ABSTRACT

Talley, Cherie Pittillo. THE EFFECTS OF RAINFALL ON THE DISTRIBUTION AND SUCCESSION OF ADULT BEETLE (COLEOPTERA) IN BOVINE MANURE. (Under the direction of Susan J. McDaniel) Department of Biology, May 1981.

Occurrence of beetles in bovine manure samples in an open pasture was ascertained after 24, 48, 72 and 96 h exposure. At each interval samples which received various amounts of water at different intervals and samples which received no water were investigated. Succession of adult beetles and the effects of artificial rainfall on the distribution of adult beetles were studied.

Forty-six species of adult Coleoptera were recovered from March through May, 1974, from 276 bovine manure samples which included two species of Histeridae, 21 species of Staphylinidae, 15 species of Scarabaeidae, and eight species of Hydrophilidae. A total of 22,917 beetles were collected.

Unlike results of other studies which were conducted during summer months, succession of adult coleopterans followed a different pattern during this spring study. Coprophagous hydrophilids increased in abundance from 24-96 h while the coprophagous scarabs decreased slightly from 24 h to 96 h. Predaceous staphylinids increased from 24 h to 72 h with a slight decrease at 96 h. The total population of histerids was small but the population showed a slight increase at 96 h.

Statistical analyses showed no significant differences in effects of rainfall on the distribution and succession of adult beetles as hydrophilids increased from 24 to 96 h in each group of samples which

received no rain or various amounts of rain. Cercyon sp. A was the most abundant hydrophilid. Staphylinids generally increased from 24 to 96 h with Platystethus americanus as the most abundant. Scarabs were distributed with a decrease from 24 - 96 h with Aphodius lividus as the most numerous species.

Visual observations showed the manure samples did not form a crust in the early part of the study. This indicated that air temperatures affected the evaporation rate by slowing down the process. Since the microhabitat did not change rapidly, the early-arriving hydrophilids and certain scarabs could remain longer and feed on the liquefied manure. If the dung emitted different odors at different ages and attracted different species, the occurrence pattern of arrival and departure for each species would be altered. All families had their peak densities during the latter part of this study. It is noteworthy the greatest peak of abundance for each family coincided with the warmest temperatures of the study whether or not the beetles were exposed to artificial rainfall.

THE EFFECTS OF RAINFALL ON THE
DISTRIBUTION AND SUCCESSION OF
ADULT BEETLE (COLEOPTERA) IN
BOVINE MANURE

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

Page

Page

INTRODUCTION

According to Sanders and Dobson (1966) Portchinsky (1885) in Russia first considered cattle droppings as ecological units. Mohr (1943) was the first in the United States who considered cow droppings as microhabitats. Having studied the physical changes of bovine manure as well as the insect complex, he considered the microsuccession within the dung microhabitat. Pioneer species, along with abiotic factors, altered the microhabitat to make it unsuitable for them. Due to these changes the pioneer species left but now the microhabitat was suitable for other organisms. Knight (1965) stated the microsuccession in cattle droppings is unlike macrosuccession as no climax community was found. The dung pad became an indistinct part of the microenvironment.

Many studies have described the insects of the cow dung community which included mainly species of Diptera, Coleoptera, parasitic Hymenoptera plus mites (Acarina), a species of Isoptera and one of Orthoptera and soil arthropods (Pratt, 1912; Hafez, 1939; Mohr, 1943; Landin, 1961; Sanders and Dobson, 1966; Poorbaugh, Anderson and Burger, 1968; Valiela, 1969, 1974; Kessler and Balsbaugh, 1972; Blume, 1970, 1972; Nakamura, 1975). Researchers found distinctly different insect populations in bovine manure in an open area compared with pads in a shady area (Mohr, 1943; Poorbaugh et al, 1968; Nakamura, 1975; Nealis, 1977). Presumably the droppings, whether in a shady or sunny area, served as habitat for many insect species by providing food directly or indirectly, shelter and as a breeding medium (McDaniel and Balsbaugh, 1968).

Both Hafez (1939) and Mohr (1943) described the general physical changes of the outward appearance of bovine manure as it aged due to evaporation. Within 24 h after deposition a thin crust formed over the blackish-brown surface which contained moist depressions. During the third day of exposure the brown surface was covered with a dry crust which precluded arthropods not adapted for digging. During the next stage the pad was light brown with a thick crust while the final stage was a light brown chip, entirely dry. Complete drying depended upon the weather.

Within the beetle community studies showed species of Hydrophilidae were generally most abundant in the first 24 h after deposition and became less abundant as the manure aged. When the dung pad was 48-72 h old, species of Scarabaeidae were most abundant. The greatest densities of predaceous species of Staphylinidae in bovine manure occurred at 72 h while species of Histeridae were more numerous after 72 hours (Mohr, 1943; Sanders and Dobson, 1966; Kessler and Balsbaugh, 1972; Bernhardt, 1977). These studies agreed that the succession of adult beetles generally followed the pattern that adult coprophagous beetles arrived first followed by predaceous beetles.

Several studies have referred to the importance of the early arriving species. Mohr (1943) and Sanders and Dobson (1966) indicated the burrows formed by dipterous larvae, Sphaeridium beetles and adult Aphodius increased evaporation in the dung pad by aeration. However, Valiela (1974) found Sphaeridium spp. and Aphodius spp. arrived early and riddled the dung with tunnels which enabled the fly larvae to then feed in the droppings. Also, the predaceous staphylinids arrived later and were observed to use the tunnels as they lacked structural adaptations for burrowing. Furthermore, parasitoid wasps walked over the surface and crawled into burrows probably to oviposit in certain dipteran larvae (Mohr, 1943 and Sanders and Dobson, 1966). Bernhardt (1977) found a 78 per cent reduction in staphylinids in samples which lacked tunnels. He also found the succession of beetles was altered in samples from which certain tunneling species were eliminated. After three days exposure, Hafez (1939) estimated a 25 per cent moisture loss in dung pad by aeration possibly due to tunnels formed by Coleoptera.

Since hydrophilids are usually the first beetles to arrive at newly deposited dung and usually leave bovine manure as it loses moisture content, this study attempts to determine the effects of rainfall on the succession of adult Coleoptera in bovine manure in an open pasture. For each beetle family, samples receiving no rainfall were compared with samples receiving rainfall by Student's t-test. Samples which received various amounts of artificial rainfall were compared by analysis of variance to samples with no rainfall to determine the effects on the distribution of adult Coleoptera. In addition this study determined adult species of Coleoptera in bovine manure during the spring.

MATERIALS AND METHODS

The study area was located at a commercial dairy 2.8 km northwest of Greenville, Pitt County, North Carolina 0.2 km off State Highway 43. The 59 member cattle herd was composed of 57 Holstein cows, one Holstein bull and one Guernsey cow. They were allowed to graze freely over 74 ha of unshaded pastures. In addition to pasture grasses these cattle were fed Purina Test Chow® supplemented with corn silage and peanut hay twice daily.

The study area was located in the southwestern corner of a fenced-in 2.4 ha treeless pasture. This pasture was one of three pastures where the cattle could graze daily. The study area was bounded on the south by another pasture, on the west by a harvested silage corn field and on the east and north by the 2.4 ha pasture. Twenty-three depressions approximately 29.3x18.5x3.7 cm were dug in a 1.8x1.4 m area. Each depression was surrounded by pasture grasses.

Aluminum dissecting pans, 29.3x18.5x3.7 cm, were modified to contain the samples. Holes, 1.2 cm in diameter, were drilled in each corner and center of each pan for drainage. Each hole was covered by 14/18 mesh screen wire held in place by aluminum paste. All pans were painted flat green to reduce sunlight reflection and blend with the surroundings.

This study was conducted from March 5 to May 30, 1974. For the first five weeks fresh manure was collected seconds after deposition on each Monday except the third week when a sleet storm prevented collection. Manure collection was on Tuesday of that week. Fresh manure was shovelled immediately into an 18.9 liter plastic bucket and closed with a tight fitting lid. After three buckets were filled, they were carried to the study site where an approximate 29.3x18.5x3.7 cm bovine manure pad was constructed per pan. Each pan with a sample was placed in a depression so the pan rim was level with the ground. The depressions containing the pans were arranged in five rows with four samples per row and one row with only three samples.

During each of the remaining weeks of this study, manure was collected on Sunday morning as the cows were milked. Manure was enclosed in the buckets until it was placed in the pans. Generally manure was put into all pans at noon (EDT) and then specific pans were collected at 24, 48, 72, and 96 h after exposure ± 2 h from noon. Time intervals were based on Bernhardt (1977) and Valiela (1974) as Valiela had found soil arthropods and plant fauna in manure exposed after five days.

To prevent natural rainfall on the manure samples a cover of four ml transparent polyethylene was nailed onto a 3.1x2.1 m frame of 2.5x7.6 cm lumber. Then each corner of this cover was nailed onto four 5.1x5.1 cm posts 1.2 m high at one end sloping to 1.1 m at the lower end to allow for water runoff.

At least four days prior to each study week an 18.9 liter plastic carboy was filled with tap water and left uncovered to allow chlorine ions to escape. This water served as artificial rain throughout the study. To disperse this water, holes 0.6 cm in diameter, were drilled along the bottom of a 29.3x18.5x3.7 cm pan. This pan was held approximately 7.6 cm above each sample pan which received water. Then 669 ml of the tap water (equivalent to half an inch of rain) was poured slowly through the leaky pan.

The twenty-three pans with manure were divided into six groups for four days per week of the study. Group I was the control with four pans containing manure and received no water during the 96 hours exposure. A pan from Group I was collected at 24 h intervals with the first pan exposed for 24 h and the fourth pan exposed for 96 h. (Table 1.)

Group II contained four pans; each received 669 ml artificial rain at hour one. At 24 h exposure the first pan was collected and each of the remaining pans received 669 ml water. After 1,338 ml of rain the second pan was collected at 48 h exposure while the third and fourth pans received 669 ml water each. The third pan received a total of 2007 ml and was collected at 72 h exposure. The fourth pan received the final 669 ml water at that time. It was collected at 96 h exposure with a total 2,676 ml water (equivalent to two inches rain).

In Group III each of four pans received 669 ml artificial rain only at hour one. A pan was collected at 24 h intervals; the earliest was exposed for 24 h and oldest for 96 h.

Of four samples in Group IV three received 669 ml water each at 24 h exposure only. The first pan was collected at 24 h exposure and had not been watered. The second, third, and fourth pans were collected at 48, 72, and 96 h exposure respectively.

At 48 h exposure two of the four pans of Group V received the 669 ml water each. One was collected at 72 h and the fourth at 96 h. Of the two pans which did not receive water, one was collected at 24 h and the second at 48 h.

TABLE 1

TOTAL AMOUNT OF ARTIFICIAL RAINFALL PER SAMPLE OF BOVINE MANURE PER DAY AT 24 H INTERVALS

SAMPLE NUMBER	AGE OF MANURE IN HRS	GROUP I CONTROL	GROUP II RAIN AT HOURS 1, 24, 48, 72	GROUP III RAIN AT HOUR 1	GROUP IV RAIN AT HOUR 24	GROUP V RAIN AT HOUR 48	GROUP VI RAIN AT HOUR 72
1	24	0.0 ml	669 ml	669 ml	0.0 ml	0.0 ml	Not Sampled
2	48	0.0 ml	1,388 ml	669 ml	669 ml	0.0 ml	0.0 ml
3	72	0.0 ml	2,007 ml	669 ml	669 ml	669 ml	0.0 ml
4	96	0.0 ml	2,676 ml	669 ml	669 ml	669 ml	669 ml

Although Group VI had three pans, only one pan received the 669 ml water which was at 72 h exposure. It was collected at 96 h exposure while pans number one and two were collected at 48 h and 72 h exposure respectively. In total 23 pans were collected per week for 12 weeks.

When each sample was collected, the pan was placed and sealed in a 30.3 liter plastic bag. This was inserted into another 30.3 liter plastic bag and tied to prevent escape of beetles during transport to the laboratory.

In the laboratory, method of removal of insects from manure pad was based on Bernhardt (1977). As the plastic bags were removed, each pad and sample were submerged in 20 liters of tap water in a stainless steel sink. Eight 60 watt bulbs were positioned behind the sink to direct light onto the water. As adult beetles floated to the surface, they were collected with forceps and immediately placed in 70 per cent ethyl alcohol. The manure pad was visually divided into eighths and each eighth was crumpled gently with a gloved hand underwater to allow flotation of beetles which had not previously surfaced. Although this method was time consuming, beetles were in excellent condition for identification.

Initially collected beetles were separated into four families by consulting Dillon and Dillon (1961). Each species was assigned a species number, separated and counted. Representative specimens of Scarabeidae, Hydrophilidae, and Histeridae were sent to National Museum of Natural History, Washington, D. C. while members of Staphylinidae were sent to University of California at Riverside for identification.

Samples which received no rainfall were compared with those which received various amounts of rainfall at 24 h intervals up to 96 h exposure for each beetle family by Student's t-distribution (Schefler, 1969):

$$S_p^2 = \frac{\Sigma x_A^2 - \frac{(\Sigma x_A)^2}{N_A} + \Sigma x_B^2 - \frac{(\Sigma x_B)^2}{N_B}}{N_A + N_B - 2}$$

where S_p^2 is the pooled variance; Σx_A^2, Σx_B^2 are the sums of squared deviations from the two sample means and $N_A + N_B - 2$ are the degrees of freedom. After the standard error of differences between means is computed, the t-value is computed as:

$$t = \frac{\overline{X}_A - \overline{X}_B}{S_{\overline{X}_A - \overline{X}_B}}$$

where $\overline{X}_A - \overline{X}_B$ are the differences between the means and $S_{\overline{X}_A - \overline{X}_B}$ is the standard error of differences between the means.

To compare all the samples with each treatment for each 24 h exposure analysis of variance was used:

$$S.\ S._{total} = \Sigma X^2 - \frac{(\Sigma x)^2}{N}$$

where $S.\ S._{total}$ is the total sum of squares found by ΣX^2, the sum of squared deviations; X refers to each measurement and N to the total number of measurements. Next the sum of squares is computed between groups:

$$S.\ S._{between} = \frac{(\Sigma X_A)^2}{k_A} + \ldots \frac{(\Sigma X_2)^2}{k_Z} - \frac{(\Sigma X)^2}{N}$$

where K_A, K_Z are the numbers in each group. Since the total sum of squares equals $S.\ S._{between}$ plus the $S.\ S._{within}$:

$$S.\ S._{within} = S.\ S._{total} - S.\ S._{between}$$

The final step is:

$$F_{A,B} = \frac{M.\ S._{between}}{M.\ S._{within}}$$

where the F-distribution equals the division of the mean square between group variance by the mean square within group variance. The degrees of freedom A, B are located on a standard F-table and the critical value compared with the obtained F-value where F-values of one or less are nonsignificant.

RESULTS AND DISCUSSION

Forty-six species of adult Coleoptera were recovered from 276 bovine manure samples which included two species of Histeridae, 21 species of Staphylinidae, 15 species of Scarabaeidae, and eight species of Hydrophilidae (Table 2). Of these 46 species 20 were also found by Bernhardt (1977) and 14 by Davis (1966) in piedmont North Carolina. A total of 22,917 beetles were collected during this study (Table 3).

Population Characteristics. Population seasonal trends are indicated in Figure 1 for each of four families of Coleoptera collected. Unlike peak densities of each family found by Bernhardt (1977) in the summer, predaceous staphylinids and coprophagous scarabs had simultaneous peak densities during the eighth and eleventh weeks of this spring study (April 29-May 2; May 20-23). However, the peak density for the coprophagous hydrophilids did coincide at the eighth week with one of two peaks for scarabs. A small sample, which totaled 25 specimens of histerids, had two peak densities at the seventh and tenth weeks during the twelve week study. Since histerids and staphylinids prey upon dipterous larvae, perhaps they occurred when their prey species were more abundant. No data were collected to substantiate this hypothesis. Also, the eighth week had the highest air temperatures during the collecting period. Cloudsley-Thompson (1953) stated that fluctuating temperatures accelerated growth of different stages of insects and different insects. However, no studies were found correlating critical temperatures with abundance of dung beetles.

TABLE 2

ADULT COLEOPTERA RECOVERED FROM BOVINE MANURE

Family	Species
Scarabaeidae	X *Aphodius distinctus* (Müll.)
	X* *Aphodius vittatus* Say
	X *Aphodius haemorrhoidalis* (L.)
	X* *Aphodius lividus* (Oliver)
	X* *Aphodius fimetarius* (L.)
	X* *Aphodius ruricola* Melsheimer
	X* *Aphodius stercorosus* Melsheimer
	X* *Aphodius erraticus* (L.)
	X* *Ataenius platensis* (Blanchard)
	X *Ataenius spretulus* (Harold)
	Ataenius sp. A
	X* *Onthophagus pennsylvanicus* Harold
	X* *Onthophagus hecate* Panzer
	X* *Copris minutus* (Drury)
	X* *Geotrupes blackburnii blackburnii* F.
Hydrophilidae	* *Sphaeridium scarabaeoides* L.
	* *Sphaeridium bipustulatum* Fabr.
	Cercyon sp. A
	Cercyon sp. B
	Cercyon sp. C
	Cercyon sp. D
	Cercyon sp. E
	Cercyon sp. F

X Recorded by Davis, 1966

* Recorded by Bernhardt, 1977

TABLE 2 (Cont.)

Family	Species
Staphylinidae	*Philonthus longicornis* Steph.
	Philonthus ventralis Erichson
	* *Philonthus flavolimbatus* Erichson
	* *Philonthus rectangularis* Sharp
	Philonthus sp. A
	Tachinus axillaris Erichson
	Aleochara bimaculata Gravenhorst
	Aleochara sp. A
	Aleocharinae A
	Aleocharinae B
	Aleocharinae C
	Aleocharinae D
	Aleocharinae E
	* *Platystethus americanus* Erichson
	* *Falagria dissecta* Erichson
	Megarthus sp.
	Oxytelus sp.
	Medon sp.
	* *Rugilus* sp.
	Staphylinidae A
	Staphylinidae B
Histeridae	* *Hister abbreviatus* Fabr.
	Xestipyge conjunctus (Say)

TABLE 3

TOTAL NUMBER ADULT BEETLES COLLECTED FROM MARCH THROUGH MAY FOR GROUPS I-VI FOR SCARABAEIDAE, STAPHYLINIDAE, HYDROPHILIDAE, AND HISTERIDAE IN BOVINE MANURE SAMPLES

Group	Scarabaeidae				Staphylinidae				Hydrophilidae				Histeridae				Total Number
	24	48	72	96h	24	48	72	96h	24	48	72	96h	24	48	72	96h	
Group I	344	192	279	216	139	230	477	428	430	477	568	674	3	4	7	11	4479
Group II	55	122	198	194	24	130	208	345	208	433	652	773	0	0	2	9	3353
Group III	90	230	259	276	49	149	270	393	175	418	583	776	0	8	9	5	3680
Group IV	266	341	262	207	83	98	252	343	183	559	735	745	1	0	6	5	4086
Group V	272	236	232	199	86	226	228	296	142	421	861	974	0	2	3	9	4187
Group VI	X	198	254	196	X	182	240	393	X	377	529	747	X	6	2	7	3132
	1027	1319	1484	1288	381	1015	1675	2198	1138	2685	3928	4679	4	20	29	46	22,917

X - Not Sampled

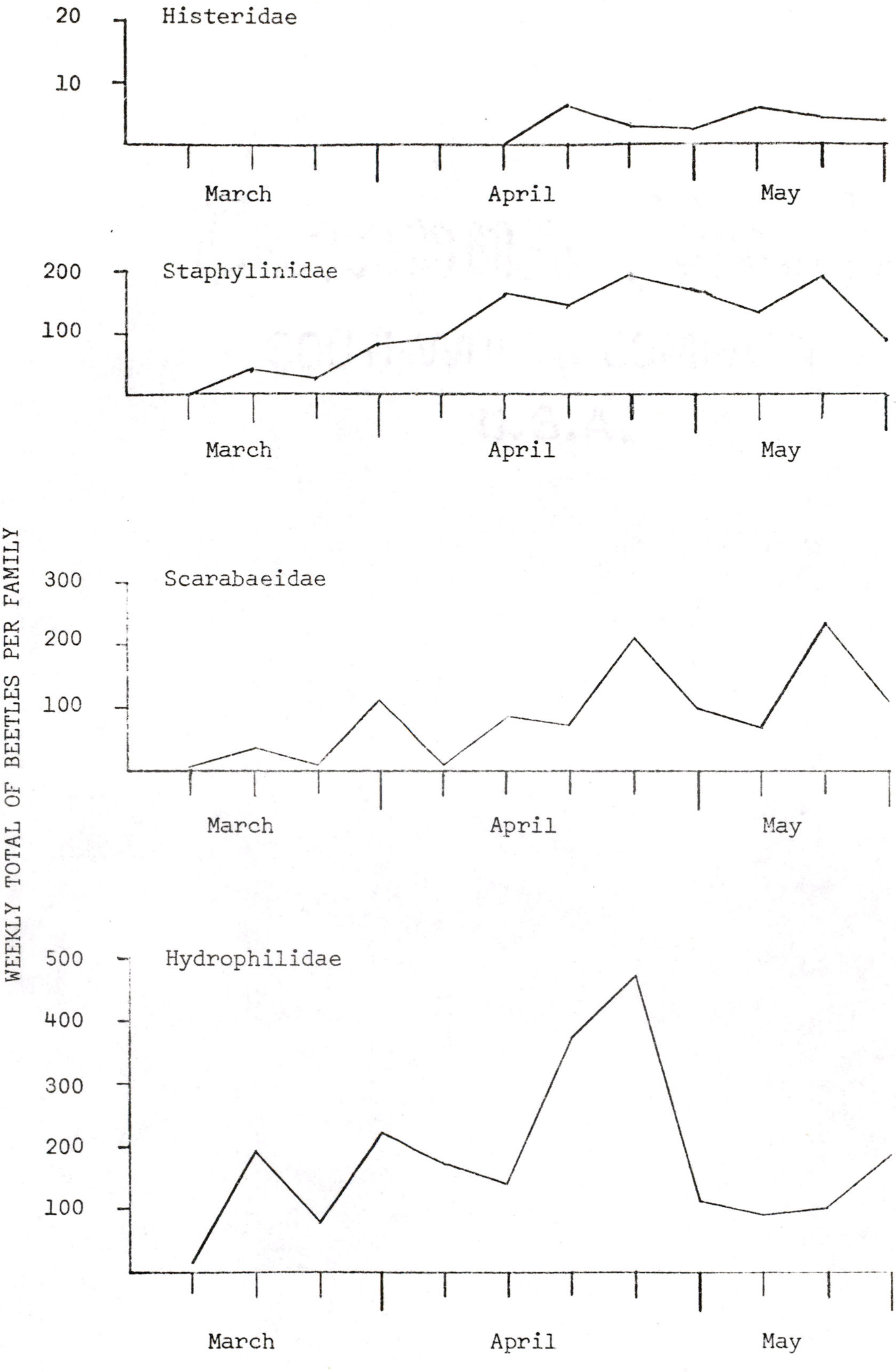

Figure 1. Seasonal peak density of each family of Histeridae, Staphylinidae, Scarabaeidae, and Hydrophilidae in bovine manure samples in Group I.

Weekly frequencies of species representative of each beetle family collected are represented graphically in Appendices A through D. Highest densities for representative familes, with or without rainfall, are illustrated in Figures 2, 3, and 4. Highest densities for representative species are illustrated in Figure 5. In general both predaceous and coprophagous species had greater densities during the latter part of the study. Possibly warming air temperatures were conducive for increased distribution.

Three coprophagous genera Sphaeridium, Onthophagus, and Aphodius were cited by Hafez (1939) and Mohr (1943) as important to predators which use their tunnels to enter manure. Of the two species of Sphaeridium in this study, Sphaeridium scarabaeoides was not collected in every sample of Group I until the seventh week. Although not present in large number, it was present in every sample except one after the sixth week. Onthophagus pennsylvanicus were more numerous than the rare O. hecate in Group I samples. Although Aphodius lividus was the most abundant beetle in the summer study by Bernhardt (1977), Cercyon sp. A, an hydrophilid was the most prominent in this spring study. A. lividus was the second most abundant beetle species but Cercyon sp. A was 234 times greater. These species made many tunnels in manure especially toward the latter portion of this study as observed in manure samples brought into the laboratory.

Succession of species of adult beetles. Peak densities of representative specimens at 24 h intervals for Group I manure samples are shown in Figure 6. Figures 7, 8, and 9 illustrate succession of each family through 24 h collection intervals.

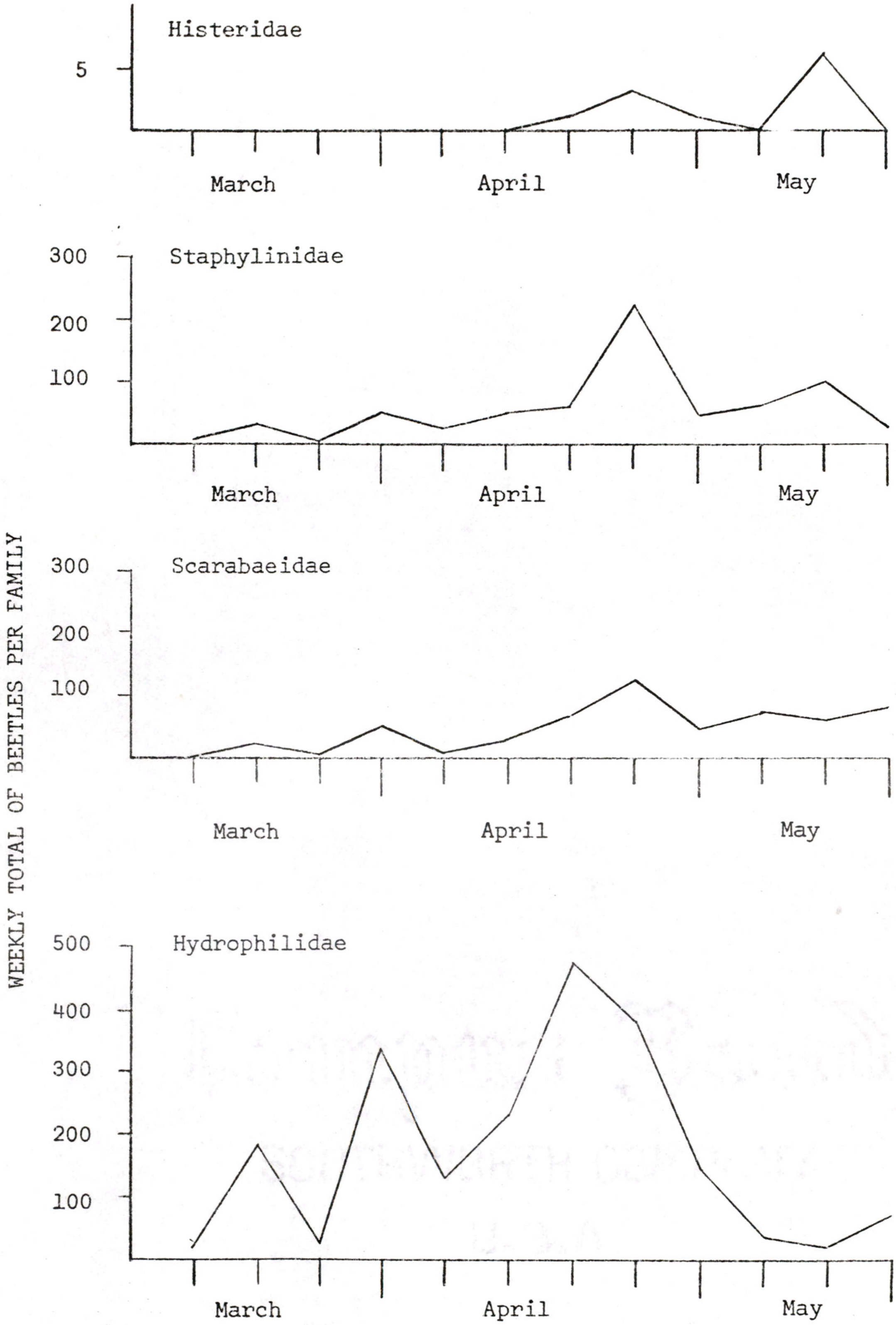

Figure 2. Seasonal peak density of each family of Histeridae, Staphylinidae, Scarabaeidae, and Hydrophilidae in bovine manure in Group II.

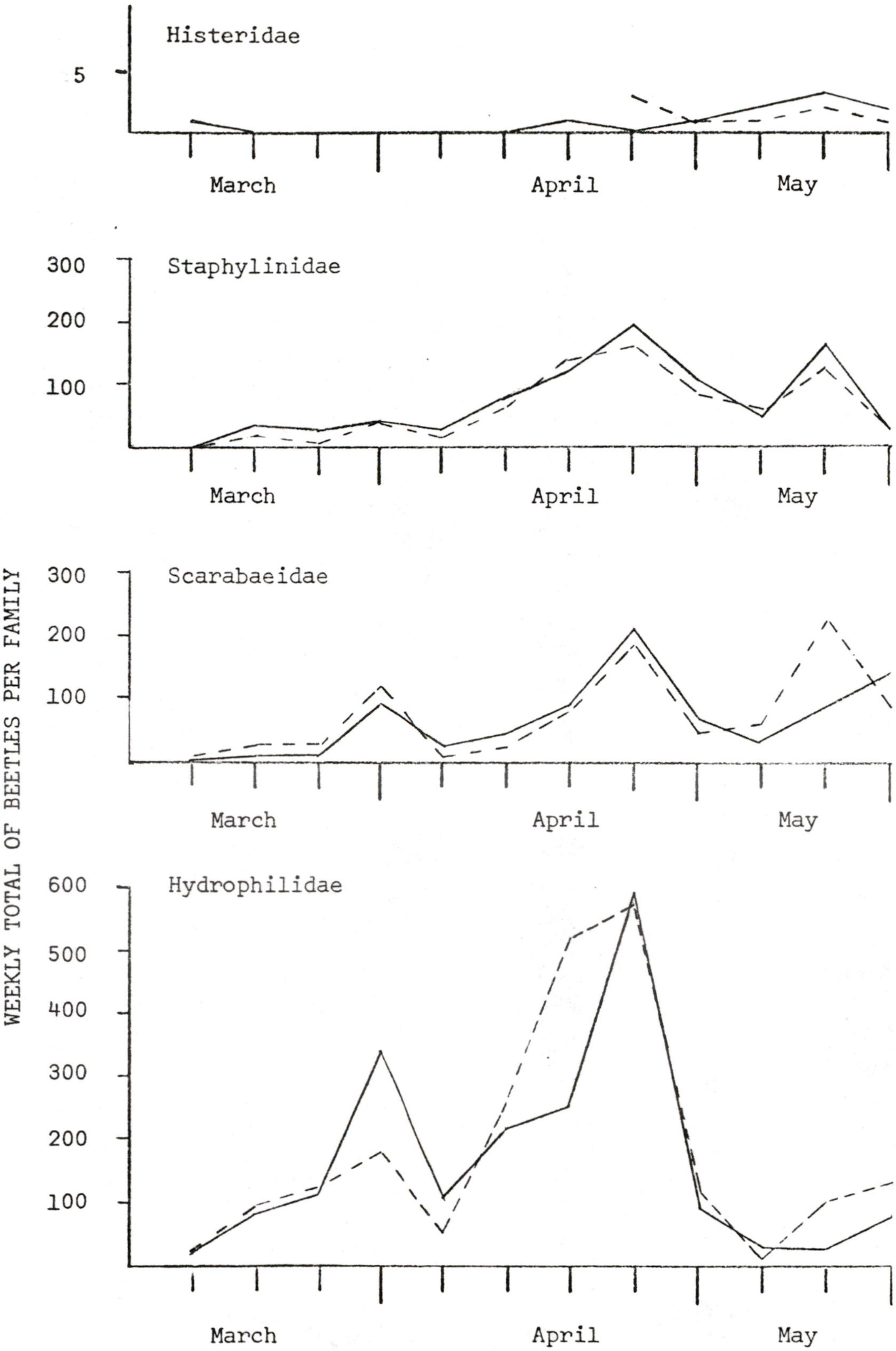

Figure 3. Seasonal peak density of each family of Histeridae, Staphylinidae, Scarabaeidae, and Hydrophilidae in bovine manure samples in Group III, IV. Solid line indicates Group III; broken line, Group IV.

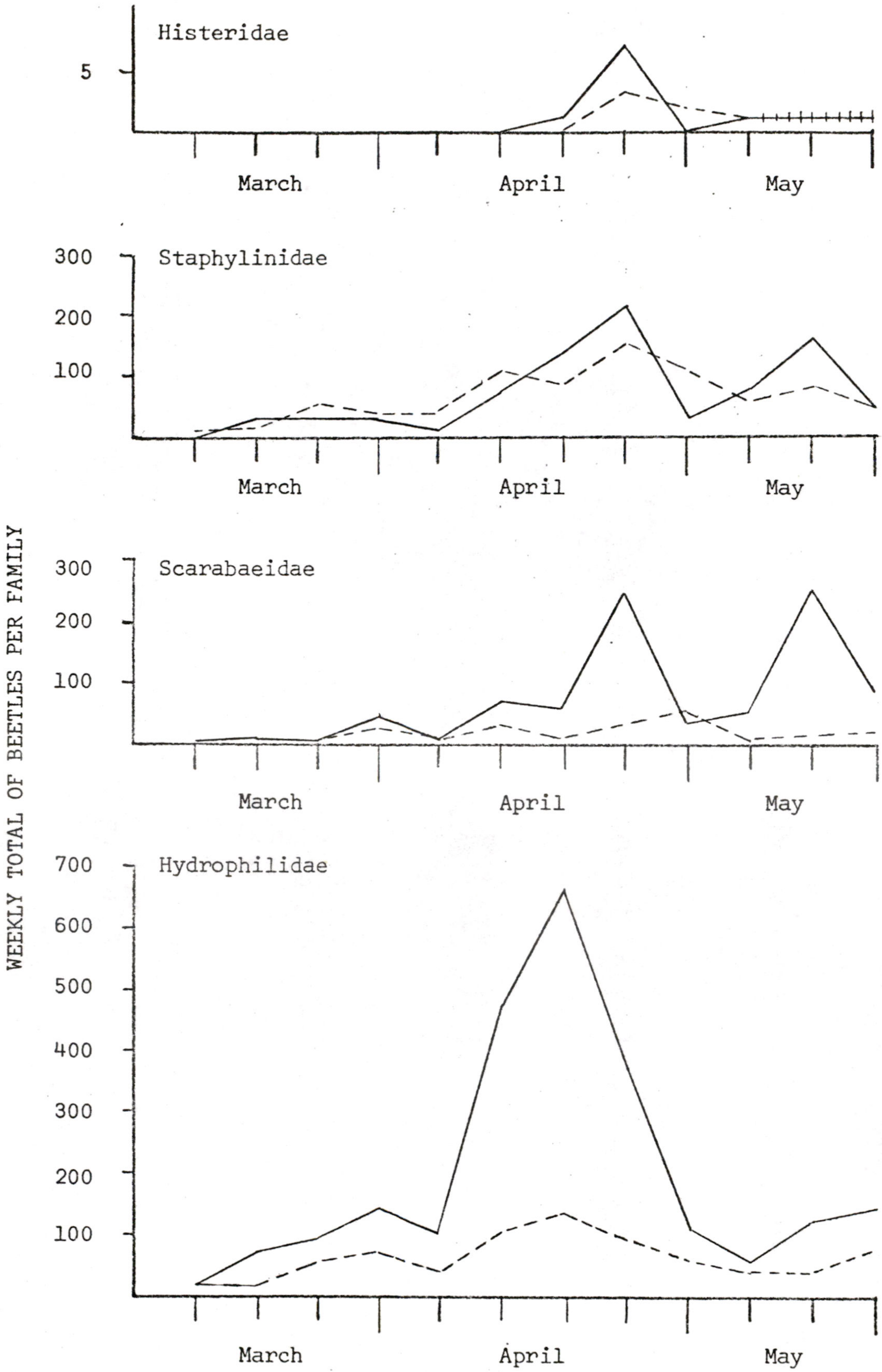

Figure 4. Seasonal peak density of each family of Histeridae, Staphylinidae, Scarabaeidae, and Hydrophilidae in bovine manure samples in Group V, VI. Solid line indicates Group V; broken line, Group VI.

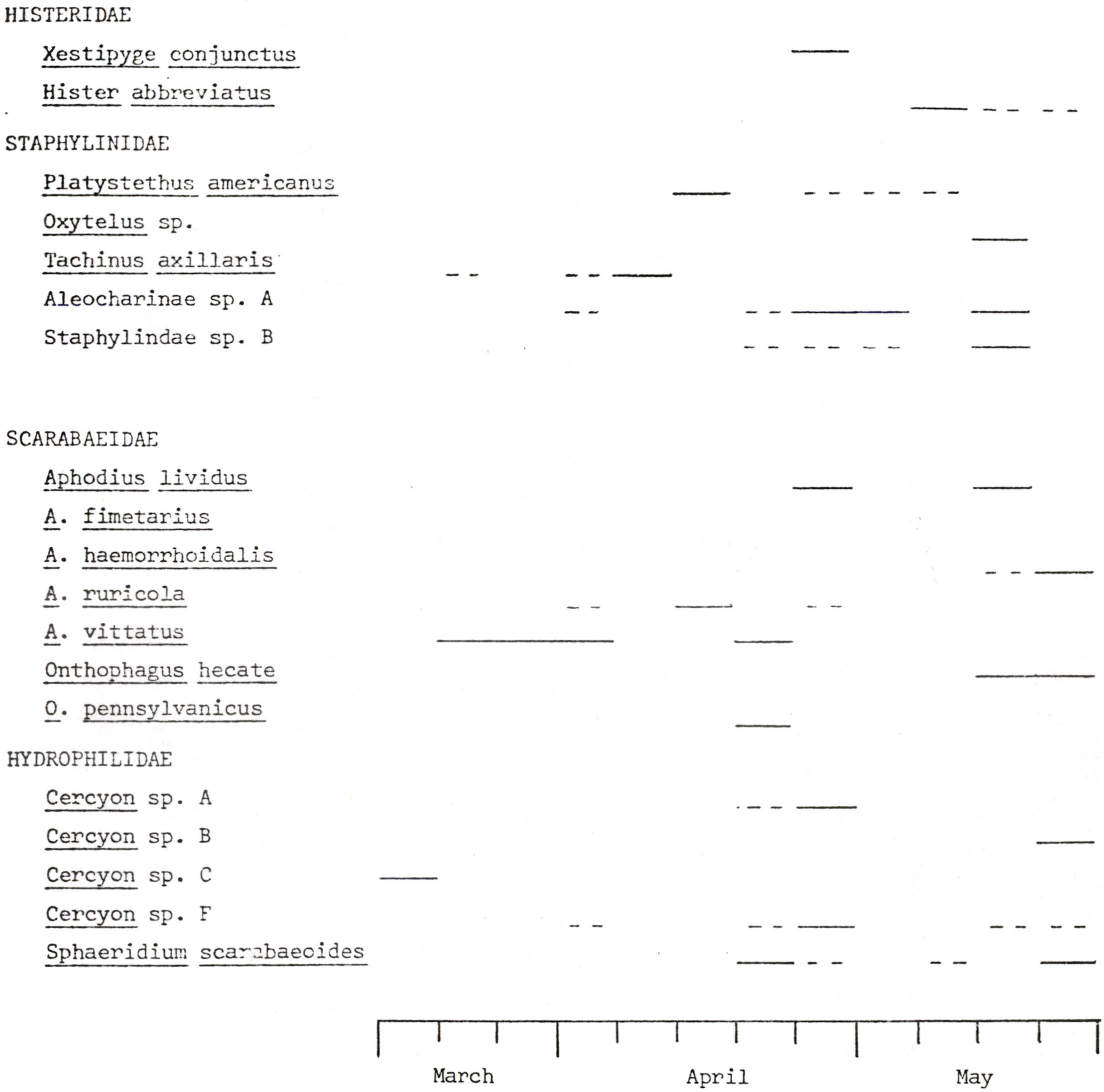

Figure 5. Seasonal peak densities of members of Histeridae, Staphylinidae, scarabaeidae, and Hydrophilidae in Groups I-VI. Solid bar indicates peak density. Broken lines indicate sample 60 percent of peak density.

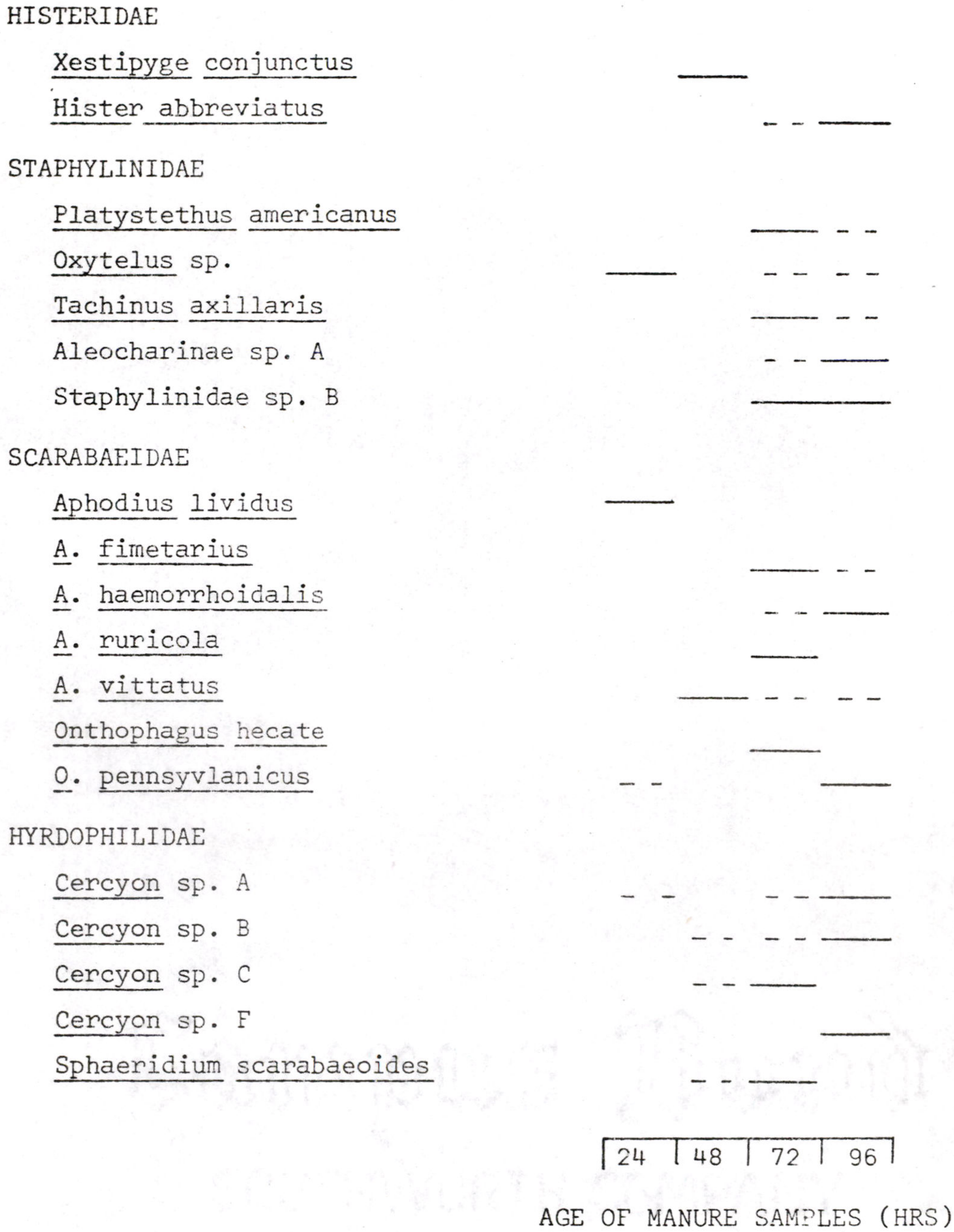

Figure 6. Peak density of members of Histeridae, Staphylinidae, Scarabaeidae, and Hydrophilidae in four ages of bovine manure. Solid bar indicates peak; broken lines indicate sample 60 per cent of peak density.

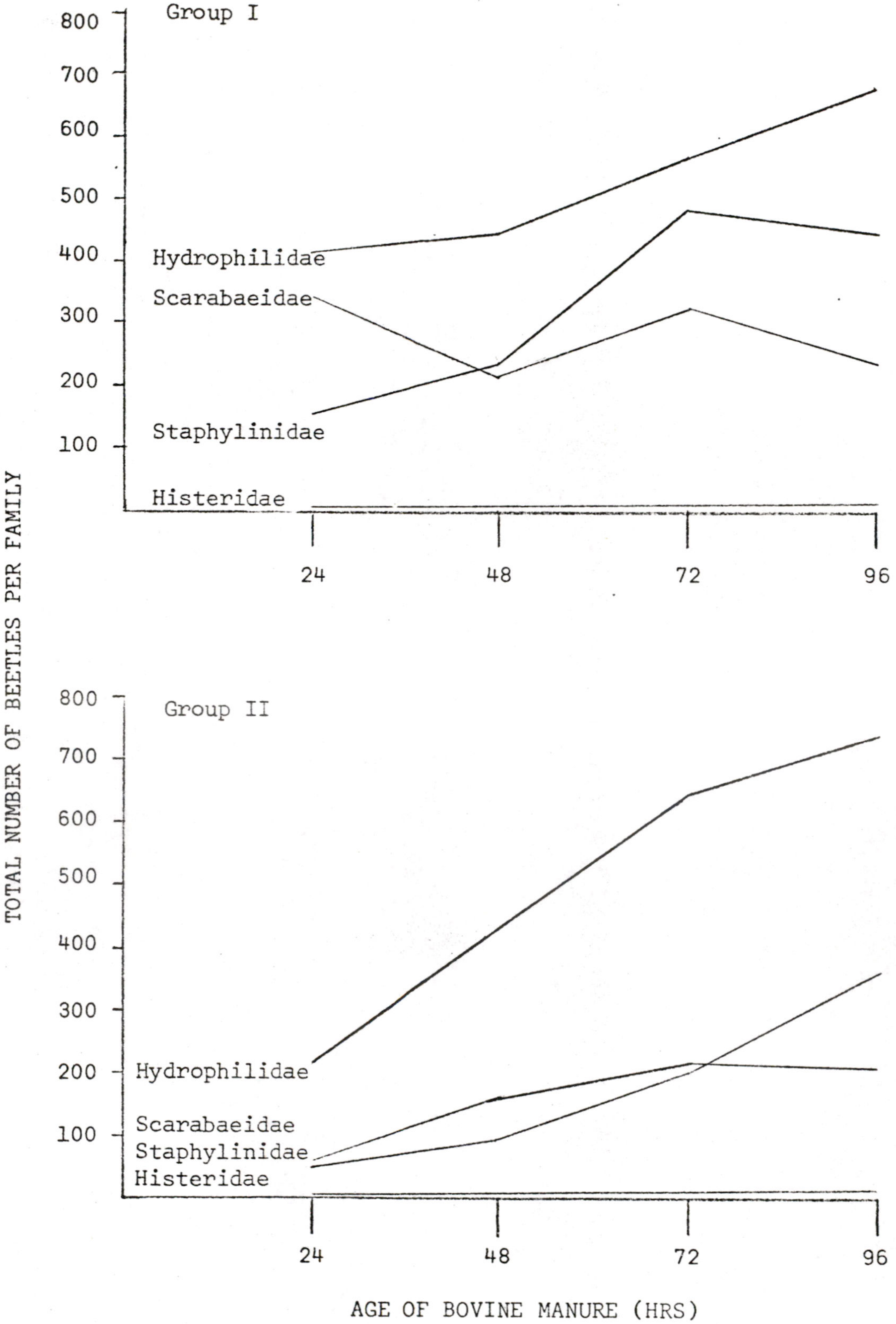

Figure 7. Succession of each family of Histeridae, Staphylinidae, Scarabaeidae, and Hydrophilidae for Groups I, II in four ages of bovine manure.

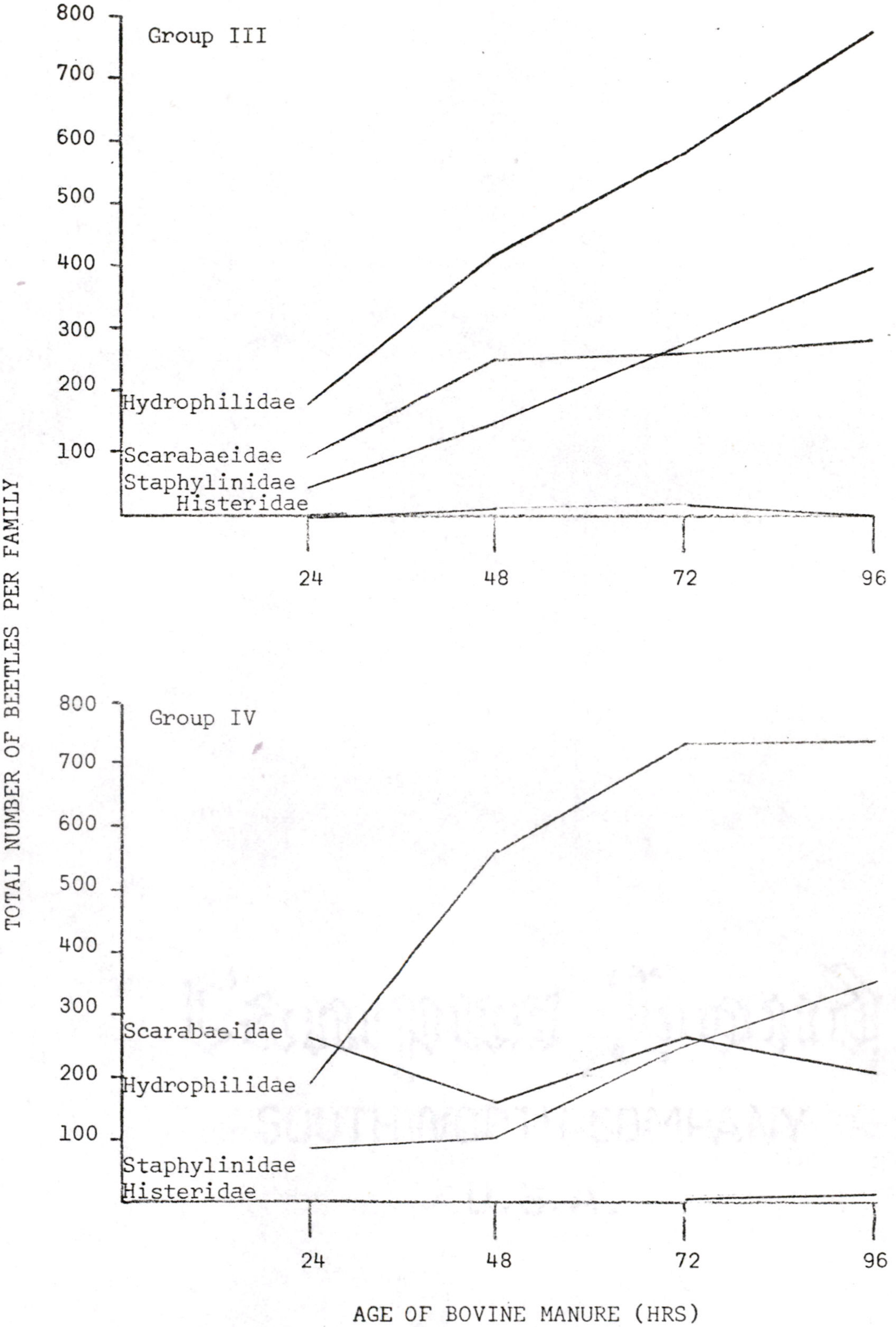

Figure 8. Succession of each family of Histeridae, Staphylinidae, Scarabaeidae, and Hydrophilidae for Groups III, IV for four ages of bovine manure.

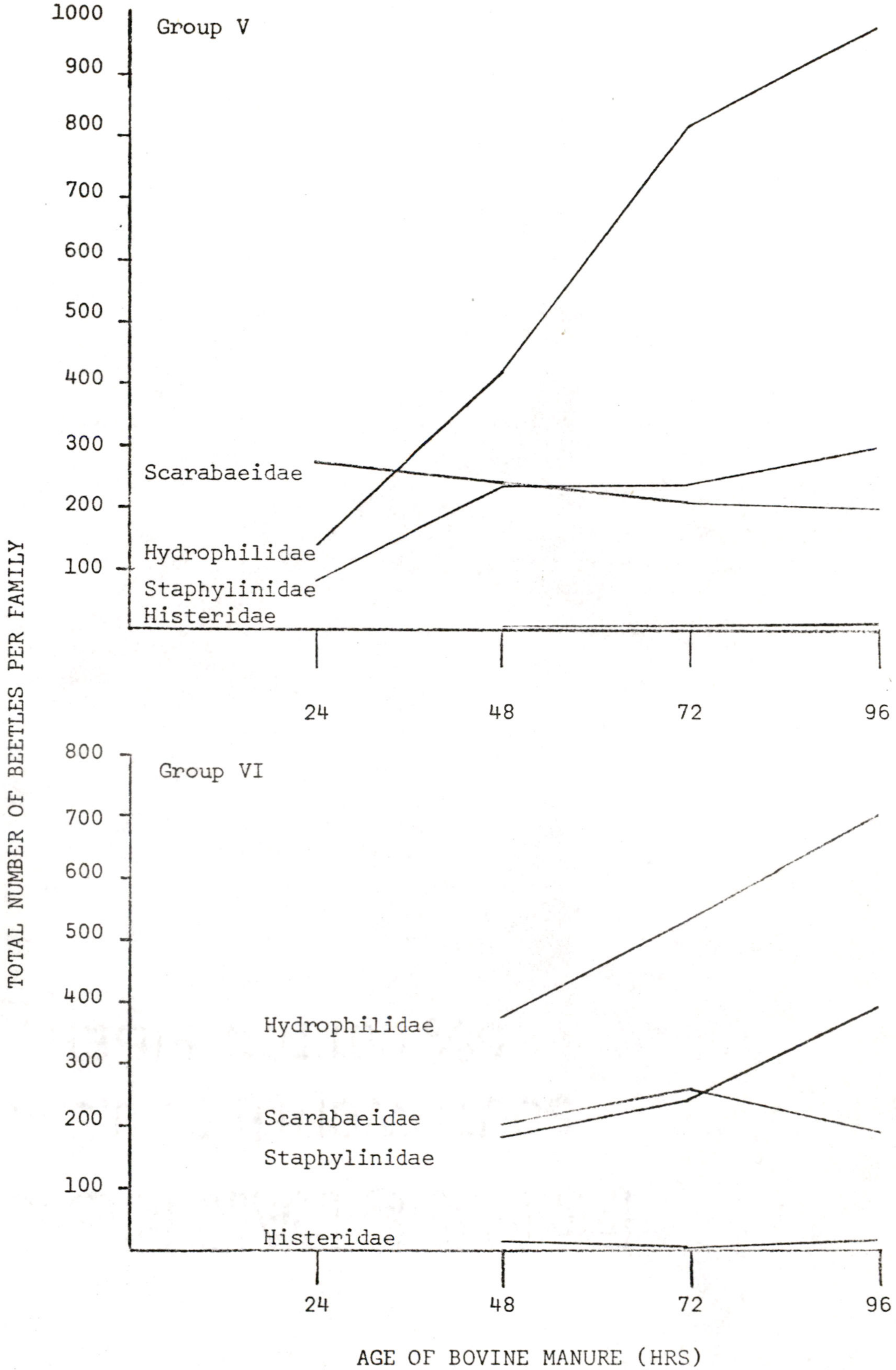

Figure 9. Succession of each family of Histeridae, Staphylinidae, Scarabaeidae, and Hydrophilidae for Groups V, VI for four ages of bovine manure.

This succession does not vary with rainfall. Surprisingly, succession of adult beetles in bovine manure in this study did not follow successional patterns reported by other authors (Mohr, 1943; Sanders and Dobson, 1966; Kessler and Balsbaugh, 1972; and Bernhardt, 1977). These authors agreed that hydrophilids generally were most abundant within 24 h of deposition while scarabs were present in dung 48-72 h old. Staphylinids had greatest numbers in manure at 72 h but histers were more numerous after 72 h.

Hydrophilids reached peak densities at 96 h exposure (Figure 7); this trend continued except for Cercyon sp. C which reached the peak at 72 h (Figure 6). Scarabs were present from 24 to 96 h with a decrease at 48 h and 96 h and increase at 72 h. Of the scarabs Aphodius lividus was the most abundant and was collected in largest numbers at 24 h (Figure 6). The lowest density for scarabs was at 48 h. Some uncommon scarabs had peak densities at 72 h such as A. ruricola, A. fimetarius, O. hecate. Generally staphylinids were most abundant at 72 h which coincided with results from the above authors. Platystethus americanus was the most abundant staphylinid during this spring study. Histers were more numerous after 72 h but a total of 25 specimens was a small population.

The discrepancy between occurrence of hydrophilids at 96 h with those at 24 h in other studies could possibly be due to the season of the year. Most studies were completed during summer months while this study was undertaken during spring. Since climate has been shown as a major factor which contributed to loss of moisture from cow dung, cooler weather could have slowed down evaporation. During the first three weeks of this study the brown dry crust, as defined by Mohr (1943) did not form. Since it did not form, perhaps the role of coprophagous species as early tunnelers was not as critical for predaceous species. If the manure did not lose moisture as rapidly in spring as in summer, the microhabitat would remain suitable for a longer time for the hydrophilids. Also Mohr (1943) and Bernhardt (1977) hypothesized different ages of manure emitted different odors and attracted different species. Deithier (1947) found dung beetles used their antennae to orient to dung. If manure did not lose moisture as quickly as in the aging process described by Mohr, the succession of beetles could possibly be delayed. However, Rainio (1966) found hydrophilids were abundant during the first three days after deposition in exposed habitats, and Nakamura (1975) found a large number of them after three days.

Effects of artificial rainfall. Artificial rainfall was used to determine effects on distribution and succession of adult coleopterans in bovine manure. Specifically patterns of arrival and departure for coprophagous species should be altered with changes in microhabitat by addition of rainfall. As mentioned previously, coprophagous species changed their microhabitat by tunneling which probably increased aeration of the manure pad and loss of moisture. Tunnels enabled certain predaceous species to enter manure to search for prey. If the occurrence pattern of coprophagous adult hydrophilids and adult scarabs varied, occurrence patterns of predaceous species would change.

To statistically compare effects of artificial rainfall on the distribution of each family at each 24 h interval of exposure, the Student's t-test was used. The total number of beetles of each family collected during the twelve week study in pans number one after 24 h exposure from Group I, IV (Table 1) which received no water were compared with samples from Groups II, III which received at hour 1 an equal amount of rain (669 ml each). According to the t-test for scarabs, hydrophilids and staphylinids at 24 h exposure there was no significant difference. Data for histers were too small to analyze. When total number of beetles was compared between samples with water and those without at 24 h exposure, there was failure to reject the null hypothesis at 0.05 and 0.01 levels of significance. To analyze each treatment of the samples between Groups I-V for each beetle family at 24 h exposure, analysis of variance was used. Differences were not significant. Possibly no significant difference could be expected as the manure was fresh and moist so added moisture did not affect early colonizers.

At 48 h exposure number two pans were collected from Group I, V, VI which received no rainfall and were compared with pans number two from Group II, III, IV. The Group II pan had received 1,338 ml water; Group III pan 669 ml water at hour 1 and Group IV pan 669 ml water at h 24. Differences were not statistically significant for each family of beetles nor total number of specimens. An analysis of variance between treatments showed no significant difference between each family or total of families at 48 h exposure with or without rainfall.

After manure samples were exposed for 72 h, number three pans from Groups I, VI were compared individually and totally with number three pans from Group II, III, IV, V. There were no significant differences in samples with or without rain on the population of beetles.

At 96 h after exposure number four pans from Groups II-VI were compared individually with number four pans from Group I which received no rain. Group II sample had received 2,676 ml rain; Group III sample had received 669 ml rain at hour 1; Group IV sample had received 669 ml rain at h 24; Group V sample had received 669 ml rain at h 72. No significant differences between the number of beetles in each family or with the total population were found in the samples with or without rain.

As mentioned earlier personal observations revealed manure samples of the first three weeks in this study did not obtain the brown dry crust at the third day as Mohr (1943) described. Landin (1961) studied climatic factors which affected cow droppings in exposed localities. They included air temperature, humidity, precipitation, ground temperature, wind and light intensity. He found the maximum temperature in bovine droppings after deposition was reached between 10:00 a.m. and 4:00 p.m. Crust formation depended on insolation as on hot, sunny days the surface of bovine manure hardened within half an hour. Cloudy weather slowed crust formation and constant rain prohibited it. The inner and lower parts were slowly heated because the crust served as an insulator. However, there was a loss of water from the surface by evaporation before crust formation. High air temperatures and strong wind increased evaporation. An intact crust slowed evaporation. Underhay and Dickinson (1978) concluded that the most rapid drying of cattle dung was during mid-summer while one of the slowest rates of moisture loss occurred during February - April. Landin (1967) stated if the air temperature directly over the manure surface was 12-14^{o}C with overcast sky or rain, the dung beetles dug into the droppings 1-2 mm or remained under them. When this air temperature reached 15-16^{o}C, the beetles were observed to move on the surface. During high temperatures six or seven were seen plunging in and out of the manure (Landin, 1967).

Figure 10 shows the mean maximum and minimum air temperatures during this study along with occurrence of members of each family. For the first three weeks of this study air temperatures varied from 19.4 to 3.9°C, 26.7 to 0°C, and 21.7 to 3.8°C, respectively. It is noteworthy the greatest peak of abundance for each family coincided with the warmest temperatures of the study whether or not the beetles were exposed to artificial rainfall. Although the purpose of this study was to determine effects of rainfall on succession and distribution of adult beetles, the influence of climate during this study must not be overlooked as statistical results indicated no significant differences in samples with or without rainfall. In addition, no data were collected to determine the influence of the height of the protective covering to prevent natural rainfall.

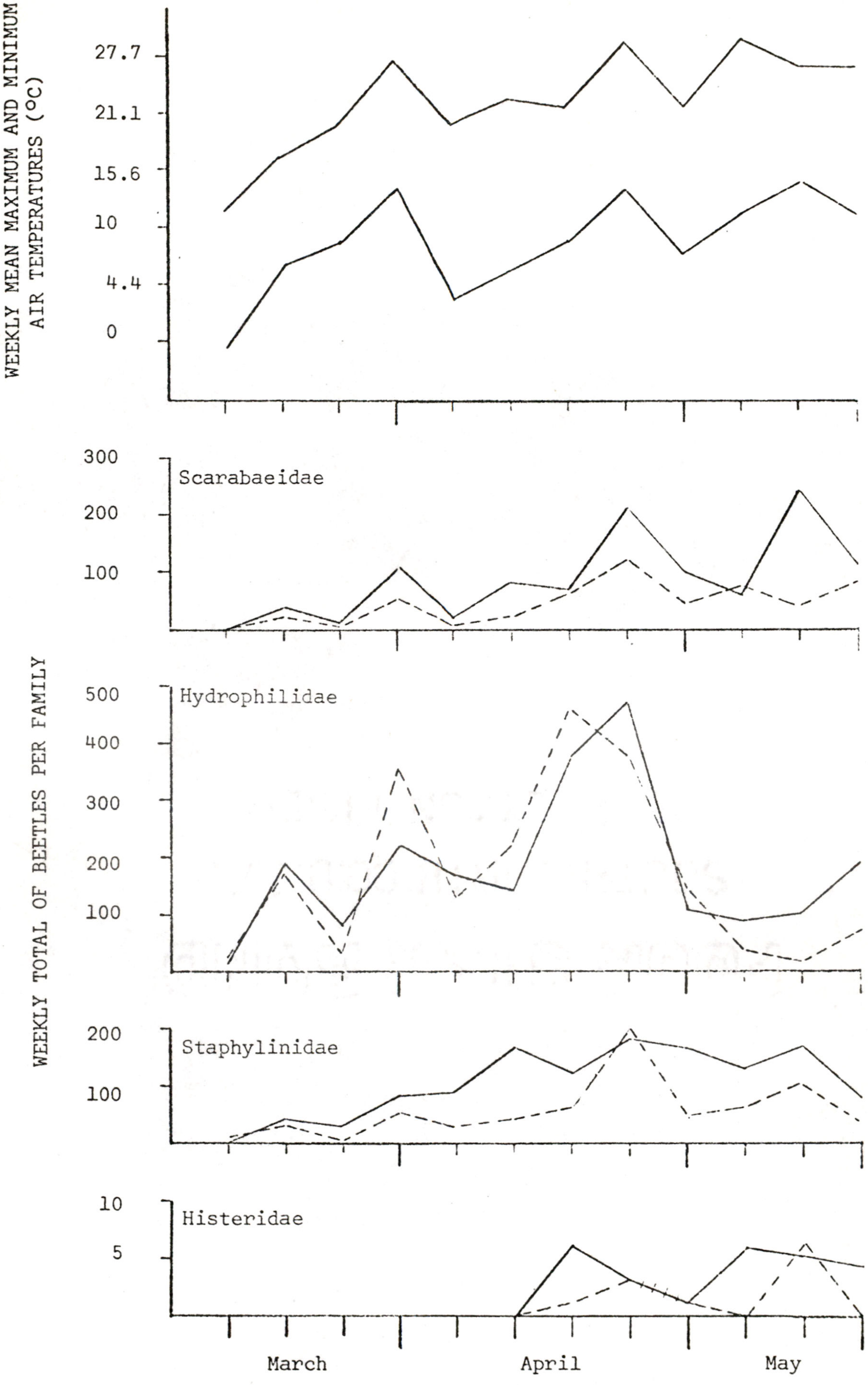

Figure 10. Mean maximum and minimum air temperatures for March through May with seasonal occurrence of each family of Histeridae, Staphylinidae, Scarabaeidae, and Hydrophilidae for Groups I, II. Solid line indicates Group I; broken lines indicate Group II.

SUMMARY AND CONCLUSIONS

Forty-six species of adult Coleoptera were recovered from 276 bovine manure samples which included two species of Histeridae, 21 species of Staphylinidae, 15 species of Scarabaeidae, and eight species of Hydrophilidae from March through May, 1974. A total of 22,917 beetles were collected during this study.

Beetles were considered in two groups depending on feeding habits; scarabs and hydrophilids were dung feeders and staphylinids and histers were predaceous. During this study coprophagous scarabs and predaceous staphylinids had simultaneous peak densities. Perhaps predaceous species occurred when their prey was abundant. Both dung feeders and predators had greater densities during the latter part of this study. Possibly increased air temperatures influenced their distribution.

Many researchers have cited the importance of tunneling by the genera *Sphaeridium*, *Aphodius*, and *Onthophagus*. Tunneling allowed predaceous beetles as well as parasitoid wasps to enter manure as they lack structural adaptations for digging. Tunnels also increased the evaporation rate of manure which made their microhabitat unsuitable for adult dung feeders so they departed.

Surprisingly, succession of adult beetles in bovine manure did not follow successional patterns reported by previous researchers where hydrophilids were most abundant within 24 h of deposition while scarabs were present at 48-72 h. Staphylinids were most numerous at 72 h and histers were more numerous after 72 h.

In this study hydrophilids reached peaked densities at 96 h; Cercyon sp. A was the most abundant species. Scarabs had peak densities at 24 and 72 h. The most abundant scarab was Aphodius lividus. As in other studies, staphylinids were most abundant at 72 h. Platystethus americanus was the most abundant staphylinid. Histers were more numerous after 72 h but a total of 25 specimens was too small a population sample on which to generalize succession patterns.

The effects of artificial rainfall on succession and distribution of beetles was determined from bovine manure at 24, 48, 72, and 96 h after exposure. Specifically patterns of arrival and departure for coprophagous species should be altered with changes in the microhabitat by addition of rainfall. If their patterns were altered, then predaceous species patterns should be altered. However, statistical analyses showed no significant differences between samples which received artificial rainfall and those which did not.

Since the occurrence pattern of hydrophilids and scarabs of this spring study differed from results obtained by other researchers in summer studies, perhaps the season of the year was a major factor. Studies have shown that air and ground temperatures, humidity, wind and insolation affect moisture loss from bovine manure. One of the slowest rates of evaporation in bovine manure occurred from February through April according to one study. Since adult coprophagous species fed on liquefied materials in dung, a slow rate of moisture loss would allow dung feeders to remain in manure longer. When peak densities for each family of beetles were compared with maximum and minimum daily temperatures during this study, highest peaks of occurence coincided with highest temperatures of the study whether or not beetles were exposed to artificial rainfall. Although this study was designed to study effects of rainfall on distribution and succession of adult coleopterans, the possible influence of climatic factors must not be overlooked. Other studies are needed to determine the succession of adult beetles in the spring.

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APPENDIX A: Scarabaeidae

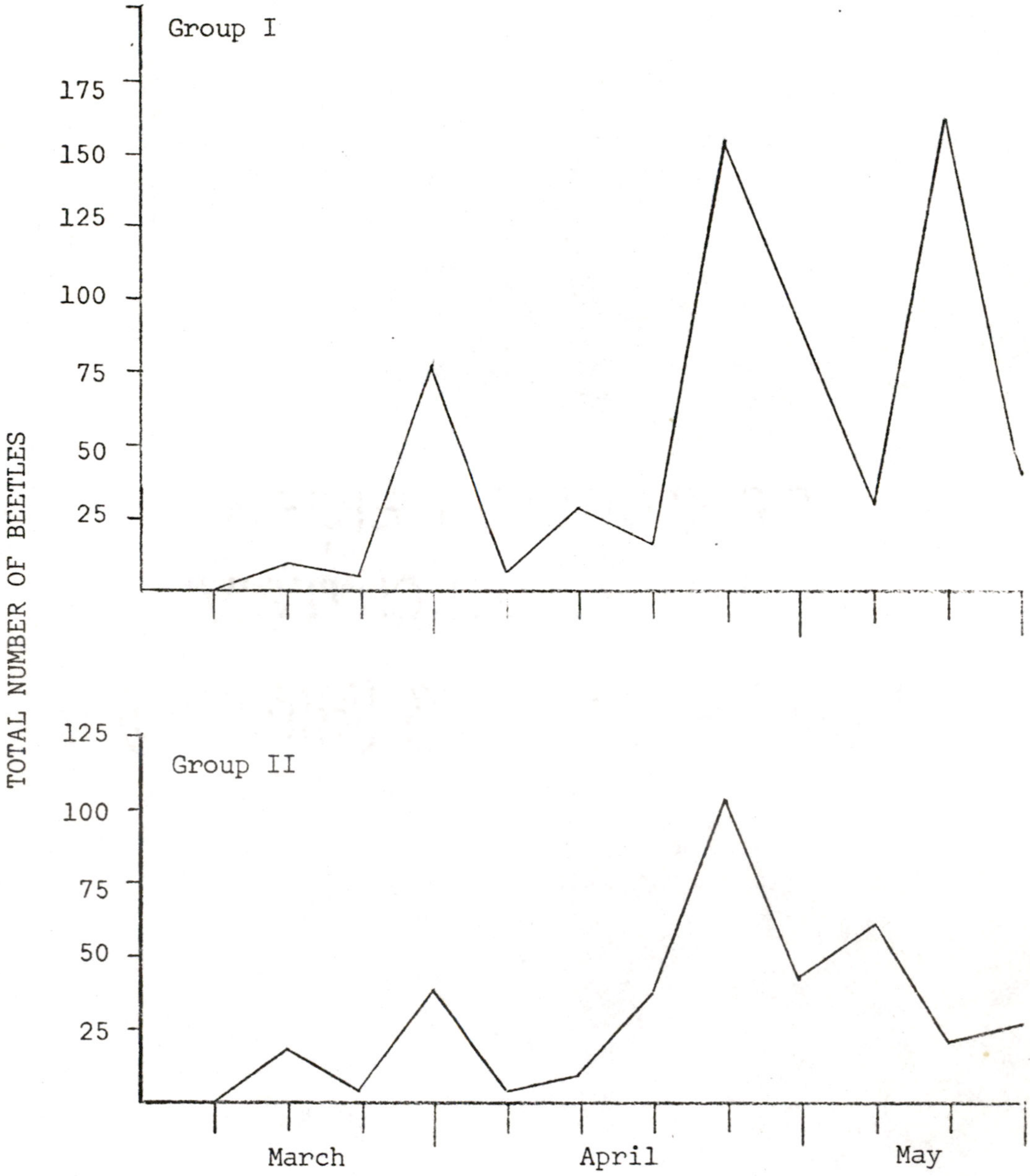

Figure 11. Occurrence of Aphodius lividus in bovine manure samples in Group I, II during March through May.

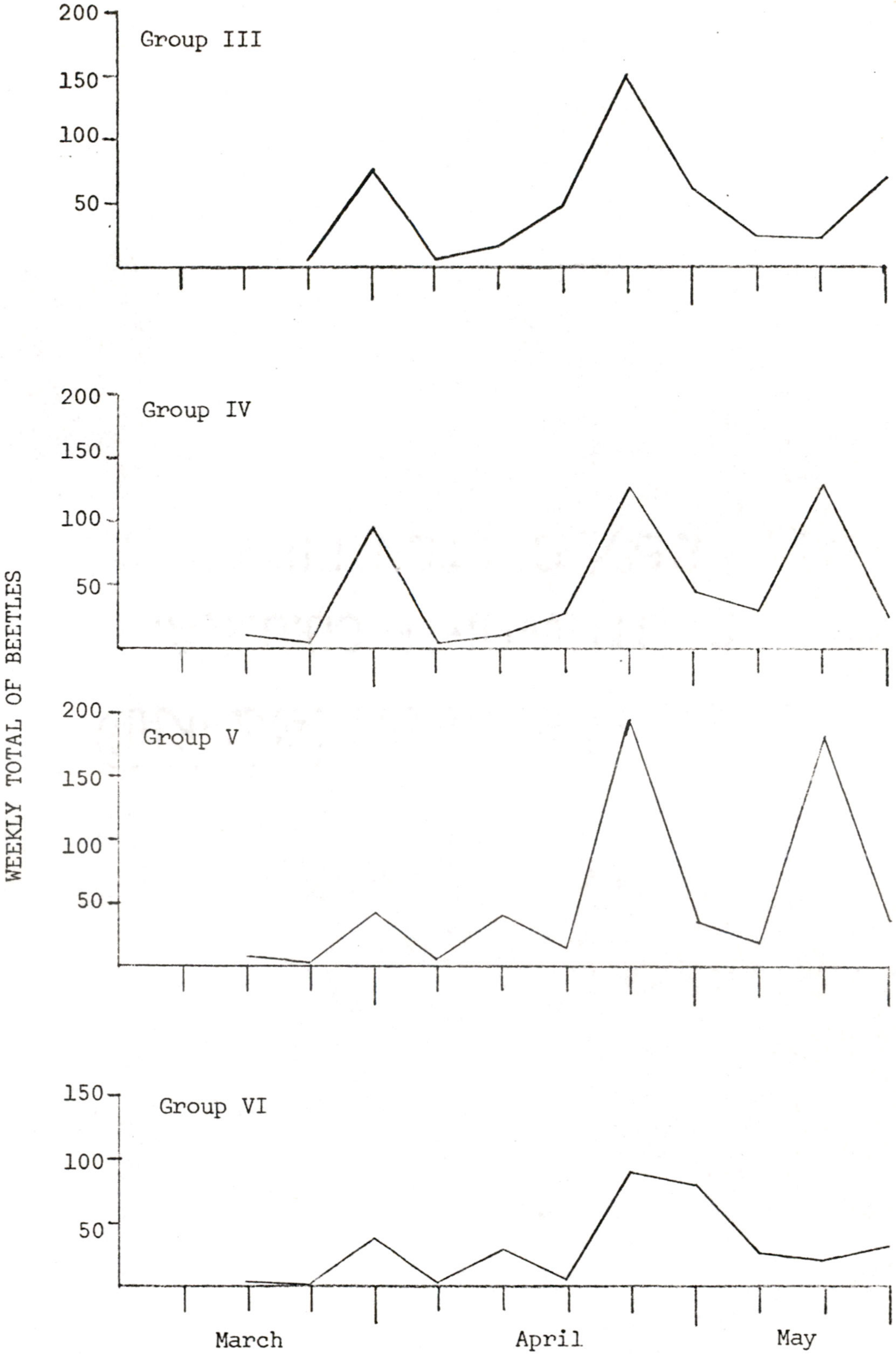

Figure 12. Occurrence of Aphodius lividus in bovine manure samples in Group III, IV, V, VI during March through May.

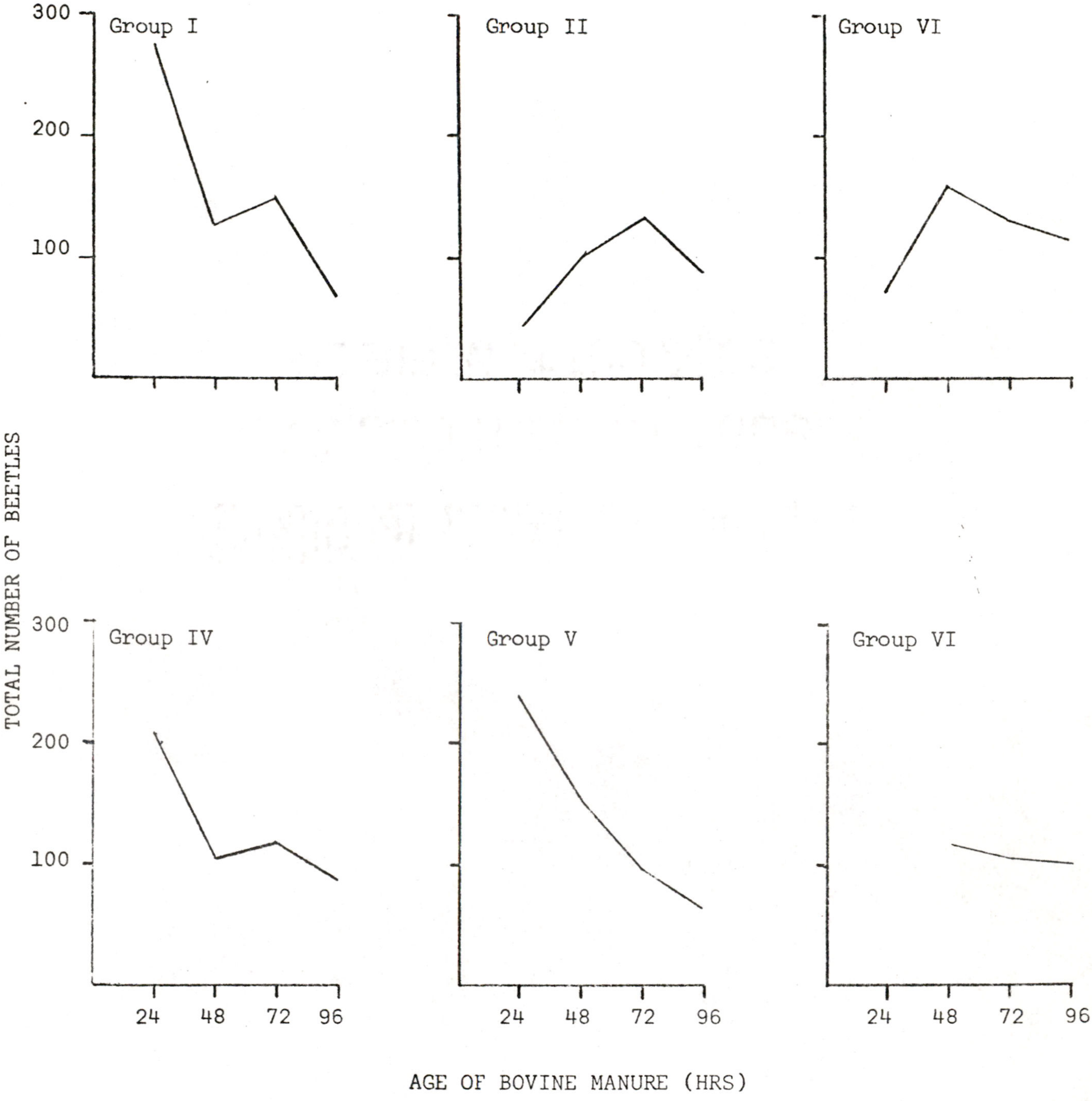

Figure 13. Succession of Aphodius lividus in bovine manure samples in Groups I-VI with four ages of manure.

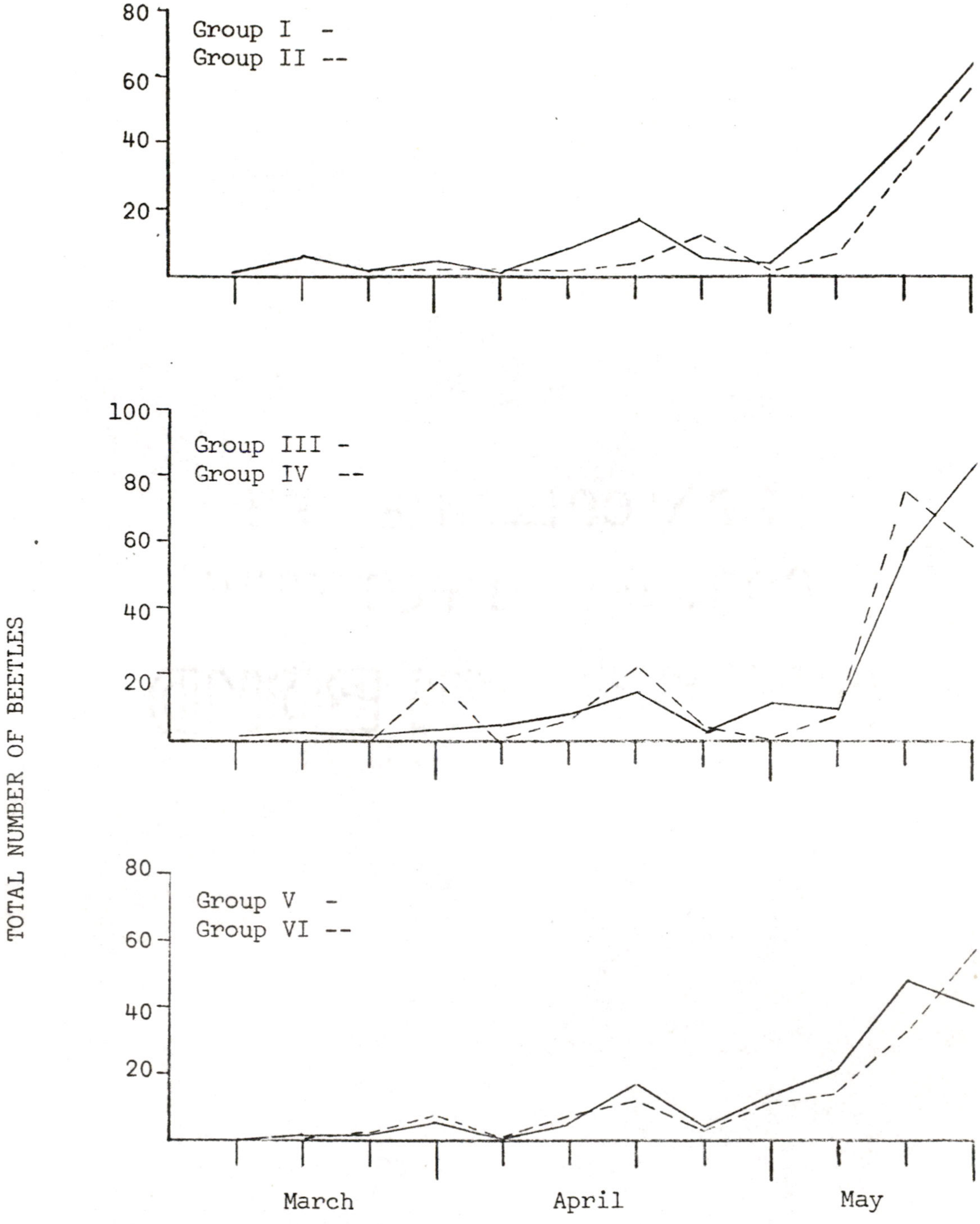

Figure 14. Occurrence of Aphodius haemorrhoidalis in bovine manure samples in Groups I-VI during March through May.

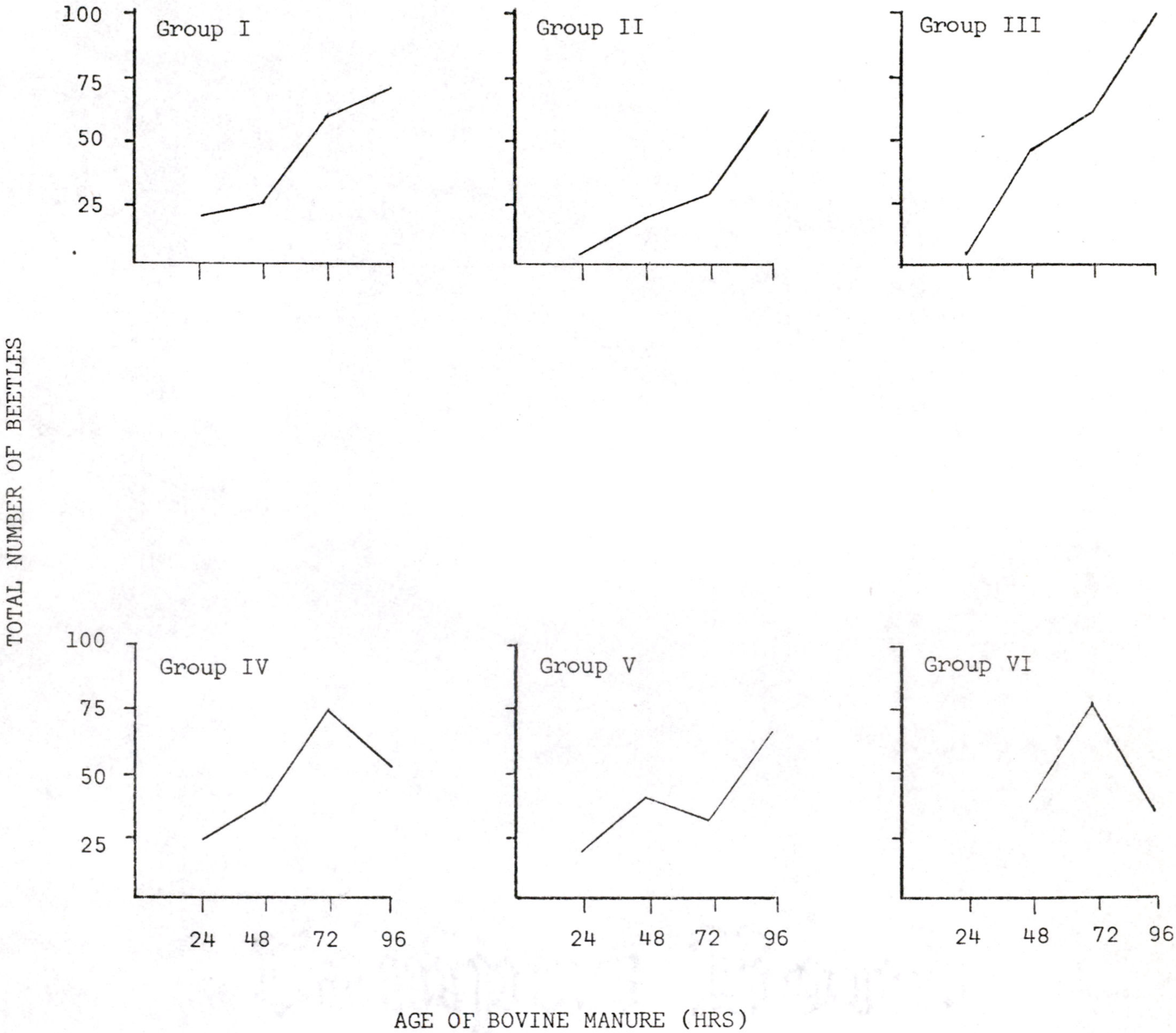

Figure 15. Succession of Aphodius haemorrhoidalis in bovine manure samples in Groups I-VI with four ages of manure.

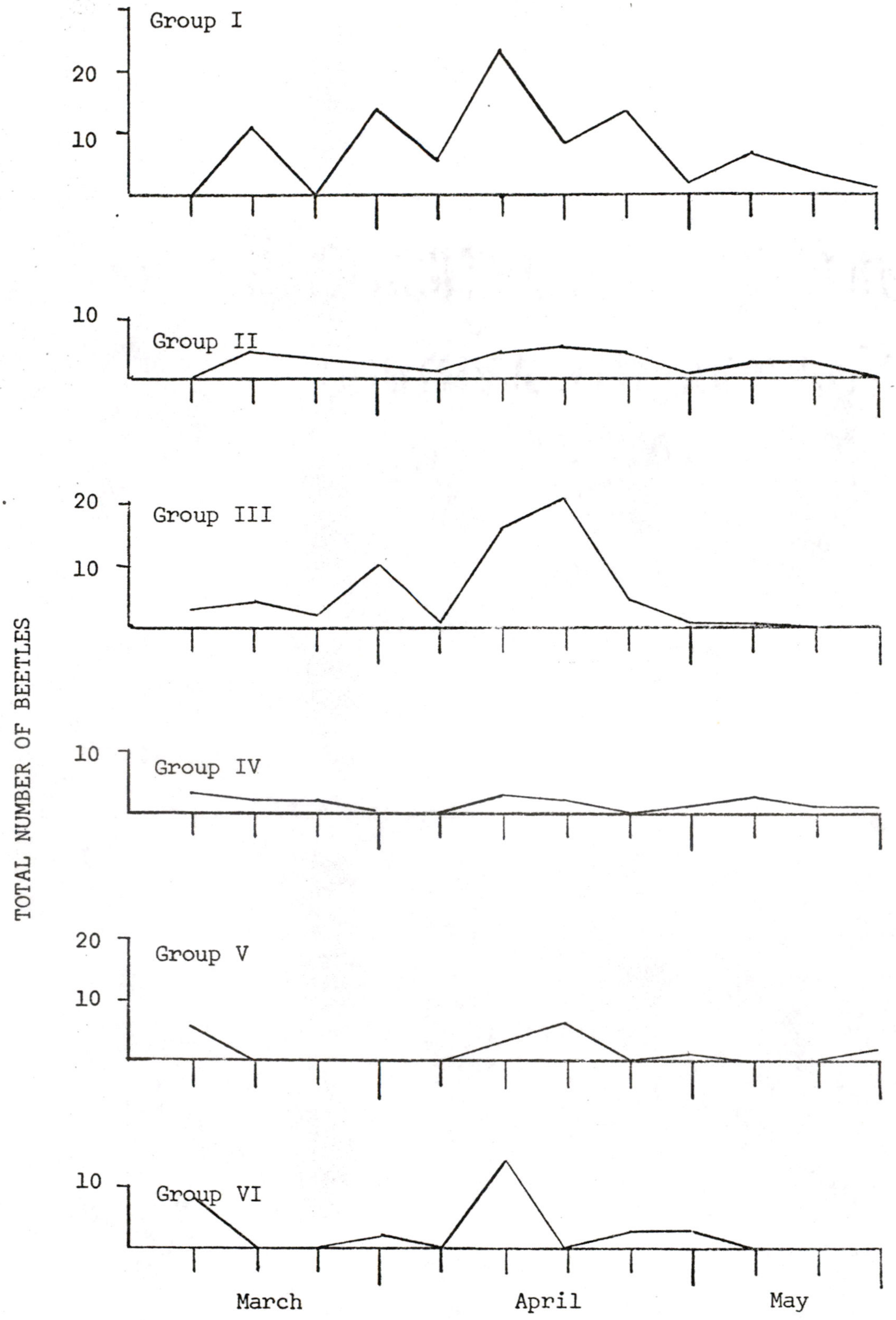

Figure 16. Occurrence of <u>Aphodius ruricola</u> in bovine manure samples in Groups I-VI during March through May.

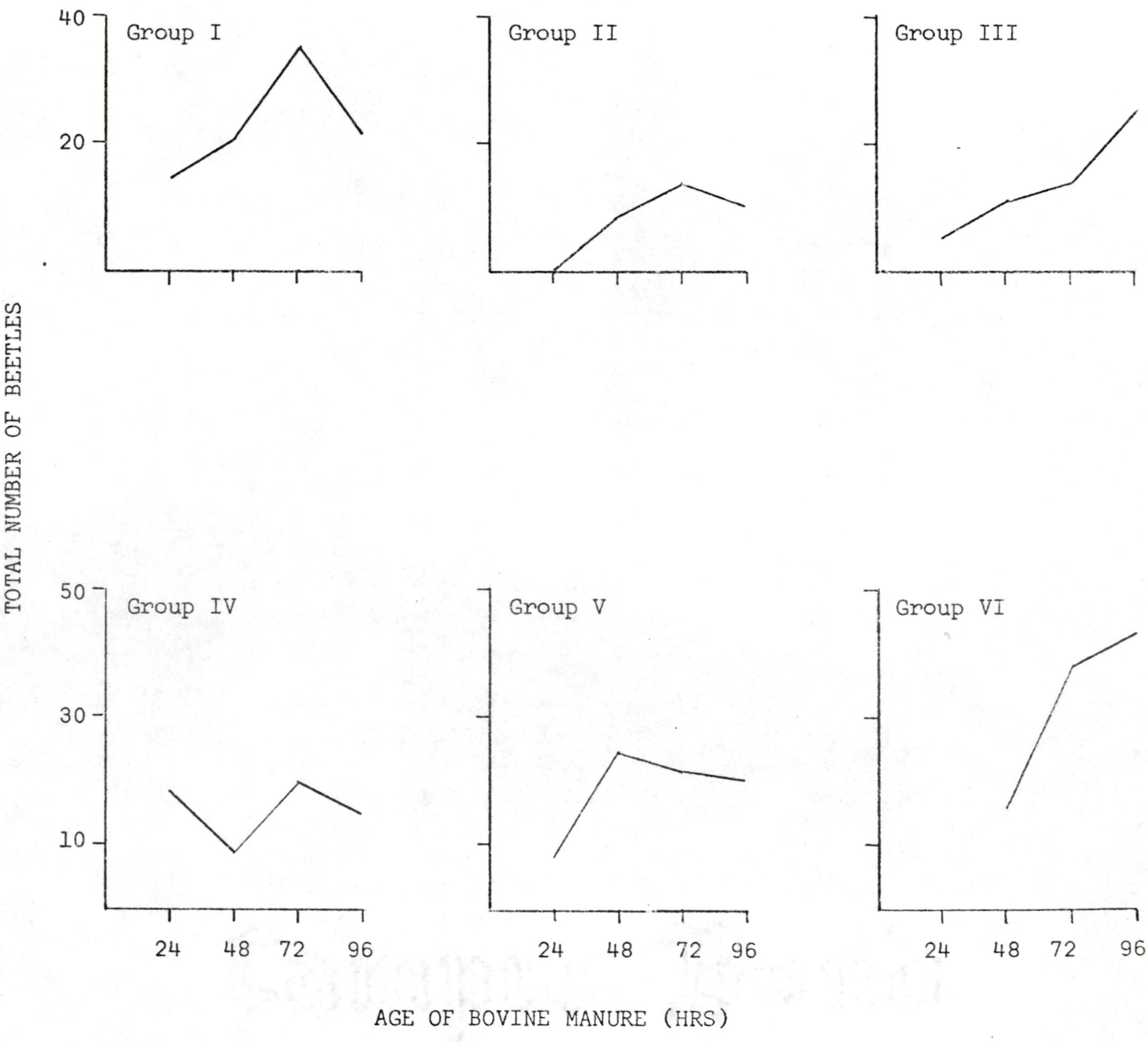

Figure 17. Succession of Aphodius ruricola in bovine manure samples in Groups I-VI with four ages of manure.

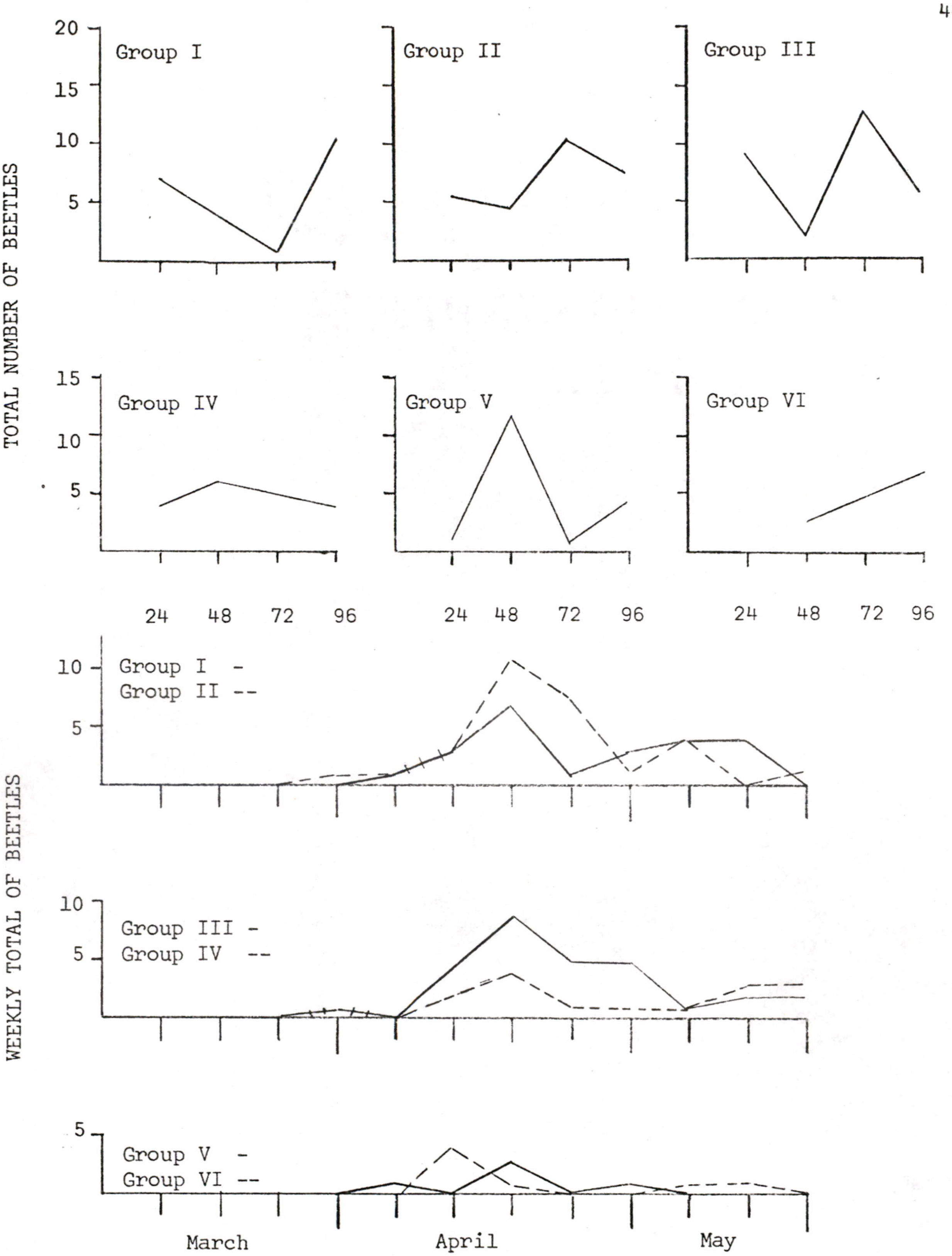

Figure 18. Total abundance of Onthophagus pennsylvanicus in bovine manure samples in Groups I-VI during March through May and with age of sample.

APPENDIX B: Hydrophilidae

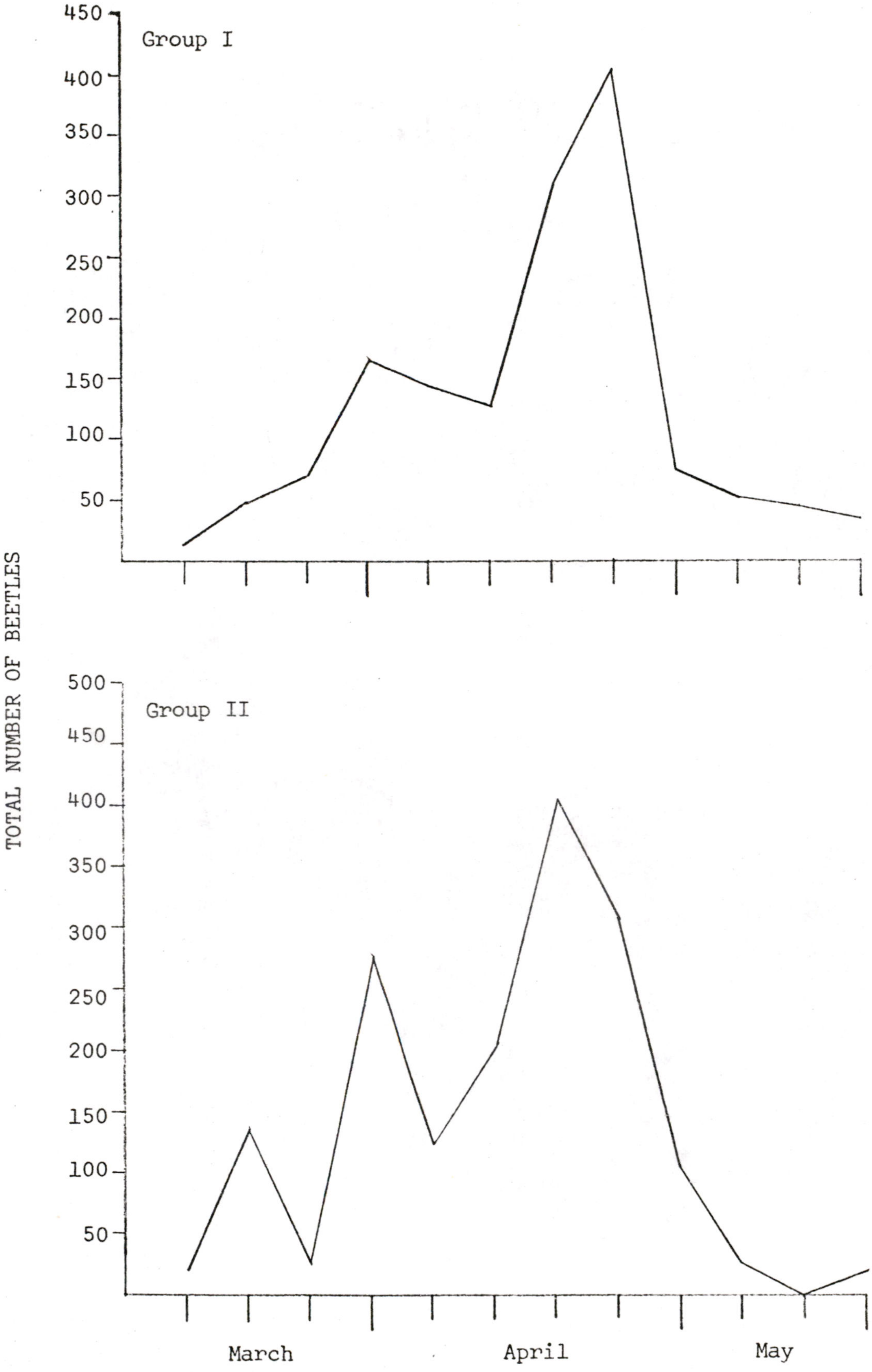

Figure 19. Occurrence of Cercyon sp. A in bovine manure samples in in Groups I, II during March through May.

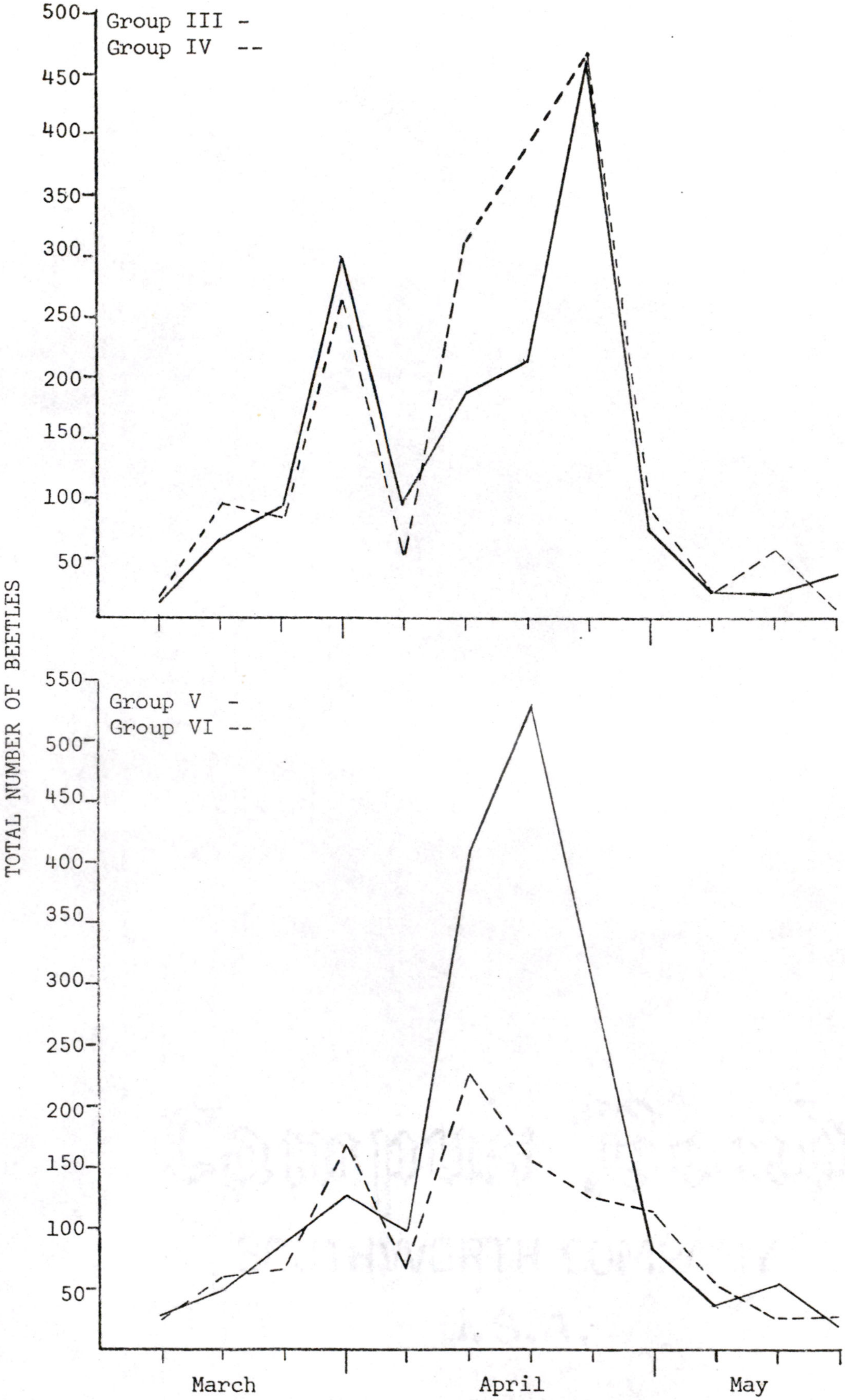

Figure 20. Occurrence of Cercyon sp. A in bovine manure samples in Groups III, IV, V, VI during March through May.

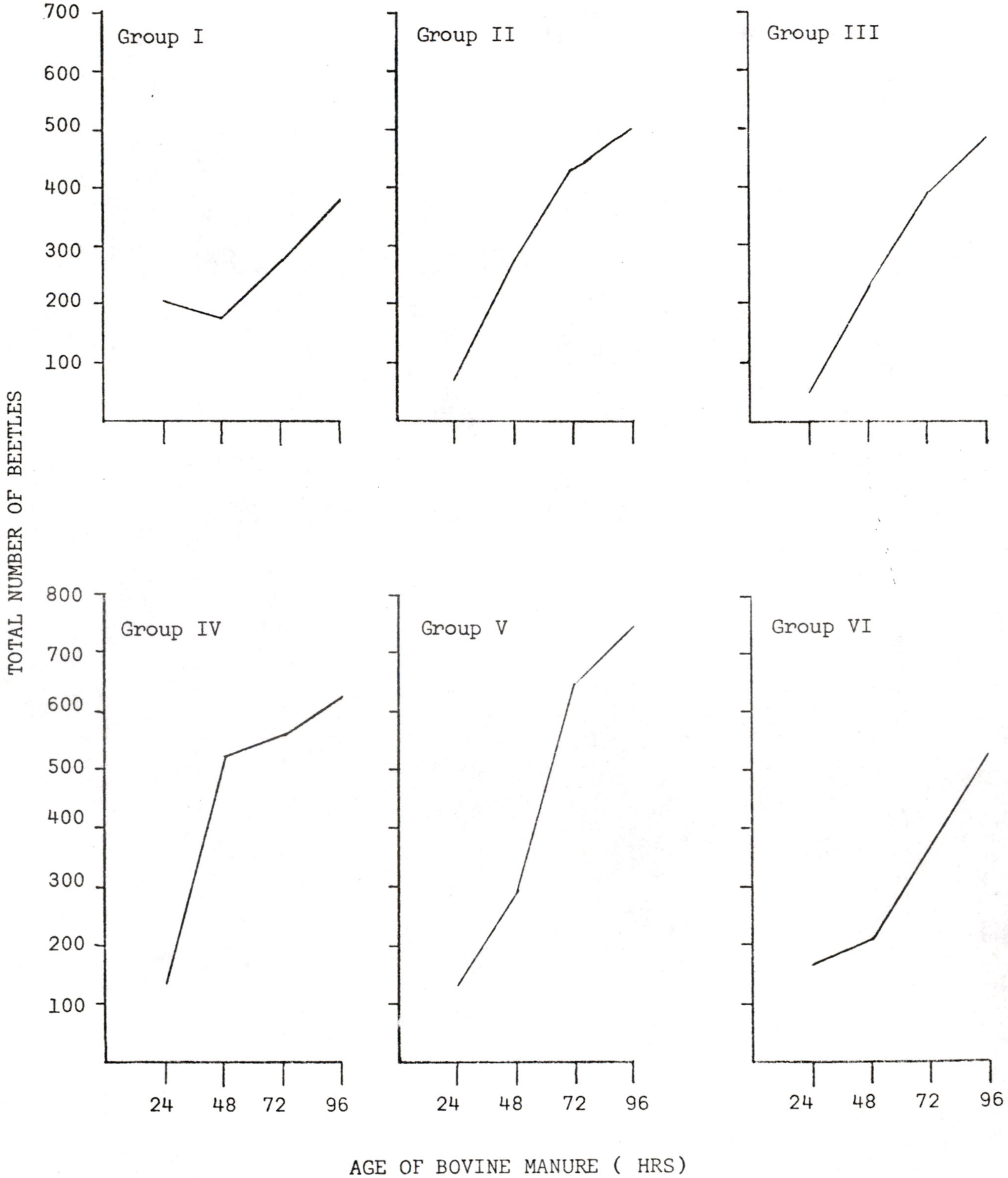

Figure 21. Succession of Cercyon sp. A in bovine manure samples in Groups I-VI with four ages of manure.

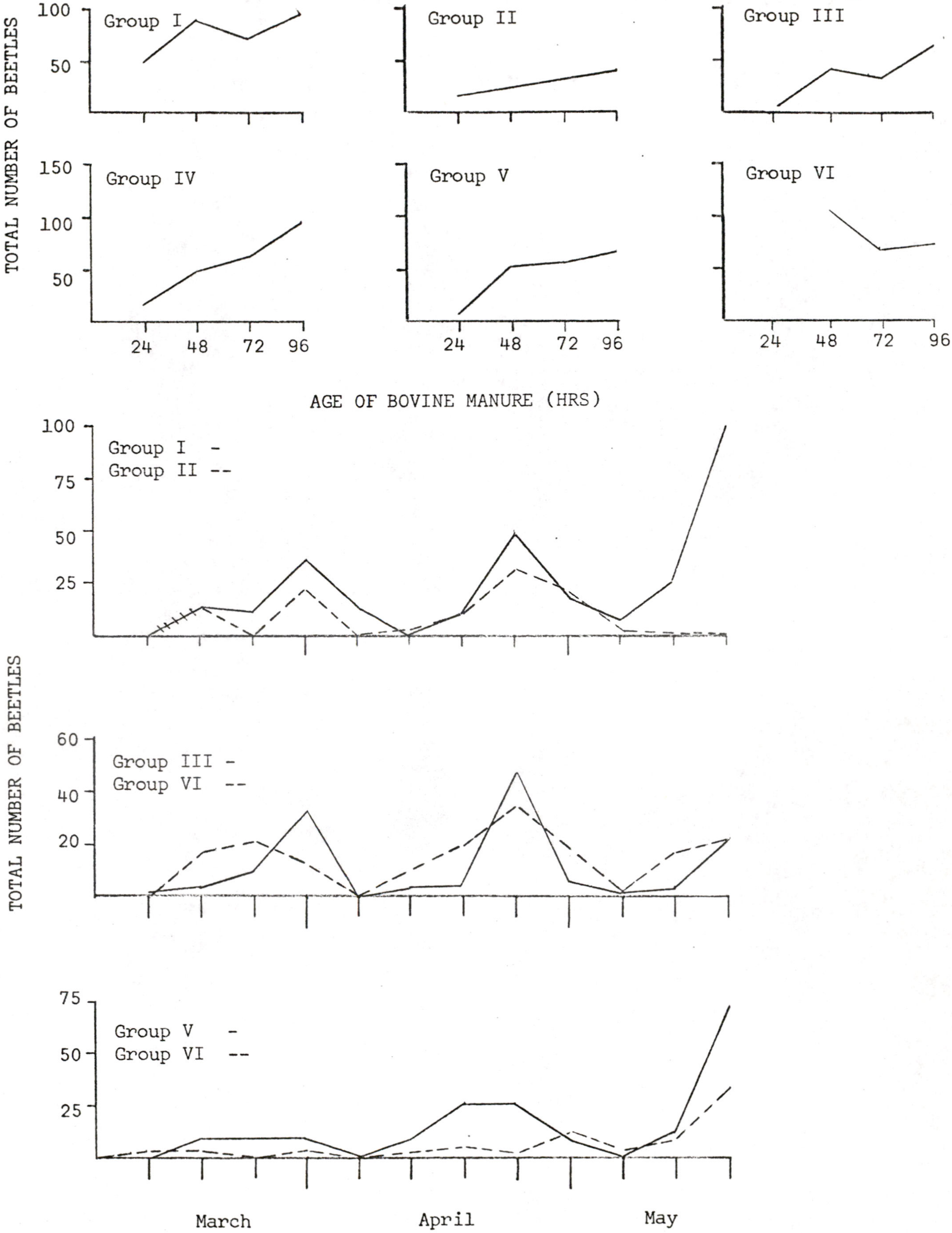

Figure 22. Total abundance of <u>Cercyon</u> sp. B in bovine manure samples in Groups I-VI during March through May and with age of sample.

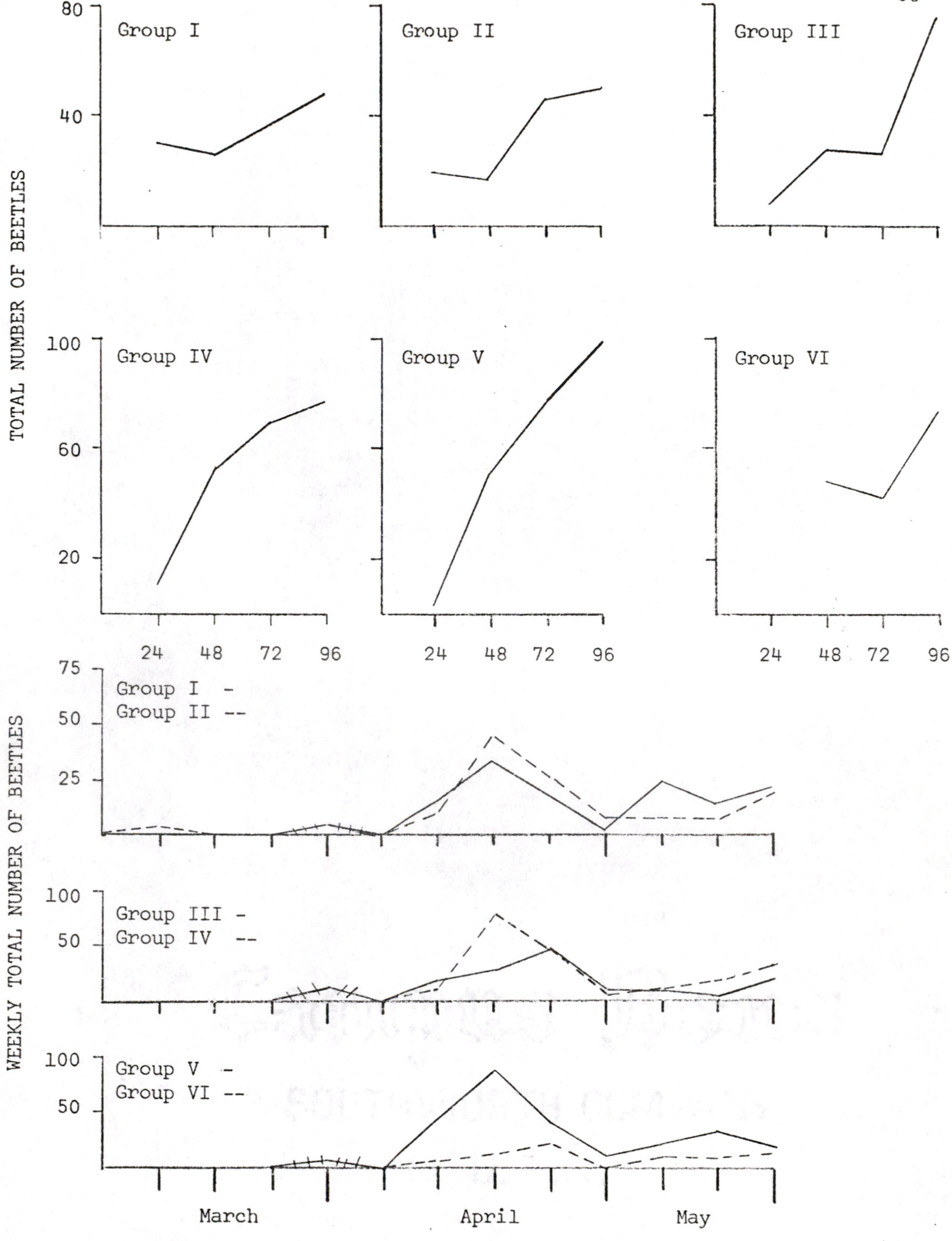

Figure 23. Total abundance of Sphaeridium scarabaeoides in bovine manure samples in Groups I-VI during March through May and with age of sample.

APPENDIX C: Staphylinidae

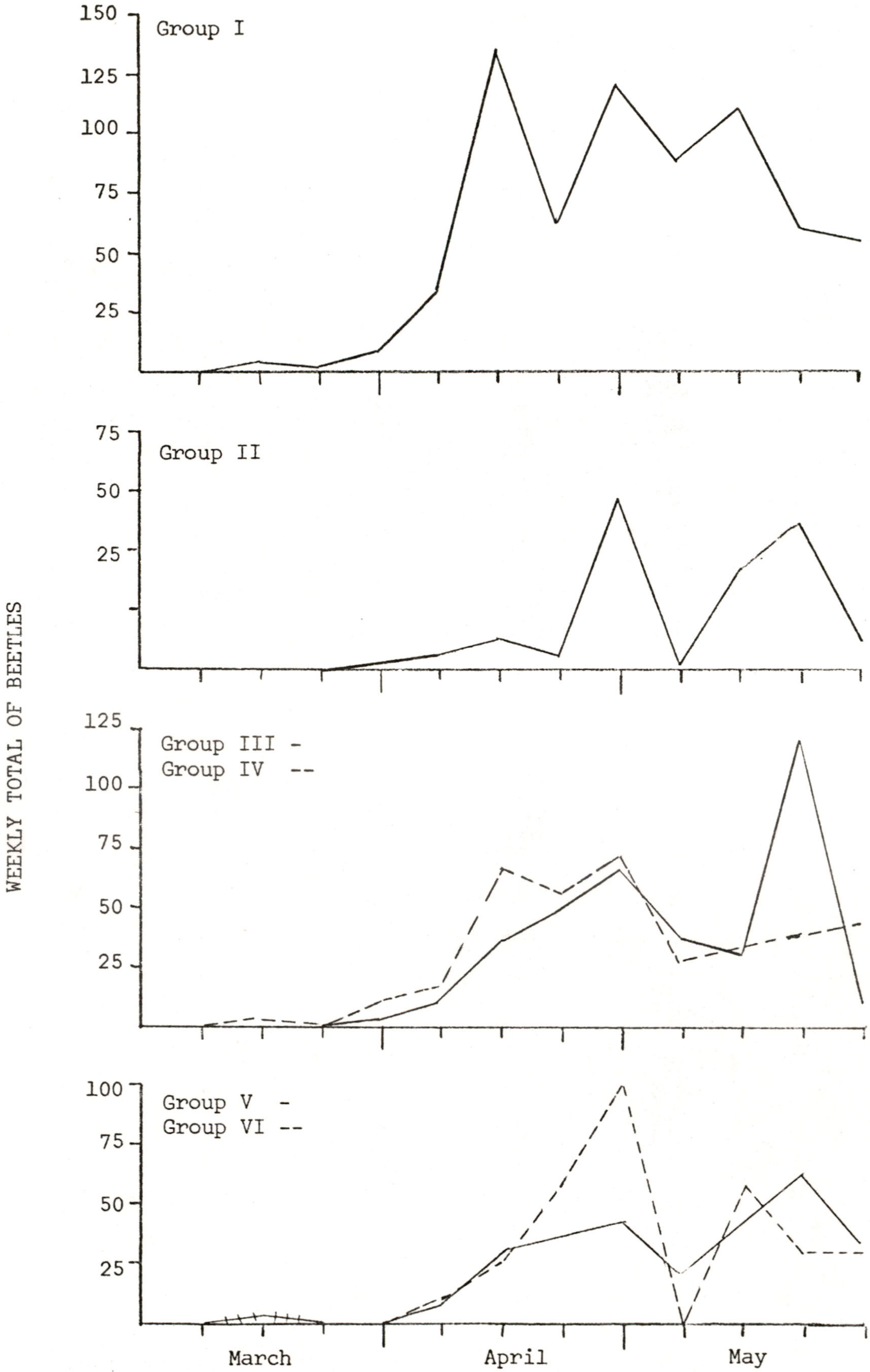

Figure 24. Occurrence of Platystethus americanus in bovine manure samples in Groups I-VI during March through May.

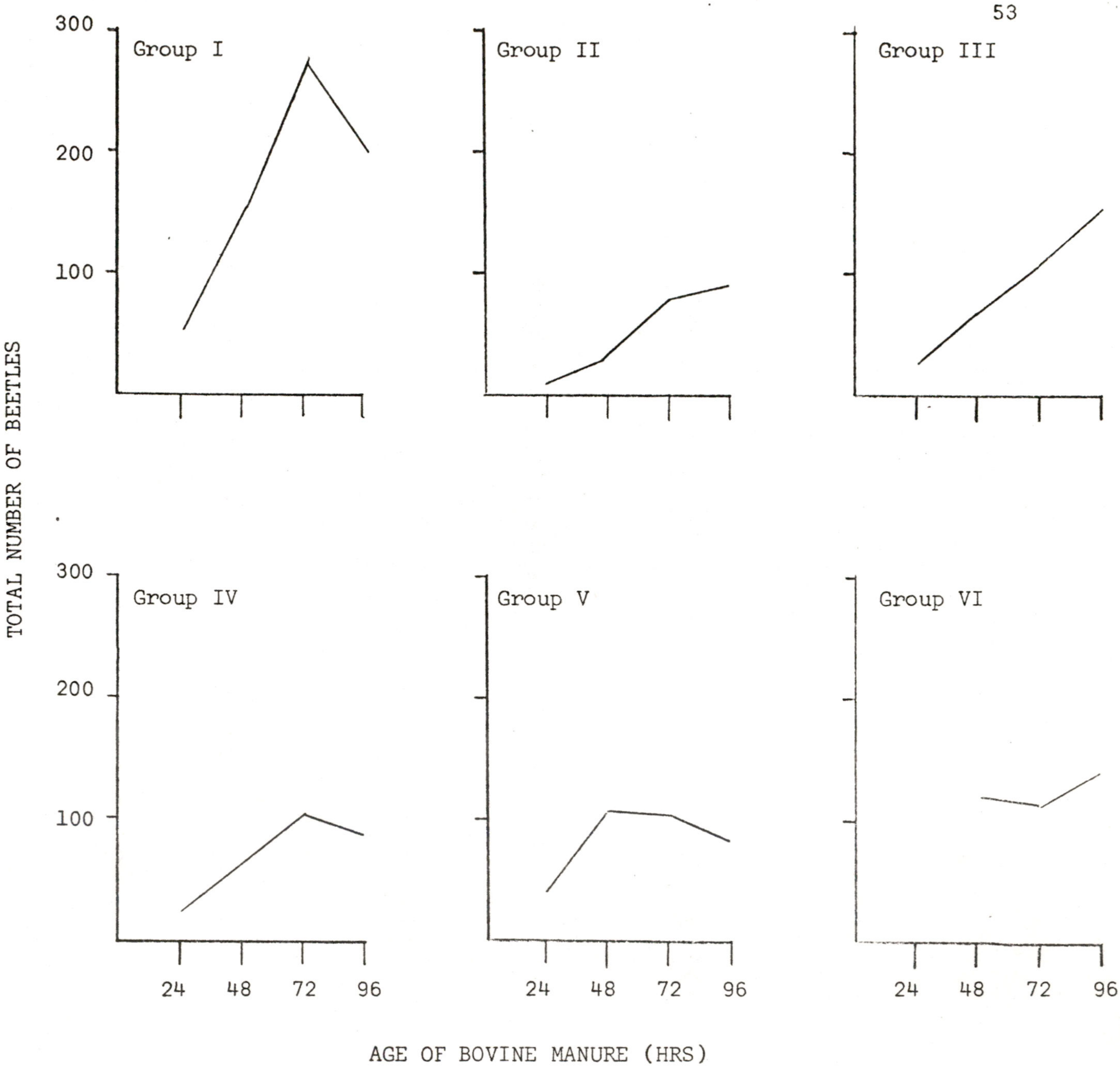

Figure 25. Succession of Platystethus americanus in bovine manure samples in Groups I-VI with four ages of manure.

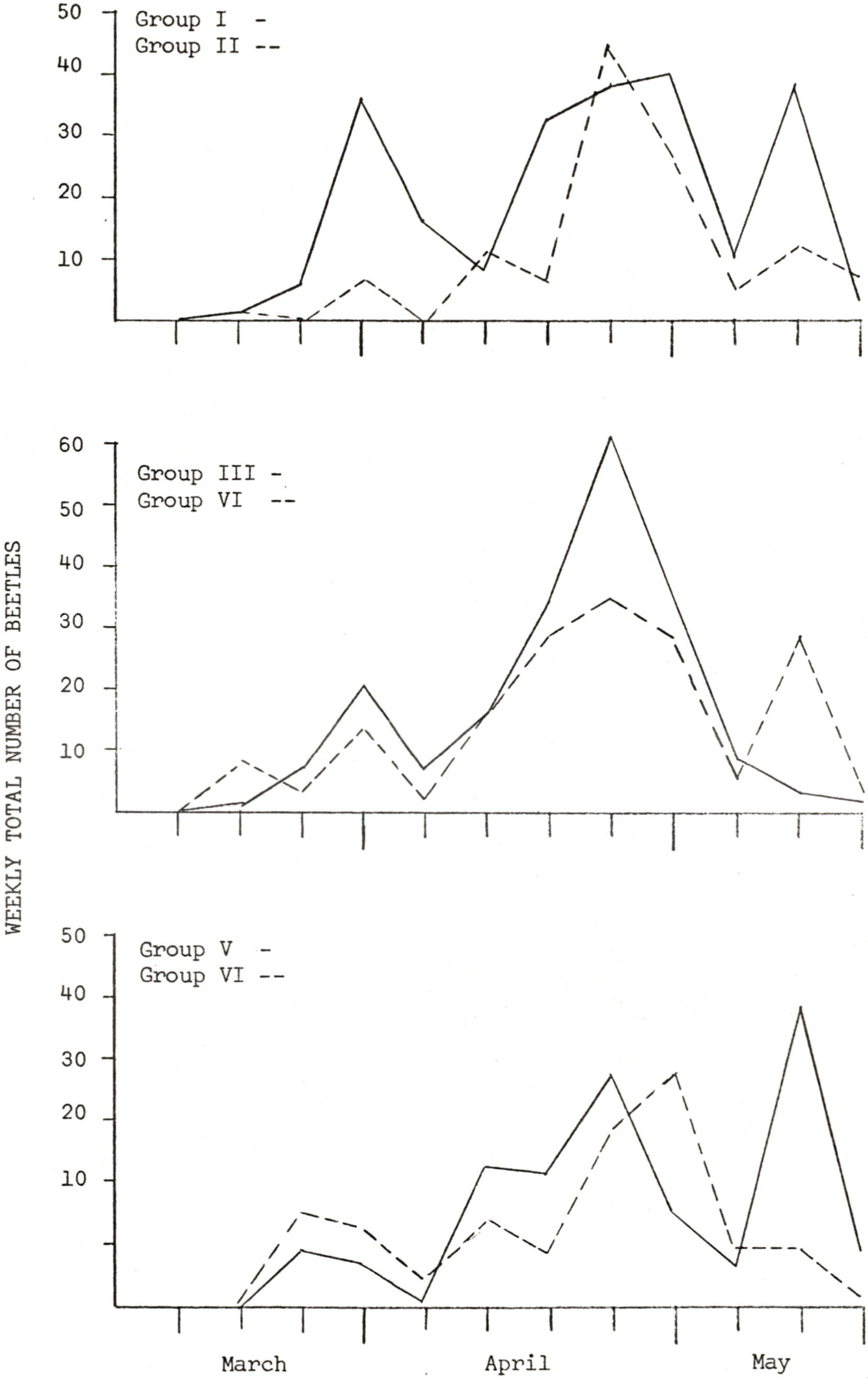

Figure 26. Occurrence of Aleocharinae A in bovine manure samples in Groups I-VI during March through May.

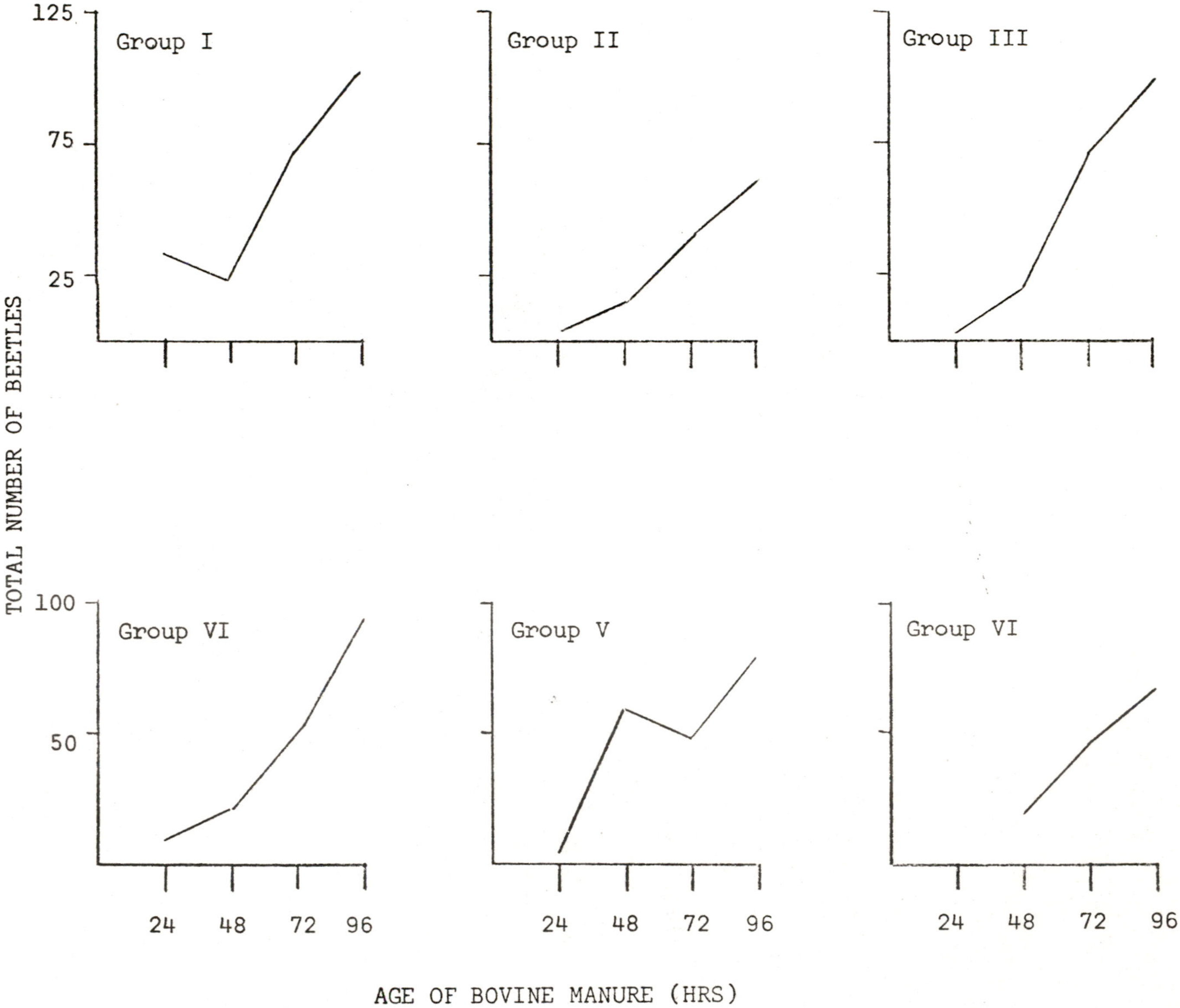

Figure 27. Succession of Aleocharinae A in bovine manure samples in Groups I-VI with four ages of manure.

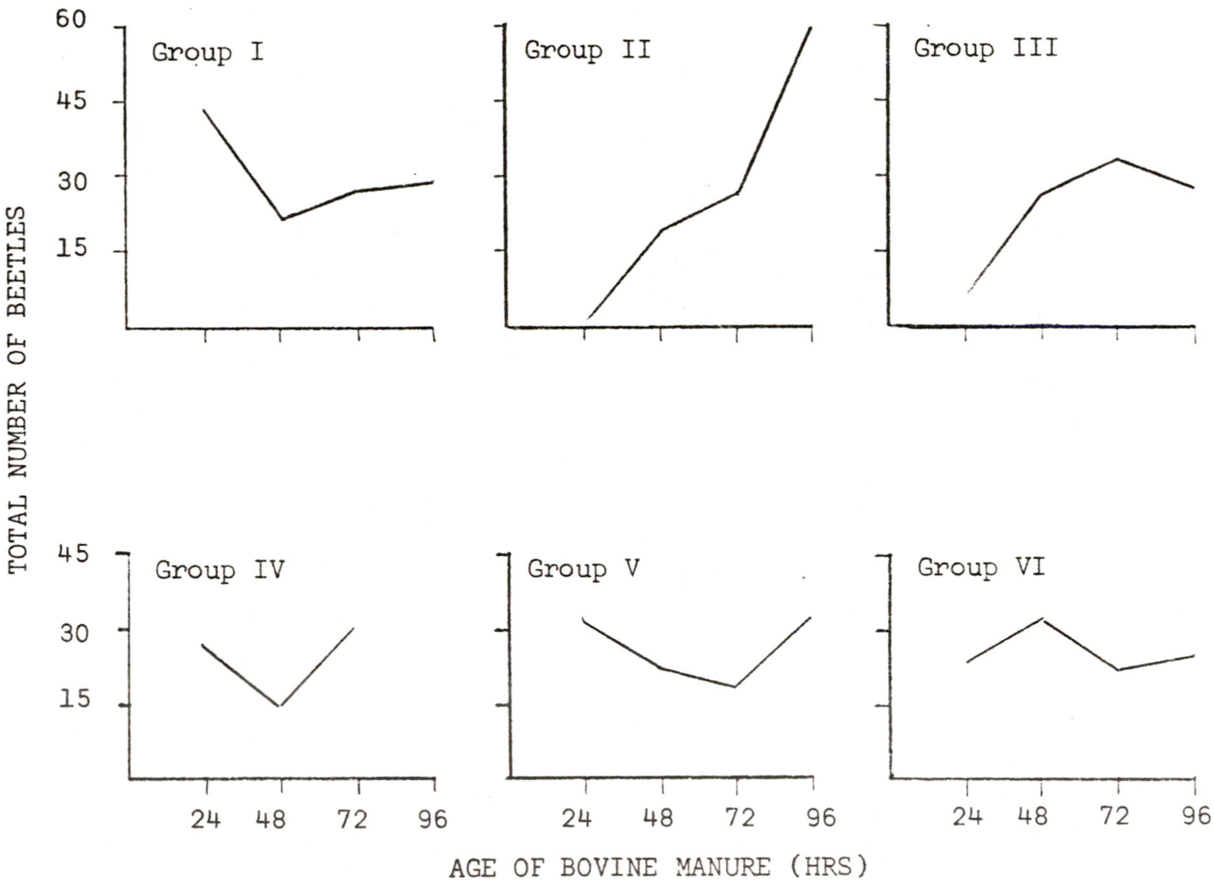

Figure 28. Succession of Oxytelus sp. in bovine manure samples in Groups I-VI with age of sample.

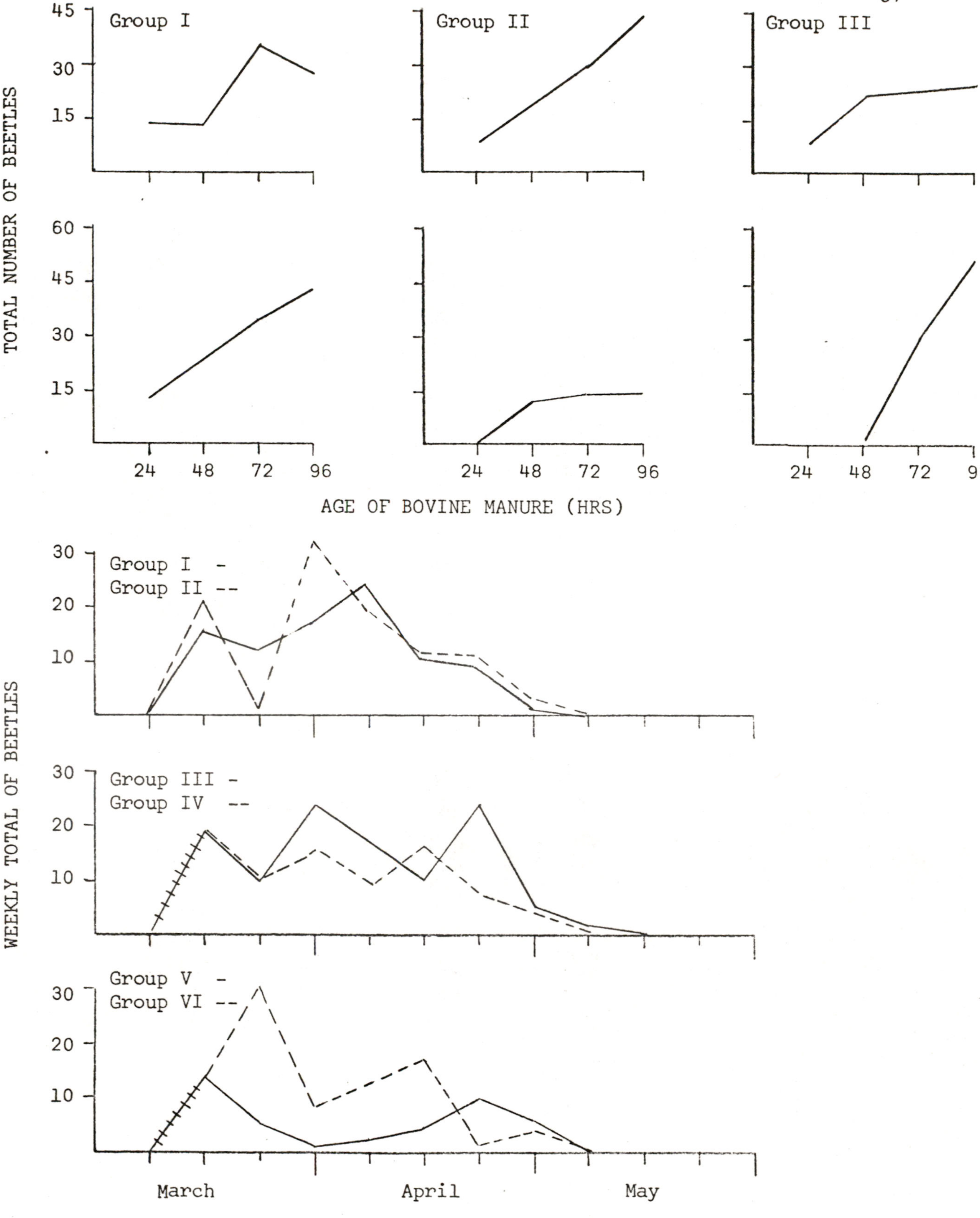

Figure 29. Total abundance of Tachinus axillaris in bovine manure samples in Groups I-VI during March through May and with age of sample.

APPENDIX D: Histeridae

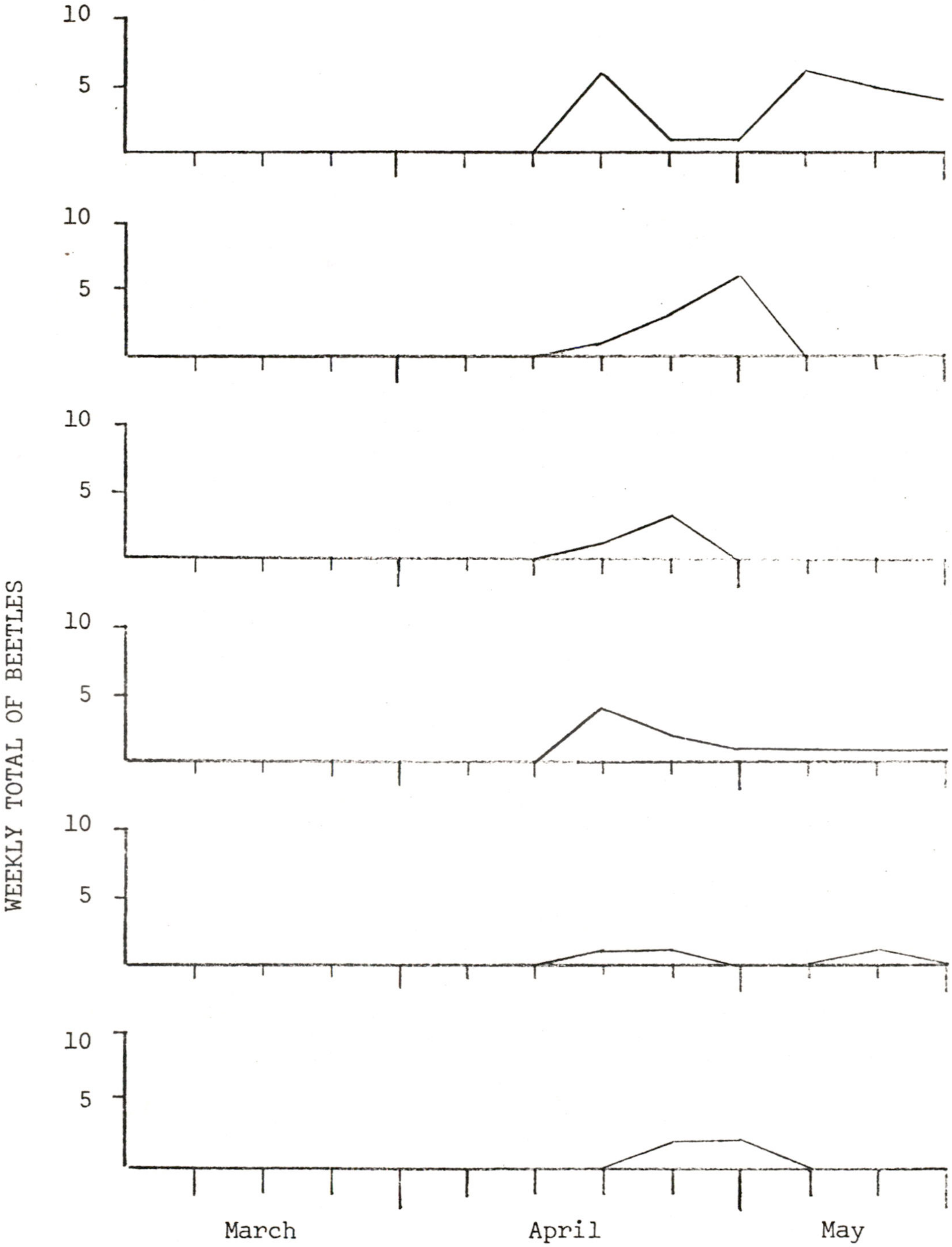

Figure 30. Occurrence of Hister abbreviatus in bovine manure samples in Groups I-VI with four ages of manure.