.049 per cm^2 of leak hole each second.

The distance that hydrogen phosphide can traverse in a predetermined period of time was verified, approximately, in a small replicated experiment. Three aluminium phosphide pellets were placed on the top surfaces of masses of wheat at 10°C in each of three 12 bushel drums. The drums were sealed at once and gas concentrations were determined by means of Drager tubes at a distance of 132 cm below the pellets after 6 hours had passed. The hydrogen phosphide concentrations and the times of determination are shown in Table I.

Table I. Data required to find the velocity of diffusion of Ph_3

Time elapsed (hrs)	Gas concentration ppm Ph_3
6.173	8.0
7.173	15.0
10.256	26.6
13.256	35.0
15.000	46.6

These data can be graphed and the line which can be drawn through the first and last of the points also intersects the 0 ppm line at about 260 minutes. This point of intersection, which represents the approximate time of arrival of the first hydrogen phosphide molecules to the site of analysis, can be used to calculate the velocity of diffusion. This velocity is about 0.51 cm/minute, a little greater than the calculated 0.49 cm/minute shown above. The difference between these numbers is almost meaningless in practical terms. The grain temperature of 11.5°C probably contributed to the increased velocity of diffusion obtained experimentally. Furthermore, graphic analysis will admit small errors. The remarkable fact is that the measured and calculated velocities were very close.

CONCLUSIONS

Fluctuations of temperature and of barometric pressure can cause the air and fumigants in the intergranular spaces of masses of grain to expand and contract and the laws of gases are useful to calculate the amount of expansion or contraction of the air-fumigant mixtures in masses of grain. Since the expansion of air-fumigant mixtures in grain causes the mixtures to "overflow" from the grain, fumigant is lost; the inspiration of fresh air, when the air-gas mixture contracts, dilutes the fumigant in the grain.

Graham's Law serves as a basis for the calculation of the rate of diffusion of phosphine and sulfur hexafluoride through wheat. Fumigants and other gases diffuse readily from places of high concentration to places of low concentration, which may be close to points of leakage in the granary walls. Once a leak is reached through diffusion, the fumigant can diffuse out of the granary rapidly and be lost.

These phenomena occur continuously and concurrently during fumigations and cause the translocation of air and fumigants in and out of grain bins.

ACKNOWLEDGEMENTS

I wish to thank Drs. S.R. Loschiavo, L.B. Smith, G. Wiley, P.H. Westdal, and F.L. Watters of this station for their valuable comments on this manuscript.

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(Received 21 April 1975)

HYDROGEN PHOSPHIDE CONCENTRATION GRADIENTS IN WHEAT[1]

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ABSTRACT: Measurement of gas concentrations at various distances from the points of fumigant release in three experimental bins containing 546 l of wheat showed that there was a gradient in gas concentrations from a high at the point of gas generation to a low at the point of gas leakage. These data agree with similar observations made during fumigation of large elevator bins where low concentrations of hydrogen phosphide were often recorded near the bottom valves of the bins where leakage may occur.

The existence of these gradients of fumigant concentrations may explain erratic results in insect control and the survival of insects near bin valves.

INTRODUCTION

Gases diffuse through air quite readily and it is possible to calculate accurately the rate of diffusion of any gas in comparison with hydrogen which has been used as a standard (Parkes and Mellor, 1940). The rate of diffusion has been defined as the amount of a substance passing perpendicularly through a reference surface of unit area (cm^2) during a unit of time (sec) (Jost 1960). The rates of diffusion of some gases, including hydrogen, in air have been measured so that it is possible to reckon the rate of diffusion of any gas through air by multiplying the relative rate of diffusion of the gas by a constant (0.634) (Anonymous, 1962; Jost, 1960). Furthermore, Robertson (1948), Henderson and Oxley (1944) and Bailey (1959) have shown that carbon dioxide and oxygen diffuse through masses of grain at about 30 to 32% of the rate at which they diffuse through air. Thus, the rate of diffusion of any gas through grain can be calculated by multiplication of the rate of diffusion of the gas through air by either 0.3 or 0.32.

The rate of diffusion of a fumigant through wheat can be transformed into the velocity of diffusion through wheat. Velocity of diffusion can be defined as a distance traversed in a unit of time (cm/min). Barker (1974) was able to confirm the velocity of hydrogen phosphide by actual measurement (0.49 cm/min).

The fact that the velocity of diffusion of a fumigant can be measured implies that there is a gradient of fumigant concentrations between the source of gas generation, where gas concentrations are very high, and points at a distance from the source, where there may be extremely low concentrations of the gas. Low concentrations of fumigant gases are often associated with insect survival in stored products (Monro 1969).

It is the purpose of this paper to measure gradients of hydrogen phosphide concentration in wheat and to use the concept of gradients to explain why very low concentrations of the gas are usually obtained at the valve at the bottom of terminal and country elevator bins.

MATERIALS AND METHODS

Three cylindrical steel drums each 60 cm in diameter and 193 cm in height were filled with 546 l of wheat of 12.5% moisture and 5% dockage. The temperature was approximately 10°C through the experiment. Three aluminium phosphide pellets were placed on the floor of each drum before they were filled with wheat. Each pellet generated 0.2 g of hydrogen phosphide during the following days. Lids were placed on each drum and the cracks between the lids and the drum rims were considered as the points of leakage.

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[1] Contribution No. 662, Research Station, Canada Agriculture, Winnipeg, Manitoba, R3T 3J1.

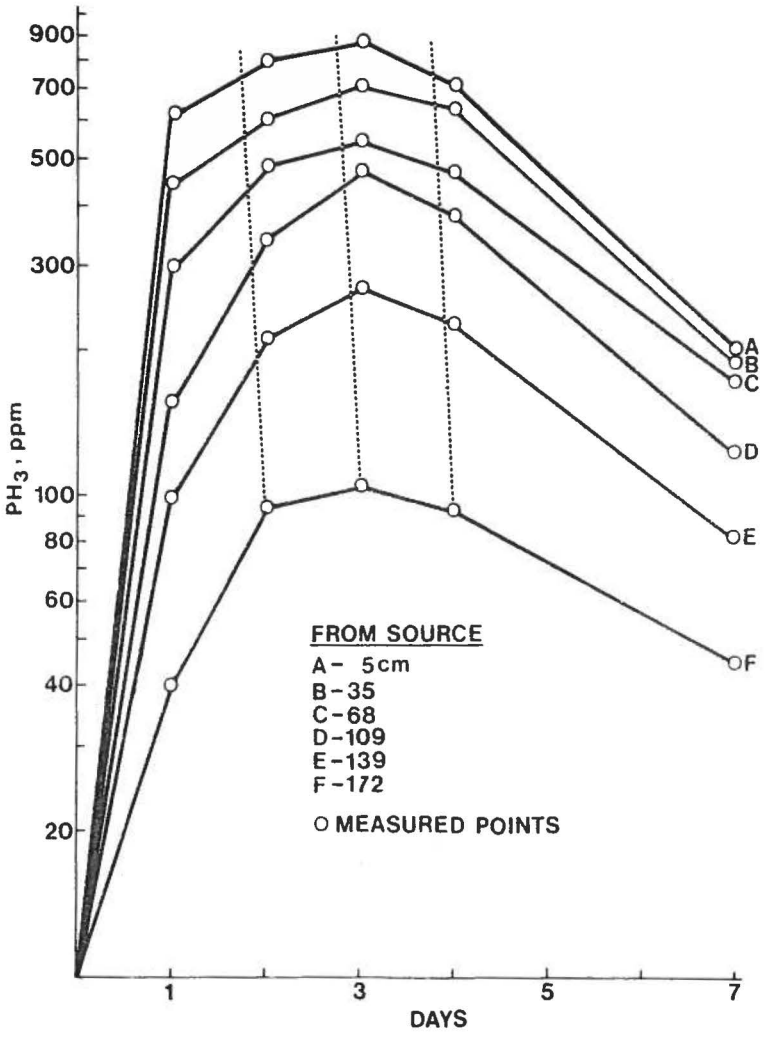

Figure 1. Concentrations of hydrogen phosphide (ppm) in interstitial air in wheat between source of gas generation (0 cm) and point of leakage (193 cm). Dotted lines were used to obtain concentrations in Figure 2.

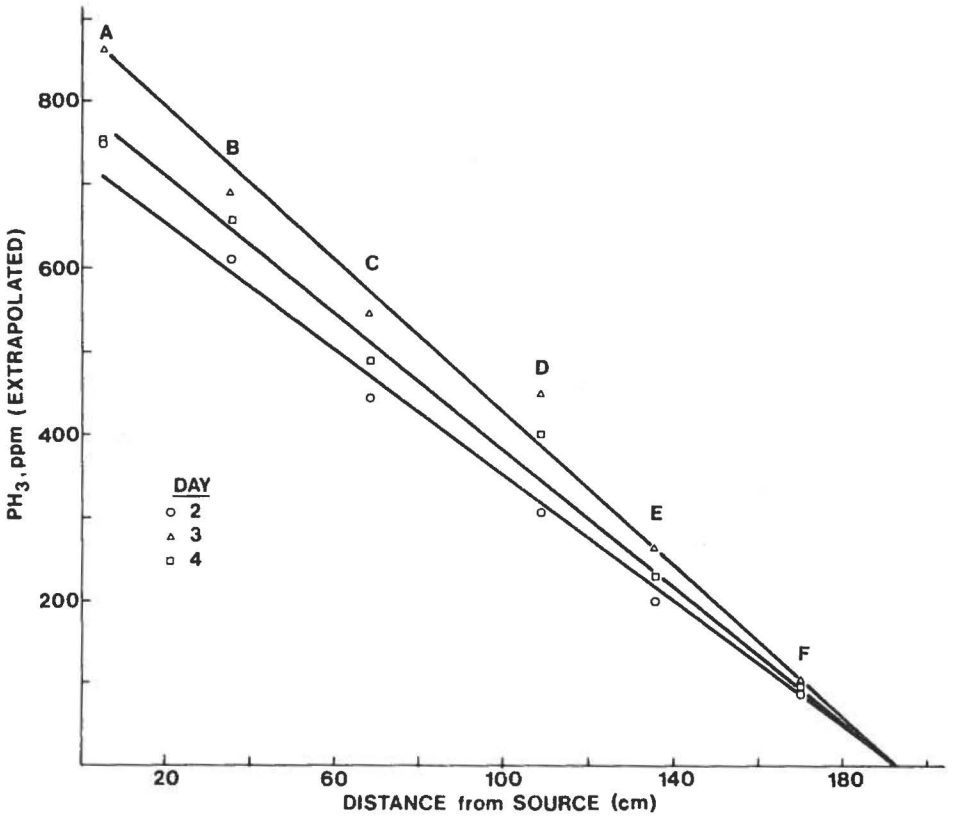

Figure 2. The relationship between concentrations of hydrogen phosphide in interstitial air in wheat and distance from source of gas generation.

Hydrogen phosphide concentrations were measured with "Drager tubes" each day at 5, 35, 68, 109, 139, and 172 cm from the floor of the drums.

RESULTS AND DISCUSSIONS

The gas concentrations obtained with the Drager tubes were plotted on semi-logarithmic paper (Figure 1). The highest concentration of gas was found 5 cm (point A) and the lowest concentration 172 cm (point F) from the point of gas generation. The maximum gas concentration was found on day 3 at each of the sampling points.

Barker (1974) has shown that the velocity of diffusion of hydrogen phosphide in wheat at temperatures close to 12°C was about 0.5 cm/min; thus it would require about 334 min (5.6 h or about 0.25 day) for diffusion of this gas from the lowest to the highest sites of gas measurement. The gas measured at 172 cm from the floor of the drum at the ends of days 1, 2, 3, and 4 left the point of gas generation on days 0.75, 1.75, 2.75, and 3.75, respectively. In Figure 1, dotted lines were used to connect the gas concentrations obtained at 172 cm from the floors of the drums with the concentrations of the previous 0.25 day at 5 cm from the drum floor. Thus, "extrapolated" gas concentrations were those obtained from the intersections of the dotted lines and the gas concentration curves. These extrapolated gas concentrations were then used to construct Figure 2 which is a plot of the gas concentration gradient (ppm PH_3) between the gas source and the point of leakage (193 cm from the floor of the drum). The lines connecting the points in Figure 2 were projected to intersect the abscissa (O ppm PH_3); it was found that O ppm PH_3 should have been obtained at 193 cm from the floor of the drums, coincident with the point of leakage since the drums were 193 cm high.

The gradient of gas concentrations, from a maximum at the point of gas generation to zero at the point of leakage, is of interest in the practical fumigation of elevator bins. Liscombe (1960, unpublished) studied the fumigation of wheat in a country elevator at Sanford, Manitoba. He used five dosages of hydrogen phosphide, namely 1.6, 3.2, 4.0, 4.8, and 6.2 g of gas per ton of wheat. He used two methods of chemical analysis to determine fumigant concentrations. With a silver nitrate salt method no fumigant was detected in analyses of 30 samples of air taken at the floors of the bins of wheat; with a pH method, fumigant was present in two samples out of 30 also taken from the floors of the bins. Liscombe *(op. cit.)* measured gas concentrations 90 cm above the bottom valves of the bins, which was at the level of the inspection hatches of each bin. These hatches were 60 x 60 cm and were made of wood which had shrunk with age and, consequently, were not airtight. Since the fumigant gas could readily leak through the cracks in the inspection hatches, it is probable that there would have been a gas concentration gradient between the points of leakage at the hatch and the point of generation of this fumigant. If Liscombe *(op. cit.)* sampled the air close to the hatch it is possible that he sampled air at the terminal end of the gradient. At this point it would contain little, if any, gas.

I obtained similar information from a good concrete silo at a flour mill in Winnipeg. A star bin of 116.37 m^3 was filled with 106.77 m^3 of wheat which was maintained at a temperature of 18.3°C with a moisture content of 13.1%. Twelve hundred aluminium phosphide pellets (240 g of PH_3) were added to the grain. The gas concentration in the air in the wheat mass was calculated to be approximately 3000 ppm of air. The gas concentration in the wheat immediately above the valve at the bottom of the bin was analyzed by means of a Drager tube 72 h after the fumigation started. Only 6.6 parts of hydrogen phosphide per million of air could be detected. It is possible, therefore, that there was a gas concentration gradient in the wheat at the bottom of the bin and that the air sampled close to the valve could not have possibly contained more than 6.6 ppm of hydrogen phosphide and any insects in the zone of low fumigant concentration would have survived the treatment.

ACKNOWLEDGEMENTS

I wish to thank G. Ayre, S.R. Loschiavo, and P.H. Westdal for their comments on the manuscript and D. Kurtz for his technical assistance.

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THE PENETRATION OF METHYL BROMIDE INTO WHEAT AT FREEZING TEMPERATURES[1]

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ABSTRACT: Methyl bromide applied to wheat columns at -0.5 and -3.3°C, penetrated in sufficient quantity to control the rusty grain beetle, *Cryptolestes ferrugineus* (Stephens) to a depth of 51 cm at concentrations of 49 to 50 mg/l and to a depth of 33 to 42 cm at concentrations of 32 to 34 mg/l. Penetration of the fumigant was greater at -0.5°C than at -3.3°C, but the difference was not significant ($P > 0.05$).

INTRODUCTION

Methyl bromide is one of the most common fumigants used to control insects in grain residues in ship holds. Monro (1969) published schedules for the use of this fumigant in empty spaces at temperatures as low as -10°C. Though Monro (1945) mentioned that fumigation of infested commodities at temperatures below 16°C was not usually advocated, he showed that methyl bromide controlled *Pyrausta nubilalis* Hbn. in bales of broom corn at -3.3°C.

A survey by Liscombe and Watters (1962) showed that the rusty grain beetle, *Cryptolestes ferrugineus* (Stephens), was the most important stored-grain pest found in empty granaries in the Prairie Provinces of Canada. Monro (1969) has shown that this species ranks third in frequency of occurrence in samples of insects taken during routine ship inspection in Canada. Freeman (1968) stated that during the early 1950's, *C. ferrugineus* was found by United Kingdom authorities only in the after holds of ships loaded with Canadian grain which had been warmed by heat from the propeller shaft tunnels.

Adults of *C. ferrugineus* undergo a process of acclimation which enables them to tolerate freezing temperatures for a few months (Smith 1970) and thus survive the Canadian winter climate. If grain is to be exported during the cold season there must be a system for the control of infestations in the grain and in the vessels.

The objective of the present work was to determine the depth to which methyl bromide would penetrate to kill adults of *C. ferrugineus* in wheat at freezing temperatures.

MATERIALS AND METHODS

Twenty-five adults of *C. ferrugineus* and 8g of wheat were placed in each of 72 glass vials that were 6.5 cm long by 2.5 cm in diameter, and fitted with snap-on caps. A hole, 1.5 cm in diameter, was drilled in each cap and covered with No. 60 mesh brass screen to allow gas exchange. Eight vials were taped to each of 9 copper rods that were 80 cm long and 0.3 cm in diameter. Each rod with its attached vials was then placed in a galvanized metal tube 76 cm long, 13 cm in diameter and closed at one end. Part of the rod projected from the tube and was used as a handle. The tubes were then filled with wheat and were placed in each of 9 fumigation chambers. The vials were positioned on the rods so that they would be at the depths indicated in Table 1.

The fumigation chambers were made from steel drums of approximately 204 l capacity. A circular hole, 2.5 cm in diameter, was cut in the top of each drum and a section of steel pipe (25.5 cm internal diameter, 1 cm thick, and 6.5 cm high) was welded over the

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[1] Contribution No. 546, Agriculture Canada, Research Station, Winnipeg, R3T 2M9.

hole. Flat circular steel disks, 31 cm in diameter and 1 cm thick were used as lids for the steel pipe sections. Seven bolts were welded onto the upper external edges of each of the steel pipe sections and seven holes were drilled into each lid to coincide with the bolts on the steel pipes. A small trough was cut around the upper rim of each steel pipe section and a gasket was inserted into the trough to make a gas-tight seal between the lid and the chamber. Each lid was provided with 2 taps for the introduction of gas into the fumigation chamber. The internal volumes of the steel pipes increased the total volumes of the chambers to approximately 207 l.

A 3.81 cm diameter hole was drilled through the larger bung-cap of each drum. This hole was covered with 0.5 cm "Perspex" and sealed in place with "epoxy resin." Two 5 cm long copper bolts (0.2 cm diameter) traversed the "perspex" and were sealed to the "perspex" with "epoxy resin."

Small electric fans were placed in each fumigation chamber to circulate the air and were connected to the copper bolts in the bung-caps. These chambers were tested to ensure that they were gas-tight. Methyl bromide gas, measured with a gas burette (1 l capacity), was placed into the chambers through the taps. The dosages were verified with a thermal conductivity meter. The chambers were kept in a concrete vault where there was very little temperature variation.

Two experiments, one at -0.5 ± 2°C and one at -3.3 ± 2°C were conducted. In each experiment, the treatments were arranged in a randomized block design with 3 replicates. There were 3 treatments (2 dosages of methyl bromide and 1 untreated check) in each replicate. Each treatment was sub-divided as to depth in grain so that the analysis performed was for a split plot design. The vials were removed after 24 h exposure and mortality was determined after an incubation period of 7 days at 30°C and 90% relative humidity (R.H.).

RESULTS AND DISCUSSION

At the higher concentration at each temperature, sufficient methyl bromide had penetrated to the 51 cm depth to kill all the beetles during the 24 h period of exposure (Table 1). At the lower concentration level, 100% mortality was obtained only up to the 42 cm depth at -0.5°C and the 33 cm depth at -3.3° C indicating less penetration by the fumigant. Based on the percent mortality of the rusty grain beetles, there was a significant ($P<0.01$) effect of concentration on penetration, as reflected by beetle mortality. The fumigant at the higher concentration level penetrated more deeply into the grain than that at the lower concentration level.

Although the fumigant penetrated in sufficient quantity to kill all the beetles at greater depths at -0.5°C than at -3.3°C, the differences due to temperature were not significant ($P> 0.05$). This was probably because of the small difference in temperature between the experiments.

At the highest concentration, the product of concentration x time (CXT) was 50x24 = 1200 mg/l/h, a little higher than the figure of 1024 mg/l/h obtained by Monro (1945) who used 4 lb of methyl bromide per 1000 cu ft (64.09 mg/l) during 16 h to control *P. nubilalis* in bales of broom corn. In Monro's experiment, sufficient methyl bromide penetrated to the middle of the bales (45 cm diameter) to kill all the *P. nubilalis*.

In this experiment, the lower dosage was about half that used by Monro (1945) although the exposure time was 1.5 times as long. The CXT products at these dosages were 768 and 816 mg/l/h, far less than the 1024 mg/l/h used by Monro (1945) but sufficient to kill 100% of the beetles at a depth of 33 cm in wheat.

Monro (1969) suggested that a dosage of 32 mg of methyl bromide per liter of air was sufficient to erradicate insects from empty ship holds at -0.5°C if the period of exposure was 12 h or more. Benazet [2] (unpublished data) fumigated the headspace of a ship's hold filled with wheat which was at a temperature of about 3°C. The fumigant concentrations reached a maximum average of 38.3 mg/l/h at 6.25 h after the fumigation was started, but

[2] Benazet, J., 1973. Fumigation Station and Laboratory, 785 Mill Street, Montreal, Prov. Quebec, Canada.

declined to 16.5 mg/l by the end of 24 h. Benazet had placed caged *Sitophilus granarius* (L.) on the surface of the grain and at depths of 60, 90 and 120 cm. All the insects on the surface of the wheat were killed, but those in the grain survived. It is clear that the concentrations of fumigant used by Benazet were not high enough to cause insect mortality at the 60 cm depth during the 24 h exposure period, even at 3° C.

Data from the present experiments which showed that 50 mg methyl bromide/l penetrated up to 51 cm in wheat at freezing temperatures and killed all the beetles suggests that methyl bromide is effective in treating thin layers of grain residues in the holds of ships during winter and confirms the findings of Monro (1969).

ACKNOWLEDGEMENTS

I wish to thank G. Gerber, S.R. Loschiavo, W. Romanow, and P.H. Westdal for their comments on the manuscript. Thanks are also due to D. Kurtz for his diligent assistance.

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(Received 7 July 1975)

Table 1. The percent mortality of *C. ferrugineus* in wheat when exposed to methyl bromide for 24 h at different depths, dosages and temperatures.

Depth (cm)	Check	Dosages (mg CH_3Br/l) 32	34	49	50
	Temp. of -3.3°C				
5	0.0	100	—	100	—
15	1.1	100	—	100	—
24	2.2	100	—	100	—
33	6.6	100	—	100	—
42	1.1	93	—	100	—
51	1.1	60	—	100	—
60	0.0	17	—	83	—
69	1.1	9	—	65	—
				(L.S.D. = 11.2)*	
	Temp. of -0.5°C				
5	1.1	—	100	—	100
15	1.1	—	100	—	100
24	2.2	—	100	—	100
33	1.1	—	100	—	100
42	5.3	—	100	—	100
51	4.0	—	90	—	100
60	4.0	—	59	—	97
69	4.0	—	34	—	84
				(L.S.D. = 15.6)*	

* At a probability level of 0.05: between dosages and depths.

THE EFFECT OF FOUR RESIDUAL INSECTICIDES ON POPULATIONS OF THE RUSTY GRAIN BEETLE, *CRYPTOLESTES FERRUGINEUS* (STEPHENS), IN WHEAT[1]

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ABSTRACT: Malathion, tetrachlorvinphos (Gardona), fenitrothion (Sumithion) and bromophos (Nexion) reduced infestations of the rusty grain beetle, *Cryptolestes ferrugineus* (Stephens) in stored wheat at 19, 24.4 and 30°C. Fenitrothion and bromophos were the most effective, whereas malathion and tetrachlorvinphos were slower in action although by the end of the experiments most of the beetles were eliminated.

INTRODUCTION

Larvae of the rusty grain beetle, *Cryptolestes ferrugineus* (Stephens) usually develop inside the germ of wheat kernels. Some of the larvae, however, emerge and wander among the kernels, especially during the first and fourth instars (Smith 1972).

Some residual insecticides used for the treatment of the interior surfaces of grain storage bins may be effective for the control of stored products insects for only a short time under certain conditions. Watters (1970) showed that bromophos and malathion rapidly lost effectiveness after application to some concrete surfaces. Rowlands (1967 and 1971) showed that many insecticides are degraded and that the amounts present on the surfaces of treated grains are reduced considerably within a month after application. Tyler and Green (1968) showed that fenitrothion and malathion, on moist heating grain, became ineffective after two weeks and that insecticide breakdown was followed by outbreaks of *Oryzaephilus surinamensis* (L.) and *C. ferrugineus.*

Some species of stored grain insects have developed resistance to insecticides commonly used for their control. Champ and Campbell-Brown (1970) have shown that a strain of *Tribolium castaneum* (Herbst) resistant to malathion was also resistant to dichlorvos, fenitrothion, and tetrachlorvinphos. Strong and Sbur (1964) have shown that individuals from some insect populations may survive treatment with some residual insecticides. They showed that adults of *Sitophilus oryzae* (L.) and *Rhyzopertha dominica* (F.) emerged from wheat treated with 10 and 20 ppm of malathion, dichlorvos and 9 other insecticides. Similarly, Kirkpatrick *et al.* (1968) showed that soft red winter wheat treated with dichlorvos at 2.5 ppm did not stop reproduction of *S. oryzae.* Harein and Rao (1972) showed that 20 ppm of tetrachlorvinphos and dichlorvos was required to effectively control immature stages of *Sitophilus granarius* (L.) within kernels of hard red winter wheat.

Pinniger (1974) found that *S. granarius* and *O. surinamensis* had behavior patterns which enabled them to use insecticide-free refuges and avoid contact with fenitrothion-treated surfaces, thus increasing by up to 10 times the time required to obtain 100% mortality.

C. ferrugineus larvae that remain inside kernels are protected from direct contact with insecticides sprayed onto grain and when they emerge as adults at a later date the insecticide residues, which have undergone some transformation, may not be toxic enough to kill them.

These experiments were designed to determine whether or not four residual insecticides could remain effective long enough to kill larvae or adults of *C. ferrugineus* that emerged from wheat kernels weeks after treatment.

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MATERIALS AND METHODS

Wheat of approximately 15% moisture, infested with the rusty grain beetle in all life stages, was used as the source of insects for the experiments. In order to obtain a sufficient number of insects for a single experiment, wheat from several jars used to culture the beetle, was bulked and sieved to remove the adults. The wheat, together with the immature forms of the insect, in lots of 0.5 kg each was then placed into a series of one-liter glass jars. The contents of each jar were either treated with an insecticide or left as a check. The following insecticides were applied with a pipette as water emulsions at the rates shown in Table 1.

1. fenitrothion; 0,0-dimethyl-0-(3-methyl-4-nitrophenyl) phosphorothioate (courtesy of Sumitomo Chemical Co., Osaka, Japan).
2. malathion premium grade; 0,0-dimethyl S-(1,2-dicarboxyethyl) dithiophosphate (courtesy of Cyanamid of Canada Ltd.).
3. tetrachlorvinphos; phenylglyoxylonitrile oxime 0,0 diethyl phosphorothioate (courtesy of Shell Canada Ltd.).
4. bromophos; 0,0-dimethyl-2-, 2-dichlorovinyl phosphate (courtesy of Ciba-Geigy, Canada Ltd.).

The dosage of malathion used approximated the dosage suggested for practical use by Smith and Kolach (1971). Fenitrothion and tetrachlorvinphos were used at similar dosages to obtain comparative data. Bromophos was used at a slightly lower dose because its residual effect was expected to be greater. The jars were sealed and tumbled for 90 minutes in a rotary mixer. The jars were then opened and adult beetles previously isolated from infested grain by the sieving technique were added to the jars to verify the initial effectiveness of the treatments against the adult beetles.

There were 4 experiments, one at each of the 19± 0.5, and 24.4± 0.5, and 2 at 30 ±0.5°C. In each experiment, the treatments (4 or 5 insecticides and a check; Tables 1 and 2) were arranged in a randomized block design with 4 replicates. The contents of each jar were sieved at weekly intervals (Table 1 and 2) and the numbers of live and dead insects were recorded and discarded. Thus, each treatment was subdivided according to time and the statistical analysis was performed for a split-plot design.

RESULTS AND DISCUSSION

The conditions within each of these experiments were uniform and there were no statistical differences between replicates. At each temperature, significantly more adults emerged from untreated grain than from treated grain, indicating that all the insecticides tested were effective, at the dosages used, in reducing the numbers of adult insects which emerged from the kernels (Table 1).

Tables 1 and 2 show that large numbers of adult beetles emerged from the wheat in the checks, indicating that there were large numbers of immature insects in the wheat at the time the insecticides were applied. The fact that in each case fewer insects emerged from treated than from untreated wheat indicates that all the materials tested killed a large proportion of the populations of immature insects in the treated wheat and show some promise for practical beetle control in grain.

Fenitrothion and bromophos were the two most effective materials tested, since very few live adult insects were recovered from wheat treated with these two insecticides in the four experiments (Table 2).

Malathion and tetrachlorvinphos were less effective than fenitrothion and bromophos at 30°C. Malathion, fenitrothion and bromophos were about equally effective at 24.4°C. At 19°C samples treated with tetrachlorvinphos at 7.1 ppm were found to contain surviving adult beetles 1-7 weeks following treatment (Table 2).

The results obtained from experiments 3 and 4 were different although both were conducted at 30°C. Population density, as expressed by numbers of insects obtained in the checks, was 2.76 times greater in experiment 3 than in experiment 4; this ratio was

approximately maintained in the fenitrothion treatment but not for the wheat treated with malathion where the number of beetles collected was 6.5 times higher in experiment 3 than in experiment 4. The mechanism which enabled the production of a large number of beetles in the malathion treatment in experiment 3 was not found, though it was suspected that the high population density in experiment 3 probably contributed towards conditions which favored malathion breakdown.

In each of the malathion, fenitrothion and bromophos treatments, all beetles collected at the end of the first week were dead (Table 1). Furthermore, in almost every treatment more insects were collected at the end of the first week than had been added to the grain indicating not only that all adult insects added to the grain had been killed, but that beetles which had emerged from the grain itself during the first week of treatment had also not survived the insecticide treatment.

Since live insects were collected in the tetrachlorvinphos treatment, it is apparent that the dosage used (7.1 ppm) was insufficient for 100% mortality. It would appear likely that some of the beetles which emerged after the treatment with tetrachlorvinphos were able to survive.

The collection of live insects from grain treated with malathion (Table 2) may suggest that the recommended dose (Smith and Kolach, 1971) is not sufficient for 100% kill of the immature insects inside wheat kernels or that malathion is degraded so rapidly as to be insufficient to kill some beetles which emerge weeks after treatment (Rowlands 1967).

The fact that live beetles were collected from malathion and tetrachlorvinphos treatments (Table 2) indicates that wheat treated with these two materials may become re-infested with the progeny of the surviving beetles.

These experiments showed that the four insecticides tested killed all adult insects added to the wheat immediately after treatment and considerably reduced the numbers of immature insects. Of the immature stages of the beetles inside wheat kernels some survived malathion (7.3 ppm) and tetrachlorvinphos (7.1 ppm) treatment at the beginning of the experiment. By the time these beetles had emerged as adults, there was insufficient insecticide present and many of these adult beetles survived.

ACKNOWLEDGEMENTS

I wish to thank Mr. D. Kurtz, of this station for his diligent work during these experiments. Thanks are also due to Drs. G. Gerber, S.R. Loschiavo, L.B. Smith, P. Thomas and P.H. Westdal for their comments on the manuscript.

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(Received 3 July, 1975)

Table 1. Numbers of *C. ferrugineus* adults collected at intervals from treated and untreated grain at 3 different temperatures

Temp. (°C)	Expt. No.	Time in weeks	Treatment (ppm)						L.S.D. (P<0.05) (week 2 onwards)
			malathion 7.3	tetrachlorvinphos 7.1	fenitrothion 7.1	fenitrothion 2.4	bromophos 5.7	check	
19	1	1	650(600)*	648(600)	625(600)	—	—	647(600)	—
		2	0	9	1	—	—	24	9.4
		3	0	13	0	—	—	67	9.4
		4	0	1	0	—	—	48	9.4
		5	0	6	0	—	—	12	9.4
		7	0	2	0	—	—	45	9.4
		10	0	1	0	—	—	40	9.4
		13	0	1	0	—	—	11	9.4
		16	0	2	0	—	—	6	9.4
Totals			650	683	626	—	—	900	55.4
24.4	2	1	160(160)	—	163(160)	168(160)	238(160)	763(160)	—
		2	13	—	1	17	17	493	25.8
		3	4	—	2	3	9	268	25.8
		4	1	—	1	0	6	174	25.8
		5	0	—	0	1	1	92	25.8
		7	2	—	0	1	1	82	25.8
		9	3	—	0	1	1	29	25.8
		11	1	—	0	0	1	11	25.8
Totals			184	—	167	191	274	1917	87.2
30	3	1	611(600)	806(600)	598(600)	—	—	1111(600)	—
		2	147	821	2	—	—	2252	77.4
		3	378	1247	0	—	—	1907	77.4
		4	475	879	0	—	—	974	77.4
		5	477	356	0	—	—	696	77.4
		6	37	60	3	—	—	622	77.4
		7	17	13	0	—	—	395	77.4
		8	6	51	0	—	—	222	77.4
Totals			1848	4233	603	—	—	8179	214.0

Table 1. (continued)

Temp. (°C)	Expt. No.	Time in weeks	Treatment (ppm)						L.S.D. (P<0.05) (week 2 onwards)
			malathion 7.3	tetrachlorvinphos 7.1	fenitrothion 7.1	fenitrothion 2.4	bromophos 5.7	check	
30	4	1	226(600)	—	224(200)	224(200)	224(200)	311(200)	—
		2	8	—	0	5	1	564	30.6
		3	14	—	0	4	0	1012	30.6
		4	22	—	0	3	0	560	30.6
		5	9	—	0	5	0	313	30.6
		6	3	—	0	1	0	200	30.6
Totals			282	—	224	242	225	2960	74.6

* Number of adults added at beginning of experiments are in brackets.

Table 2. Numbers of live adult *C. ferrugineus* found in treated and untreated grains at different time intervals.

Temp. (°C)	Expt. No.	Time in weeks	Treatment (ppm) malathion 7.3	tetrachlorvinphos 7.1	fenitrothion 7.1	fenitrothion 2.4	bromophos 5.7	Check
19	1	1	0	213	0	—	—	643
		2	0	3	0	—	—	13
		3	0	2	0	—	—	66
		4	0	1	0	—	—	48
		5	0	1	0	—	—	12
		7	0	1	0	—	—	42
		10	0	0	0	—	—	36
		13	0	0	0	—	—	6
		16	0	0	0	—	—	0
24.4	2	1	0	—	0	0	0	751
		2	0	—	1	0	0	487
		3	0	—	0	0	0	265
		4	0	—	0	0	0	174
		5	0	—	0	0	0	91
		7	0	—	0	0	0	80
		9	1	—	0	0	0	29
		11	0	—	0	0	0	10
30	3	1	0	84	0	—	—	1098
		2	11	361	0	—	—	2238
		3	49	690	0	—	—	1883
		4	299	725	0	—	—	966
		5	175	336	0	—	—	692
		6	35	56	0	—	—	615
		7	17	13	0	—	—	388
		8	6	51	0	—	—	222
30	4	1	0	—	0	0	0	308
		2	1	—	0	0	0	555
		3	1	—	0	0	0	1003
		4	1	—	0	1	0	554
		5	0	—	0	0	0	309
		6	0	—	0	0	0	196

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