ENVIRONMENTAL MONITORING REPORTS

from the

1982 Maine Cooperative

Spruce Budworm Suppression Project

Maine Forest Service
DEPARTMENT OF CONSERVATION
Augusta, Maine 04333

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JOSEPH E. BRENNAN
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RICHARD B. ANDERSON
COMMISSIONER

August 15, 1983

Dear Reader:

Once again, I am pleased to report that the environmental research conducted in conjunction with the 1982 Spruce Budworm Suppression Project supported the conclusions of the Programmatic Environmental Impact Statement and the 1982 Environmental Assessment. The reports in this document have helped the Maine Forest Service to further understand the environmental impacts of spraying and to reduce even further any adverse effects. In 1983, we began using Matacil as our principal chemical insecticide and increased our use of Bt. Both of these actions will insure that future spray projects will have minimal environmental impact. In addition, we have begun a long-term environmental monitoring program that we hope will help us answer many questions about the long-term health of the forest ecosystem in both sprayed and unsprayed areas.

Sincerely,

Kenneth G. Stratton

Kenneth G. Stratton
Director

gdr

INTRODUCTION

During the 1982 Spruce Budworm Suppression Program, the Maine Forest Service continued the environmental monitoring and research program which has been ongoing since 1976. The studies conducted were selected by the Maine Forest Service following recommendations from the Spruce Budworm Environmental Monitoring Committee.

Two of the studies continue projects begun in previous years. The report by Gibbs et al. concludes the investigation which began in 1980 on the effects of a simulated accidental overspray on a pond ecosystem. This study, which is being continued through 1983 constitutes one of the first long-term monitoring studies of the effects of insecticides on a pond ecosystem. The second continuation study, by Hansen and Osgood, looks at the relationship between temperature at time of spraying and impact upon pollination and fruit-set of wild plants. The information gained from this study will help the Maine Forest Service to reduce the impact of spruce budworm spraying on insect pollinators.

The third study details the results of a bioassay conducted upon the two most common crayfish species in Maine. The crayfish were tested at the Peck Environmental Laboratory for their sensitivity to carbaryl and its principal breakdown product 1-Naphthol, as well as to the formulated Sevin-4-Oil tank mix. The results indicate that carbaryl spraying for budworm suppression has not had an adverse effect upon crayfish populations in Maine.

Finally, the fourth study conducted by Oliveri and Famous compares bird populations in two spruce-fir forest stands, one that has suffered severe mortality from the spruce budworm, and another that has been kept alive by spraying. The temporary increase in habitat diversity resulting from mortality of the spruce-fir overstory caused an increase in the number of birds in the moribund areas as well as a shift in bird species composition toward those adapted to mixed wood and early successional stages.

Also in 1982, a University of Maine interdisciplinary team headed by Hunter and Gibbs designed a Long-Term Environmental Monitoring Techniques Manual. During 1983,

the protocol is being tested in 22 spruce-fir forest sites. The sites include areas of various histories and budworm infestation conditions. Terrestrial, aquatic, vertebrate and invertebrate organisms will be monitored as well as stream quality, leaf processing rates and terrestrial habitat factors.

Editors Note: The 1981 compilation of Environmental Monitoring Reports indicated that "A Study of Leaf-Processing Disruption in Streams Within Spruce Budworm Suppression Project Carbaryl Spray Blocks" would be conducted in 1982. That study was conducted and will be included in the 1983 compilation of reports.

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THE EFFECTS IN 1982 ON POND MACROINVERTEBRATES FROM FOREST SPRAYING OF CARBARYL, SEVIN-4-OIL, IN 1980

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ABSTRACT

The impact of a 1980 experimental aerial application of carbaryl (Sevin-4-oil^{R}) on the macroinvertebrate fauna of woodland ponds was studied in 1982 in northern Maine. Carbaryl was applied at the rate of 840 g A.I./ha as part of the 1980 State of Maine Spruce Budworm Suppression Program. Observations were made in 1982 on the benthic populations of two ponds in a treated area and two similar ponds in an untreated area which had been studied in 1980 and 1981. Neither of the treated ponds contained detectable levels of residue in 1982 in either water or sediment.

The most severe and persistent impact on the macroinvertebrates was on the Amphipoda. In both treated ponds the numbers in the samples were reduced to $0/m^2$ following treatment in 1980 and remained at or near $0/m^2$ throughout 1980 and 1981. In 1982 the numbers of amphipoda remained at or near $0/m^2$ in Treated Pond #1 but showed indication of recovery in Treated Pond #2.

Acknowledgements

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Susan Marden, Richard Morse and Carolyn Reid provided assistance in the field and laboratory.

Introduction:

The impact of a 1980 experimental application of carbaryl (Sevin-4-Oil^{R}) on the macroinvertebrate fauna of two woodland ponds and two similar unsprayed ponds was studied in 1980 and 1981 (Gibbs et al. 1982). Carbaryl residues were still present in the sediment of one of the ponds when sampling was terminated in 1981, 16 months after treatment. Immediate significant post-spray reductions were observed in numbers of Ephemeroptera, Trichoptera and Chironomidae (Diptera) but in no case were these organisms eliminated from the ponds nor did the pattern of seasonal fluctuations in numbers differ from those in the unsprayed ponds in 1980 or 1981. However, in the Amphipoda and the Odonata, the reductions in numbers were more severe in the treated ponds and persisted in 1981.

In order to determine if this long-term (beyond the season of application) persistence of carbaryl residue or effects on the macroinvertebrate populations persisted into 1982, the ponds that had been sampled in 1980 and 1981 were sampled again in 1982.

Study Area:

The study area was in the Holeb region of northwestern Maine in Somerset and Franklin Counties. Descriptions of the study ponds, their locations and spray history, are given by Gibbs et al. (1981).

Methods:

The ponds were sampled once each month from May to October and the methods of collecting and analysing samples were those described by Gibbs et al. (1981). On each sampling date samples of water and sediment were collected for carbaryl residue analysis and quantitative samples of benthic macroinvertebrates were taken.

Results and Discussion:

Residue Analysis

Carbaryl residues were not found in either water or sediment in Treated Pond 1 or Treated Pond 2 in 1982.

It thus appears that although carbaryl residue was present in water and sediment of one of the treated ponds (Treated Pond 1) in 1981, it did not persist over the winter of 1981-1982 at levels which could be detected by our analysis (0.06 ug/1 for water and 6 ug/kg (dry weight) for sediment.

Macroinvertebrates

The long-term impact of the carbaryl application varied among groups of benthic macroinvertebrates. Normal seasonal variations in numbers occur in populations of these organisms, thus, changes as a result of insecticide application can only be detected by comparing changes in treated ponds with those occurring in untreated ponds. The 1980 and 1981 observations on these ponds as reported by Gibbs et al. (1981) and Gibbs et al. (1982) are included for comparative purposes.

Amphipoda

Numbers of Hyallela azteca and Gammarus lacustris in the 1980, 1981 and and 1982 samples are shown in Table 1. The Amphipoda were the most severely affected group in the 1980 study and the effect persisted into 1981 and 1982. Numbers of H. azteca in both treated ponds were reduced to 0 or near $0/m^2$ following spray application and remained at that level throughout 1980 and 1981. Only in the October, 1981 sample from Treated Pond 2 was there an indication that the numbers of H. azteca might be recovering. The species continued to be present in Treated Pond 2 throughout 1982 although the numbers were not at the pretreatment level. H. azteca continued to be virtually absent from Treated Pond 1 during 1982 although it was consistently

present in the two untreated ponds.

Gammarus lacustris was present in Treated Pond 1 and Untreated Pond 1 before spray application in 1980. In Treated Pond 1 the numbers in the post-treatment samples remained at or near $0/m^2$ throughout 1980 and 1981. They continued to be absent from the samples from Treated Pond 1 in 1982. Characteristic seasonal increases were seen in Untreated Pond 1 in 1980, 1981 and 1982.

Thus, in the third season following spray application, there are indications that the population of H. azteca is beginning to recover in Treated Pond 2 but not in Treated Pond 1. There is no indication that the G. lacustris population is recovering in Treated Pond 1. A discussion of the sensitivity of amphipods to carbaryl and their delay in repopulating ponds from which they have been eliminated was included by Gibbs et al. (1982).

Ephemeroptera

The numbers of Ephemeroptera in the 1980, 1981 and 1982 samples are shown in Table 2. Although significant reductions of Ephemeroptera were reported immediately post-spray in 1980, none of the reported genera were eliminated from the ponds. Numbers were low in the treated ponds during the remainder of 1980 but they were also low in the untreated ponds. Numbers of Ephemeroptera increased in 1981 in Treated Pond 1 and again in 1982. An important component of this increase was the genus Leptophlebia. The ecological function of this mayfly is that of breaking down dead plant material or a "shedder" which is similar to the role filled by the Amphipoda. Whether the increase in Ephemeroptera is due to their replacing the Amphipoda in this functional role or whether this is simply part of a multi-year cycle is not known. In favor of the latter hypothesis is the fact that the increase also occurred in Untreated Pond 1.

Odonata

The numbers of Odonata in the 1980, 1981 and 1982 samples are shown in Table 4. Although the pretreatment genera and numbers of Odonata in Treated Pond 1 were similar to those in Untreated Pond 1, the numbers decreased during 1980 and remained at low levels during most of 1981. In Untreated Pond 1 they showed mid season increases in numbers in both 1980 and 1981. This was suggested (Gibbs et al. 1981) to have been due to the lack of prey organisms available and reflected in the relatively low total numbers of macroinvertebrates present in Treated Pond 1 as compared to Untreated Pond 1 (Table). In 1982 there was an increase in both the numbers of Odonata and the total numbers of macroinvertebrates present. In 1982 there was also a substantial increase in the numbers of Odonata present in Untreated Pond 1. Thus it is difficult to separate the increase of Odonata in Treated Pond 1 associated with recovery from carbaryl treatments from a normal multi-year fluctuation in numbers.

Trichoptera

The numbers of Trichoptera in the 1980, 1981 and 1982 samples are shown in Table 6. Although dead larvae were found in the treated ponds following spray application and there was a significant immediate decrease in numbers, there is no evidence that genera were eliminated or numbers decreased in 1981 or 1982.

Diptera

The numbers of Chironomidae and Chaoborus sp. in the 1980, 1981 and 1982 samples are shown in Table 4. There is no evidence of either a short or long term impact of carbaryl on the Chironomidae. Chaoborus was a genus that appeared unaffected by the spray application in Treated Pond 1. No explanation is given for its disappearance from the samples in 1982.

Table 1. Numbers of Amphipoda per square meter in the study ponds in 1980, 1981 and 1982.

	Pre-Treatment	Post-Treatment																	
		1980						1981						1982					
	5/31	6/12	6/19	7/8	8/7	9/9	10/23	5/13	6/17	7/8	8/6	9/14	10/9	5/21	6/25	7/22	8/24	9/27	10/28
Hyelella azteca																			
Treated Pond 1	121	0	0	0	0	0	2	1	0	5	0	0	0	0	0	0	0	2	1
Treated Pond 2	1326	25	1	1	0	0	9	1	0	5	0	4	112	41	70	53	43	25	22
Untreated Pond 1	161	81	396	1078	2980	1004	762	976	463	1020	1251	362	215	12	214	112	84	95	3
Untreated Pond 2	43	5	58	38	84	181	372	200	237	103	117	137	216	304	591	224	326	492	463
Gammarus lacustris																			
Treated Pond 1	1	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0
Untreated Pond 1	0	22	372	429	585	207	65	11	187	243	175	135	88	11	9	283	163	54	18

Table 2. Numbers of Ephemeroptera per square meter in the study ponds in 1980, 1981 and 1982.

	Pre-Treatment	Post Treatment																	
		1980						1981						1982					
	5/31	6/12	6/19	7/8	8/7	9/9	10/23	5/13	6/17	7/8	8/6	9/14	10/9	5/21	6/25	7/22	8/24	9/27	10/28
Total Ephemeroptera																			
Treated Pond 1	12	1	4	0	2	5	59	48	2	44	0	138	404	88	28	117	186	1153	248
Treated Pond 2	637	81	27	42	94	20	147	326	97	84	59	21	142	200	26	171	26	330	426
Untreated Pond 1	6	13	2	0	7	3	14	24	22	10	7	16	144	79	82	22	165	307	300
Untreated Pond 2	25	14	20	4	6	1	19	37	21	2	6	2	5	200	60	4	2	3	2
Callibaetis sp.																			
Treated Pond 1	5	0	0	0	1	4	8	15	0	43	0	29	11	10	3	109	45	112	36
Siphlonurus sp.																			
Treated Pond 2	507	69	20	39	3	0	0	200	84	61	2	0	0	132	13	21	0	0	0
Untreated Pond 2	17	12	20	3	0	0	0	14	15	1	1	0	0	156	1	1	0	0	0
Leptophlebia sp.																			
Treated Pond 1	0	0	0	1	0	0	51	35	0	0	0	106	287	73	0	1	137	1014	208
Treated Pond 2	63	9	1	0	0	0	14	104	10	0	0	1	8	22	0	0	0	24	46
Untreated Pond 1	0	0	0	0	0	0	9	0	0	0	0	15	152	0	0	4	144	293	272
Untreated Pond 2	2	0	0	0	0	0	0	8	2	0	0	0	0	28	16	1	0	0	0
Caenis sp.																			
Treated Pond 1	6	1	0	0	1	0	0	0	1	1	0	1	6	5	25	6	4	27	4
Untreated Pond 1	5	12	1	0	4	0	3	20	21	3	3	0	92	68	74	3	20	14	28

Table 3. Numbers of Odonata per square meter in the study ponds in 1980, 1981 and 1982.

	Pre-Treatment	Post-Treatment																	
		1980						1981						1982					
	5/31	6/12	6/19	7/8	8/7	9/9	10/23	5/13	6/17	7/8	8/6	9/14	10/9	5/21	6/25	7/22	8/24	8/27	10/28
Lestidae																			
Lestes																			
Treated Pond 1	0	0	2	0	0	0	0	0	0	0	0	1	3	0	12	2	0	0	0
Untreated Pond 1	0	2	5	11	3	0	0	0	25	6	0	0	0	1	70	20	0	0	0
Coenagrionidae																			
Enallagma																			
Treated Pond 1	4	0	0	0	0	0	0	0	2	0	0	0	13	3	0	1	4	3	1
Untreated Pond 1	5	1	4	2	3	6	2	4	0	1	8	8	22	21	8	2	0	1	7
Nehalennia																			
Treated Pond 1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	4	1	2	0
Untreated Pond 1	0	0	1	0	0	0	0	0	0	0	0	0	0	5	25	12	4	50	24
Gomphidae																			
Gomphus																			
Treated Pond 1	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0
Untreated Pond	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Aeshnidae																			
Boyrria																			
Treated Pond 1	1	0	0	1	1	0	0	0	0	0	0	2	1	0	1	2	0	1	2
Untreated Pond 1	1	1	6	5	41	10	2	4	6	12	14	8	19	10	28	51	10	4	6
Aeshna																			
Treated Pond 1	1	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	2	0	0
Untreated Pond 1	1	0	1	9	10	6	1	2	0	5	7	7	0	2	7	58	33	18	9

Table 3. (Continued).

	Pre-Treatment	Post Treatment																	
		1980						1981						1982					
	5/31	6/12	6/19	7/8	8/7	9/9	10/23	5/13	6/17	7/8	8/6	9/14	10/9	5/21	6/25	7/22	8/24	9/27	10/28
Corduliidae																			
Cordulia																			
Treated Pond 1	7	2	0	0	0	2	1	0	0	0	0	2	0	0	3	0	0	8	0
Untreated Pond 1	0	2	15	2	14	2	3	3	3	11	6	10	14	6	0	0	1	16	50
Libellulidae																			
Libellula																			
Treated Pond 1	4	2	7	2	4	1	0	4	2	4	1	0	13	6	0	2	4	4	1
Untreated Pond 1	2	8	34	28	22	0	0	2	5	9	4	6	54	162	120	94	59	16	0
Leucorrhina																			
Treated Pond 1	2	2	1	0	0	0	0	0	1	2	0	2	0	3	6	5	2	3	2
Untreated Pond 1	1	0	0	18	0	9	7	8	7	15	7	7	7	10	161	17	14	18	9
Ladona																			
Treated Pond 1	0	0	1	2	1	0	0	1	0	0	0	3	0	2	5	6	1	5	0
Untreated Pond 1	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Total Number																			
Treated Pond 1	19	6	11	5	7	3	1	5	5	7	1	10	30	14	27	24	14	26	4
Untreated Pond 1	14	14	66	74	93	33	15	23	46	59	46	46	116	228	421	325	163	123	105

Table 4. Total numbers of macroinvertebrates per square meter in the study ponds in 1980, 1981 and 1982.

	Pre-Treatment	Post-Treatment																	
		1980						1981						1982					
	5/31	6/12	6/19	7/8	8/7	9/9	10/23	5/13	6/17	7/8	8/6	9/14	10/9	5/21	6/25	7/22	8/24	9/27	10/28
Treated Pond 1	354	50	276	250	282	172	231	267	302	217	62	286	76	292	215	810	702	2157	751
Untreated Pond 1	233	149	58	1042	3207	1170	737	1284	997	1734	2126	769	1266	1215	3142	2831	1783	2229	2071

Table 5. Numbers of Trichoptera per square meter in the study ponds in 1980, 1981 and 1982.

	Pre-Treatment	Post-Treatment																	
		1980						1981						1982					
	5/31	6/12	6/19	7/8	8/7	9/9	10/23	5/13	6/17	7/8	8/6	9/14	10/9	5/21	6/25	7/22	8/24	9/27	10/28
Total Trichoptera																			
Treated Pond 1	7	0	8	3	4	15	19	5	8	1	0	14	52	11	4	9	29	60	48
Treated Pond 2	464	258	81	55	43	21	23	166	90	18	8	10	17	108	68	276	134	56	31
Untreated Pond 1	11	5	13	0	8	16	19	33	12	8	21	13	68	36	8	34	65	53	27
Untreated Pond 2	156	116	65	42	20	5	11	147	195	88	9	4	55	334	235	146	30	119	150
Limnephilus sp.																			
Treated Pond 2	464	258	81	24	15	0	18	166	89	11	0	0	0	105	44	7	64	18	16
Untreated Pond 2	49	101	64	30	1	0	0	142	188	77	2	0	0	333	204	84	8	47	1

Table 6. Numbers of Diptera per square meter in the study ponds in 1980, 1981 and 1982.

	Pre-Treatment	Post-Treatment																	
	1980							1981						1982					
	5/31	6/12	6/19	7/8	8/7	9/9	10/23	5/31	6/17	7/8	8/6	9/14	10/9	5/21	6/25	7/22	8/24	9/27	10/28
Chironomidae																			
Treated Pond 1	153	29	81	33	71	6	5	31	98	50	10	25	121	132	74	431	248	654	320
Treated Pond 2	70	79	104	380	2324	232	22	29	129	416	306	150	173	22	42	187	589	263	331
Untreated Pond 1	22	8	4	8	35	23	17	125	103	64	93	18	274	480	2244	1231	543	620	1011
Untreated Pond 2	653	75	45	37	371	13	99	234	418	374	176	52	608	174	244	1241	403	809	717
Chaoborus sp.																			
Treated Pond 1	5	1	81	112	4	33	82	5	4	2	0	43	5	0	0	0	0	0	0

SUMMARY

Aerial application of carbaryl (Sevin-4-oil^{R}) for spruce budworm control in June, 1980 resulted in contamination of ponds. Carbaryl residues persisted in pond sediment until October, 1981. However, samples of water and sediment analysed in 1982 did not contain detectable levels of carbaryl residue.

Amphipoda populations were virtually eliminated in both treated ponds in 1980. In one treated pond they failed to repopulate through 1980, 1981 and 1982. In the other treated pond some repopulation was apparent in late 1981 and 1982 but abundance had not returned to pretreatment levels.

LITERATURE CITED

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DIFFERENTIAL EFFECTS OF TEMPERATURE, WHEN SPRAYING WITH SEVIN-4-OIL, ON POLLINATORS AND FRUIT-SET IN A SPRUCE-FIR FOREST

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ABSTRACT

Populations of three pollinating insect groups (native bees, syrphid flies, and bee flies) and fruit set of two forest plants (Maianthemum canadense and Aralia hispida) were monitored in two blocks sprayed with split applications of Sevin-4-oil^{R} and in adjacent unsprayed forest areas. One block ("warm") was sprayed at temperatures above 16^{o}C; the other ("cool") was sprayed at temperatures below 5^{o}C. No significant reductions in pollinator populations or fruit set of either plant species were observed as a consequence of Sevin applications in the "warm" or "cool" blocks. Severe pollinating insect mortality and subsequent reductions in fruit set of entomophilous plants will likely result only from sprays applied on warm mornings (T>16^{o}C) because of diurnal temperature and pollinator activity patterns.

The flowering and fruiting phenologies of 57 plant species or genera in the study area are documented and the activity patterns of the most important pollinators over a range of morning temperatures were determined.

INTRODUCTION

The operational use of the broad-spectrum carbaryl insecticide Sevin-4-oil^{R} can affect a variety of non-target insects. Carbaryl can cause significant mortality among honeybees, and native bees (Hymenoptera:Apoidea), and syrphid flies (Diptera:Syrphidae) in agricultural situations (Anderson and Atkins 1968, Johansen 1977, Schneider 1969, Waller 1969) but the effects of carbaryl formulations on forest pollinator groups is less well understood. Hansen et al. (1982) showed that split applications of Sevin-4-oil^{R} targeted for spruce budworm suppression reduced populations of native bees, syrphid flies, and bee flies (Diptera:Bombyliidae) in eastern Maine. Miliczky and Osgood (1979) also attributed reductions in wild bee populations to this insecticide, though syrphid and bee flies were apparently unaffected. However, another carbaryl formulation, Sevin-2-oil^{R} (at the light dosage of 280g

AI/ha), caused no apparent mortality among forest bumblebees in New Brunswick (Holmes et al. 1981). Several other insecticides used in forest spray operations may also reduce pollinator populations (e.g. Kevan 1975, Plowright and Rodd 1980, Robinson and Johansen 1978).

Insecticide induced reductions in pollinator populations may in turn decrease the fruit set of entomophilous forest plants. Many forest plant species depend on a variety of insects, primarily native bees and certain flies, for pollination and thus successful seed and fruit development, as well as for ensuring outcrossing and gene dispersal. The fruits of entomophilous forest plants are valuable food for wildlife species, which serve to disperse the plant seeds. Reduced fruit set in a number of forest plants has been demonstrated in several Maine and New Brunswick localities sprayed with carbaryl and other insecticides (Hansen et al. 1982, Miliczky and Osgood 1979, Thaler and Plowright 1980). Reduced fruit set occurring as a result of forest spray programs may affect the feeding patterns of frugivorous wildlife species under certain conditions (Hansen et al. 1982).

In our earlier study, we suggested that ambient temperatures at the time of spray application might influence carbaryl induced pollinator mortality, and in turn modify any fruit set reductions occurring as a consequence of reduced pollinator availability (Hansen et al. 1982). Temperature may affect pollinator insecticide interactions by: 1) determining whether or not the pollinators are active during or shortly after application; and 2) reducing or increasing the toxicity of the insecticide to these non-target insects. Ambient temperatures can shape this latter effect by altering the rate of spray residue drying, the breakdown of the toxic portion in the environment, and the absorption and metabolic processing of the insecticide by the insect.

The primary objectives of this study were: 1) to determine the effect of

warm and cool ambient temperatures at the time of carbaryl application on three forest pollinator groups (native bees, syrphid flies, and bee flies); and 2) to study how temperature effects on the carbaryl pollinator interaction may alter the fruit set of insect pollinated plants in a spruce-fir forest. Additionally, we sought to document the flowering and fruiting phenologies of plant species found in eastern Maine forests and to determine the activity patterns of the most important pollinators over a range of morning temperatures.

MATERIALS AND METHODS

Two spray blocks in northern Hancock County were selected for study (Fig. 1): block MO-70 (351 ac), Township 34 M.D. and block MO-65 (1645 ac), Township 3 N.D. Both were scheduled for a split application of the carbaryl insecticide Sevin-4-oil^{R} in 1982 and had no previous spray history. The forest cover was predominantly second-growth red spruce and balsam fir, with areas of eastern hemlock and white pine and scattered black spruce and various hardwood species. Access to the spray blocks and surrounding unsprayed localities was provided by logging roads and trails.

Block MO-70 ("cool") was sprayed in the morning of May 21 and again in the morning of May 28. Air temperatures at ground level were approximately 2°C (36°F) during both spray periods. Block MO-65 ("warm") was sprayed in the evening of May 27 and again in the evening of June 11; air temperatures during application were about 22°C (72°F) and 16°C (60°F) respectively. These temperatures were not as high as we had hoped for, particularly for evening spraying. All spray applications utilized Sevin-4-oil^{R} at the rate of 515g AI/ha (0.46 lbs. AI/ac), applied by Bell 47 helicopters. White spray residue spots on broadleaf foliage were used to roughly delimit the spray areas.

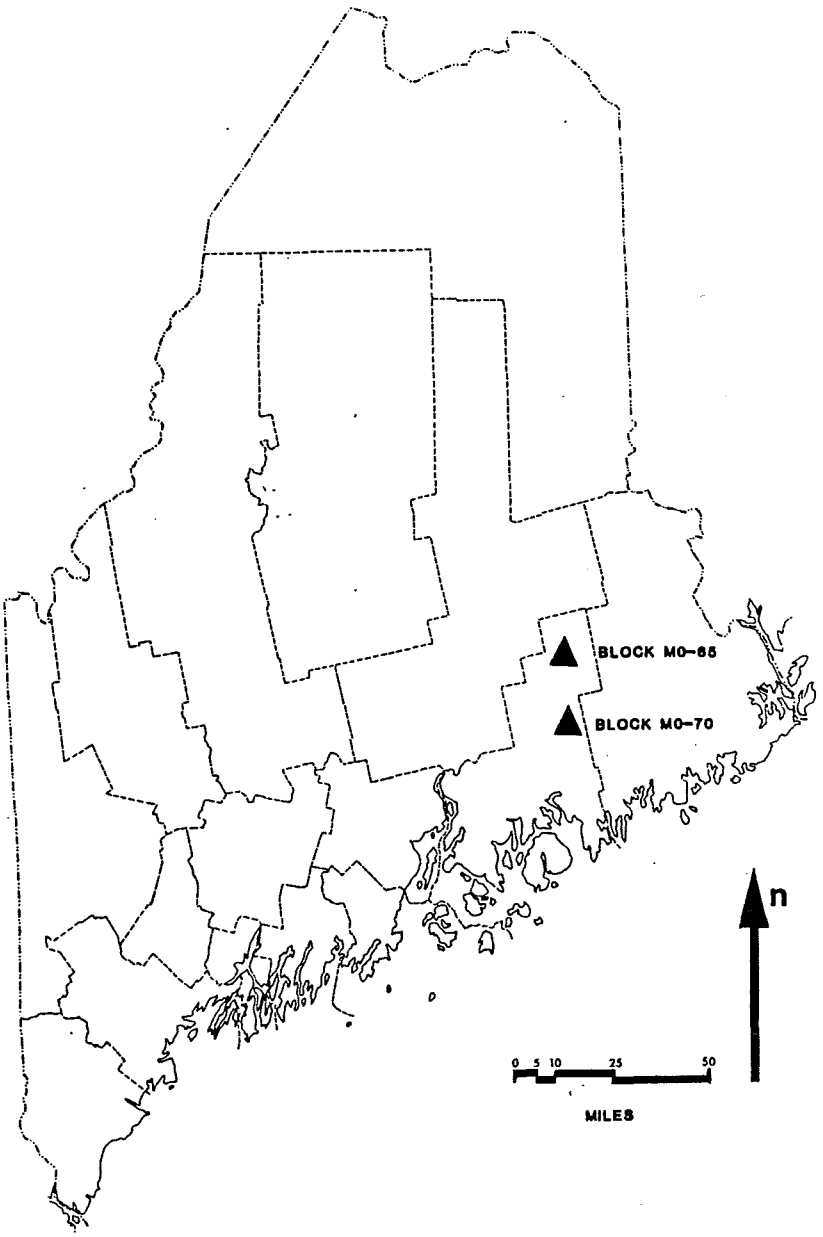

Fig. 1. Location of spray blocks, Hancock County, Maine.

Hygrothermographs were placed in each spray block, and temperatures and relative humidities were continuously recorded prior to, during, and after the spray periods.

The stationary net trap designed by Malaise (1937) is an effective means of capturing flying insects, particularly Diptera and Hymenoptera (Martin 1977) and can be used to monitor populations of these insects. Five standard Malaise traps were placed in each spray block, and five were placed in unsprayed locations to serve as controls. Three traps in the control areas were placed approximately 3.3 km (2 mi) from spray block MO-70; two were placed at a similar distance from block MO-65. The three control traps nearest to block MO-70 were later added to those near block MO-65 following completion of insect trapping in MO-70. All traps were positioned as much as possible across pollinator "flight paths" which would likely provide access to flowering plants.

Each Malaise trap possessed a plastic bottle which collected insects caught in the trap. Dichlorvos-impregnated plastic strips were placed in these containers to stun or kill trapped specimens. The bottles were removed at the end of a day's trapping period, and the total trapping time recorded for each trap. Weather conditions during the trapping period were also noted. Collected insects were sorted and pollinator groups pinned for later identification. Collecting bottles were replaced on the traps at the start of the subsequent day's trapping period.

We attempted to make the total pre-spray, post-spray 1, and post-spray 2 trapping periods as similar as possible for each spray block and their respective control trap sites (Table 1). However, spray dates for block MO-65 were considerably later than those for block MO-70, especially for the second application, and thus direct comparison between the two blocks' trapping results are not possible.

Table 1. Number of Malaise traps, trapping dates, and total elapsed trapping time in sprayed and unsprayed (control) areas

		Pre-spray		Post-spray 1		Post-spray 2	
	No. Traps	Dates	Time[a]	Dates	Time	Dates	Time
Block MO-70 ("cool")	5	5/18--5/20	19.0	5/22,5/26--5/27	19.75	5/31--6/1,6/4	21.25
Control	3	5/18--5/20	16.50	5/22,5/26--5/27	19.25	5/31--6/1,6/4	22.25
Block MO-65 ("warm")	5	5/19--5/21	17.0	5/28--6/1,6/9	24.50	6/15,6/18--6/19	16.25
Control	2 (5 for post-spray 2)	5/19--5/21	18.50	5/28--6/1,6/9	27.0	6/15,6/18--6/19	16.50

[a]Hours

Total numbers of bee flies (Diptera:Bombyliidae), syrphid flies (Diptera:Syrphidae), and native bees (Hymenoptera:Apoidea) trapped in each pre-spray, post-spray 1, and post-spray 2 collecting period were determined. These total counts were divided by the number of "trap-hours" (number of traps x total hours in trapping period) to generate relative trapping rates in sprayed and control areas.

Fruit set data were collected for two plant species: Canada mayflower, Maianthemum canadense Desf., and bristly sarsaparilla, Aralia hispida Vent. M. canadense has been a useful species for studying insecticide mediated changes in fruit set (Hansen et al. 1982, Thaler and Plowright 1980) and the flowering period of this species followed shortly after the block MO-70 carbaryl applications (Appendix A). A. hispida is an andromonoecious perrennial with a complicated flowering pattern, but apparently requires insect pollination for successful fruit set (Thomson and Barrett 1981). A. hispida is an important summer floral resource for nectar and pollen feeding insects (Thomson et al. 1982) and was selected because it flowered shortly after the "late" second carbaryl application on block MO-65. (Appendix A).

The M. canadense sampling method was the same as that used by Hansen et al. (1982). A. hispida was found primarily along roadsides; the primary (terminal) umbel or closest secondary umbel was clipped from ramets at about 18.5m (60 ft) intervals along roadside transect lines. This sampling was conducted in late July and early August when green fruits on the primary and secondary umbels were full-sized but not yet ripe. For both species, the same sampling procedures were used in sprayed and unsprayed control areas. Control areas were at least 1.6 km (1 mi) from a spray block boundary.

The numbers of potential fruits (number of flowers) and normally developed fruits were counted on each M. canadense shoot and A. hispida umbel.

Non-fruiting pedicels are persistent on M. canadense (Thaler and Plowright 1980) and unfertilized female flowers remain on A. hispida umbels, allowing fruit and flower counts to be made simultaneously. Persistent male flowers and herbivore damaged fruits and flowers were not included in the A. hispida data. Fecundity values (fruit/flower ratios) were compared between each spray block and its corresponding control localities.

Flowering and fruit development were monitored for most of the flowering plant species occurring in the general study area. From mid-May to mid-August, each plant species was recorded as possessing flower buds, flowers, immature fruits, ripe fruits, and dispersed ripe fruits. The relative progression of flowering and fruit ripening was followed over time on a scale of 1 (least developed) to 3 (most developed). The relative abundance and habitat was also noted for each plant species. This information is presented in Appendix A.

The activity patterns of pollinating insects were studied over a range of morning temperatures. Four 1 m x 2 m plots were established in an ornamental garden located near a mixed hardwood-softwood forest in Orono. Plots enclosed flowering stands of several ornamental Rosaceae (Rosa spp., Spiraea spp., Potentilla spp.). The numbers of bumblebees, other wild bees, and syrphid flies visiting flowers were recorded during 1 minute periods at each plot. Counts were begun in the early morning, when temperatures were 10^{o}C or lower, and continued every 15 minutes until temperatures had risen to 25-27^{o}C. Sun and shade air temperatures were recorded before each sequence of counts was begun, using a thermistor thermometer. These studies were conducted on clear calm days between June 30 and July 5, 1982.

RESULTS

The numbers of wild bees, syrphid flies, and bee flies captured in Malaise traps are expressed as a function of the "trap effort" (number of trap-hours) and are presented for pre-spray, post-spray 1, and post-spray 2 periods in both spray blocks and control areas (Figs. 2-4). Direct comparisons between data from the two spray blocks are not valid because of greatly different trapping dates and probable changes in insect faunas sampled. In both spray blocks, numbers of native Apoidea (Fig. 2) and of bee flies (Fig. 3) retain a consistent relationship between spray and control traps through pre-spray and both post-spray trapping periods. The numbers of syrphid flies appear to show a slight relative decrease following the first carbaryl applications in both spray blocks (Fig. 4), but this effect is not drastic and disappears by the second post-spray period.

These data indicate that significant reductions in populations of the three pollinator groups did not occur, regardless of ambient temperature during carbaryl applications.

Aralia hispida fruit set was uniformly high in control areas and in both spray blocks (Table 2), and was apparently unaffected by warm or cool ambient temperatures at the time of Sevin application. Maianthemum canadense fruit set was actually higher in spray block MO-70 (cool block) than in adjacent control locations ($t=7.85$; $p < 0.001$); fruit set in block MO-65 (warm block) was nearly equal in sprayed and control areas. It also appears that ambient temperature during spray application had little or no effect on M. canadense fruit set.

Total numbers of bumblebees, other wild bees, and syrphid flies observed (per minute) are expressed as a function of air temperature (Fig. 5). The slope of the syrphid regression line is significantly different from the

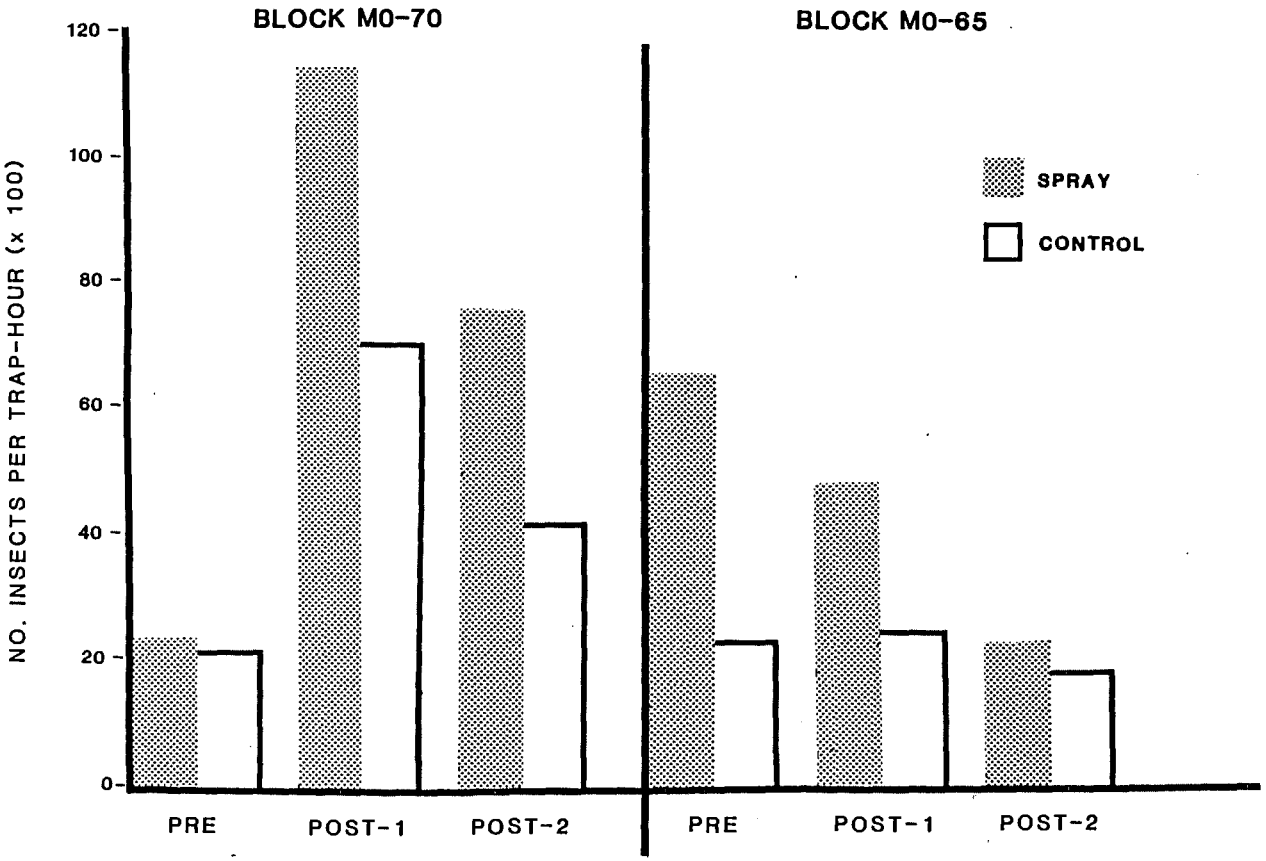

Fig. 2. Number of native bees (Hymenoptera: Apoidea) captured during pre-spray, post-spray 1, and post-spray 2 trapping periods in spray blocks and adjacent unsprayed (control) areas.

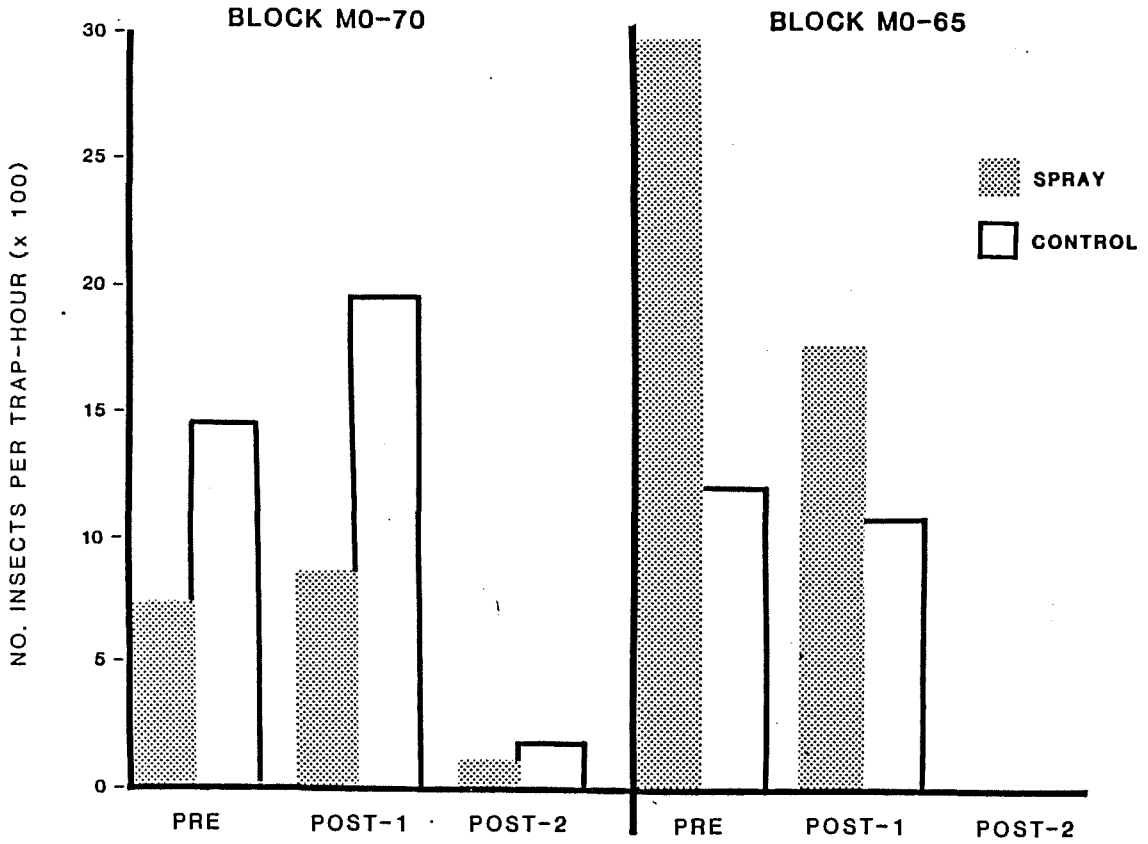

Fig. 3. Number of bee flies (Diptera: Bombyliidae) captured during pre-spray, post-spray 1, and post-spray 2 trapping periods in spray blocks and adjacent unsprayed (control) areas.

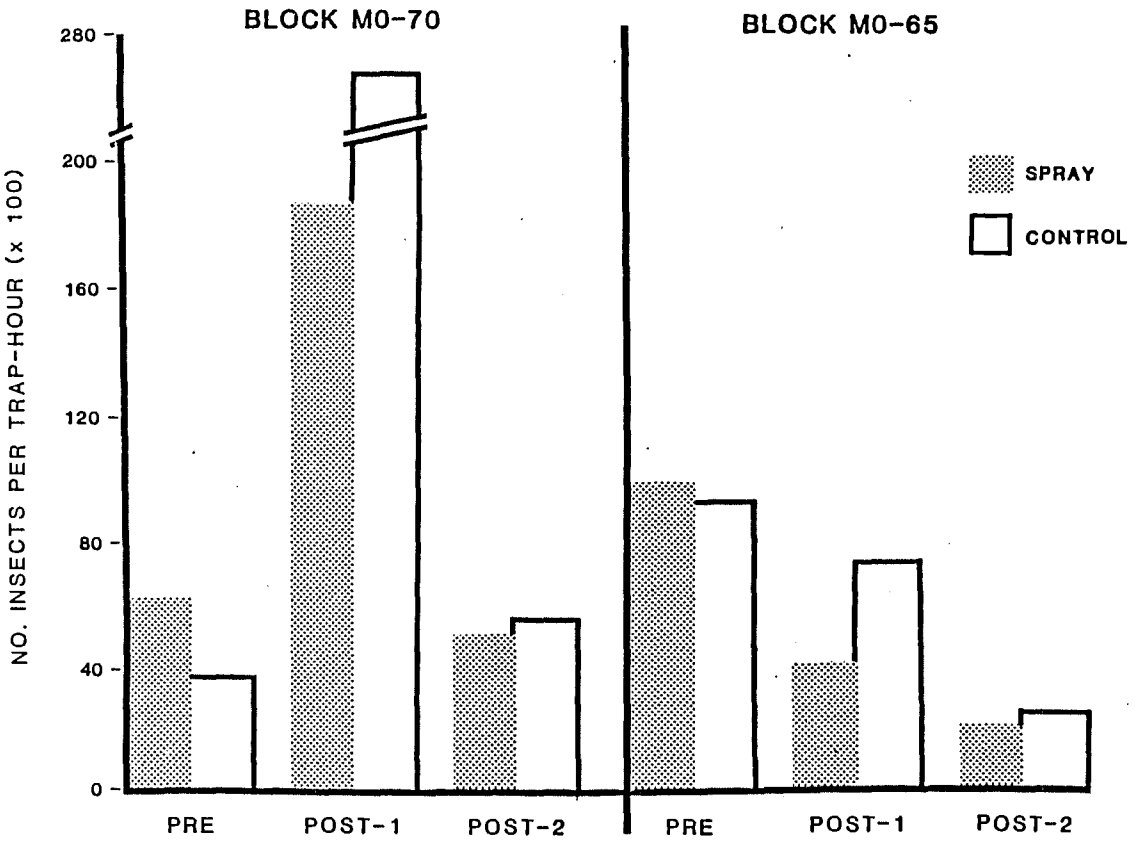

Fig. 4. Number of syrphid flies (Diptera: Syrphidae) captured during pre-spray, post-spray 1, and post-spray 2 trapping periods in spray blocks and adjacent unsprayed (control) areas.

Table 2. Fecundities of two forest plant species in sprayed and unsprayed (control) areas

Species	No. Fls.	No. Fruits	% Fecundity
Maianthemum canadense			
Block MO-70 ("cool")	14 959	6 660	44.52*
Control	14 483	4 965	34.28
Block MO-65 ("warm")	13 347	4 128	30.93
Control	12 612	3 879	30.76
Aralia hispida			
Block MO-70 ("cool")	4 153	4 103	98.79
Control	4 842	4 786	98.84
Block MO-65 ("warm")	2 185	2 146	98.21
Control	2 796	2 769	99.03

*$t = 7.85$; $p < 0.001$

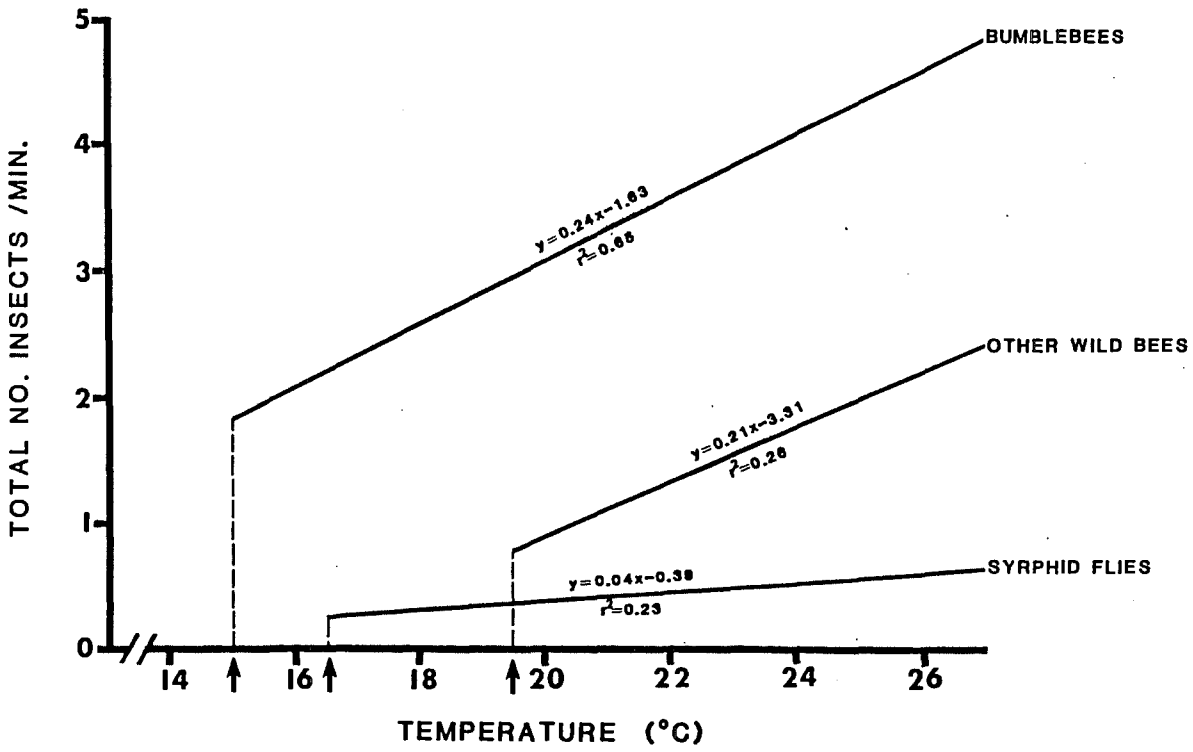

Fig. 5. Number of bumblebees, other wild bees, and syrphid flies visiting count-plots as a function of air temperature. Arrows indicate temperatures at which each insect group was first observed at flowers in count-plots.

slopes of the other lines ($p < 0.001$). The relatively small r^2 values for the three regression lines indicate that factors besides air temperature influenced this numerical expression of pollinator activity. The temperatures at which each group was first observed visiting flowers may indicate the relative sequence of flight initiation as morning temperatures increase.

DISCUSSION

Though it appears that significant reductions in pollinator populations did not occur under either temperature regime, small local population changes or fluctuations in the species composition of the pollinator fauna cannot be ruled out. This latter effect may be more likely to occur in the Syrphidae, a group which often is represented by a large number of species in an area, only a few of which contain many individuals (Small 1976). In any event, information gained from the use of stationary flight traps may be useful in detecting some numerical and taxonomic trends in insect populations. Inferences regarding the absolute size of these populations must be made with caution (Southwood 1978).

Activity patterns of a pollinator are determined by a complex of physical factors, including air temperature, soil temperature, light intensity, wind speed, and weather conditions (Linsley 1978). The timing of flower opening and closing, nectar secretion, and pollen release may also shape the daily foraging activities of pollinators.

Ambient temperature and light intensity are the most important factors determining flight patterns in temperate bees (Szabo and Smith 1972, Käpylä 1974). The effects of physical factors on syrphid or bee fly activity have not been studied. Air temperature appears to be primarily responsible for native bee flight initiation, as no flight and thus no flower visitation is

possible until a threshold temperature is reached (Lerer et al. 1982). This threshold seems to vary with the species of native bee; bumblebees become active at temperatures as low as 5°C (Heinrich and Raven 1972), Andrena spp. (Apoidea: Andrenidae) initiate flight at air temperatures of 12-15°C (La Placa Reese and Barrows 1980, Linsley 1978, Pesenko et al. 1980), Megachile rotundata (Apoidea: Megachilidae) appears to become active at 16-17°C (Lerer et al. 1982), and some halictid bees (Apoidea:Halictidae) may not begin flying until air temperatures reach 22°C or higher Pesenko et al. 1980). There appears to be a general trend for larger bees to initiate flight at lower morning temperatures than smaller bees, other factors "constant" (Kapyla 1974). Morning air temperature exhibits a close relationship with solar light intensity, and light intensity may modify the activity shaping effects of temperature. At high morning light intensities, insects may become active at lower than "normal" ambient temperatures; basking or other increased exposure may raise body temperatures above air temperature to such an extent that the threshold is reached. This ability is itself shaped by the absorptivity of the cuticle, presence or absence of pubescence, and body color (Heinrich 1981). The location of nesting or resting sites relative to exposure to the morning sun may also greatly influence air temperature effects on flight initiation (Szabo and Smith 1972). Bees resting in shaded nests may become active later than those utilizing more exposed sites.

Temperatures at which bumblebees and other wild bees were first seen visiting flowers (Fig. 5) show a relative relationship similar to that reported by other workers. Though the spectrum of bee species, bee sizes, and bee nesting sites differed between the count plots and the spray blocks, these temperature relationships should be similar, though not identical. Temperature relationships of adult syrphid flight initiation are not known

but flower visiting syrphid flies were first observed at morning air temperatures intermediate between those of bumblebees and other wild bees (Fig. 5). Despite their generally small size, syrphids may be able to initiate flight at lower than expected morning temperatures because they spend the night on plants and not in soil nests and are able to more quickly exploit morning sunlight for warming.

Though temperature is instrumental in the initiation of flight and foraging, it appears that light intensity assumes a dominant role in controlling the cessation, and hence the duration, of native bee activity (Lerer et al. 1982). Foraging in wild bees (except bumblebees) is normally completed before ambient temperatures are low enough to preclude flight (Kapyla 1974, LaPlaca Reese and Barrows 1980, Lerer et al. 1982); bee activity usually ceases in afternoon or early evening. This suggests that bee foraging comes to a halt as light intensity falls below a critical level in the late afternoon, and that ambient temperature is of secondary importance (Lerer et al. 1982). Various measures of bee activity (e.g. Fig. 5) will generally not exhibit a linear relationship with ambient temperature as the day progresses; activity can fall off rapidly, often before the day's maximum temperature is reached (LaPlaca Reese and Barrows 1980). Bumblebees, however, may remain active considerably later in the day than other native bees (Heinrich 1976).

The ambient temperatures during and for a short time after a morning insecticide application (such as those on block MO-70) will determine the activities of pollinating insects and their interactions with the spray. In afternoon and evening spray operations (including those on block MO-65), however, the activities and spray interactions of pollinators will be controlled to a greater extent by decreasing light intensity. Figure 6 shows that air temperatures in block MO-70 did not reach the temperatures at which pollinator

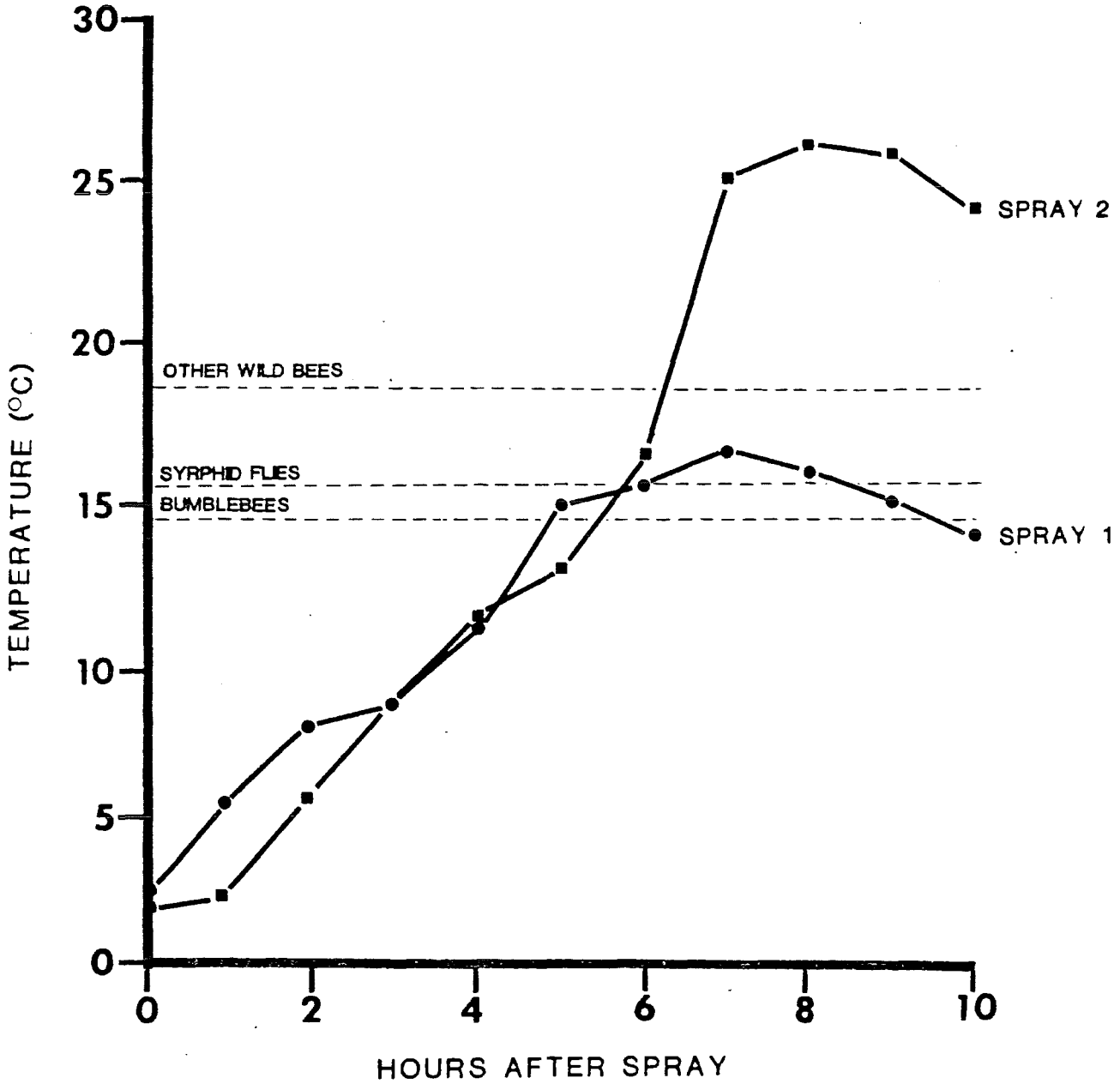

Fig. 6. Air temperatures following carbaryl applications in spray block MO-70. Dotted lines indicate temperatures at which activity of various pollinator groups was first observed (see Fig. 5).

activity was first noted (see Fig. 5) until five to six hours after spray application; following the first spray, temperatures never reached out observed "threshold" for native bees. Because of differing exposures to morning sunlight, a number of pollinators may have been active before these "critical" air temperatures were reached. However, wholesale activity was very unlikely during and for a number of hours following both block MO-70 spray applications, and direct exposure to the carbaryl droplets or to fresh spray deposit would be limited. Pollinator mortality under an early morning, low temperature spray schedule, such as that exhibited on block MO-70, should be negligible.

Figure 7 shows that air temperatures were near or above the suggested "thresholds" for pollinator activity (from Fig. 5) during, and for several hours after, both block MO-65 carbaryl applications. However, native bee activity may have been limited or absent by the time of these evening sprays (6:00-7:00 PM) since decreasing afternoon or evening light intensities probably terminated the daily flight period (see earlier discussion). The time at which such critical light intensities will be reached will vary with bee species, shading, cloudiness, etc., but it is not unreasonable to expect that by the 6:00 to 7:00 PM spray applications few native bees were active. Little bee mortality could be expected under these conditions. Bumblebees, however, do remain active for a considerably longer period of time in the evening than other bees (Heinrich 1976), and may have been directly exposed to carbaryl spray droplets in block MO-65. Bumblebee population reductions might be expected under the MO-65 ambient temperature and spray application regime, but these insects were quite scarce in our trapping collections, and are typically uncommon in the spring and early summer and in areas as heavily forested as our study sites (Heinrich 1976). Bumblebee population reductions

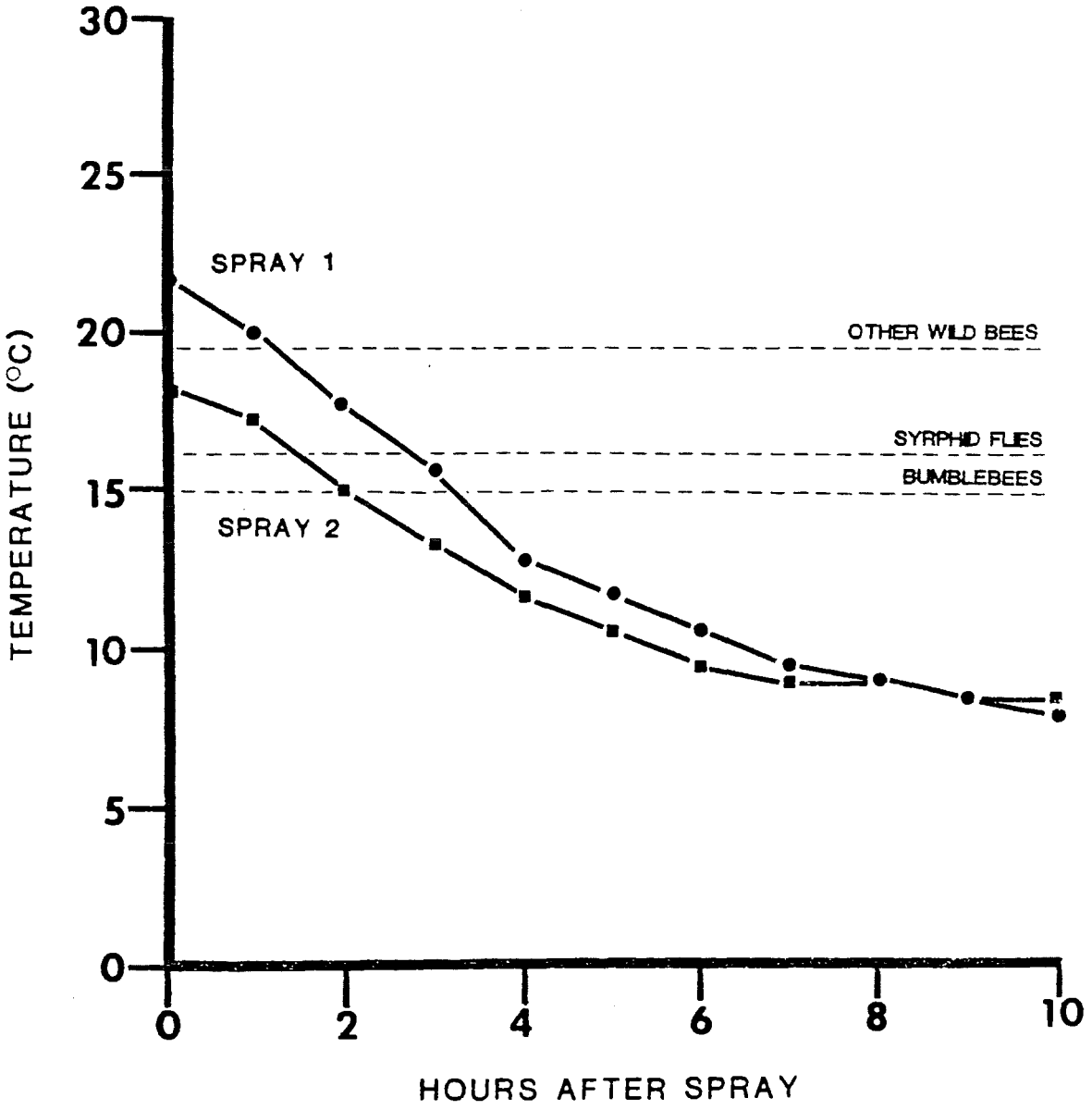

Fig. 7. Air temperatures following carbaryl applications in spray block MO-65. Dotted lines indicate temperatures at which activity of various pollinator groups was first observed (see Fig. 5).

occurring at this time would probably not seriously reduce fruit set of early flowering spruce-fir forest plants.

The factors which terminate syrphid fly or bee fly activity have not been examined. Ambient temperatures during the block MO-65 spray periods would not be low enough to exclusively limit most fly activity (Fig. 7), and significant direct carbaryl induced mortality might be expected among these groups. Since no large scale bee or syrphid fly mortality did occur (Figs. 3,4), an illumination threshold may also be responsible for flight termination in these insects. Bee flies were trapped in considerably smaller numbers than wild bees or syrphid flies, and probably occur in relatively small numbers in a spruce-fir forest. Even if population reductions did occur, they would likely have a minimal impact on pollination and fruit set. Syrphid flies, though abundant, are considerably less important that native bees in ensuring pollination of most forest plants (Løken 1981). Reductions in syrphid fly numbers would probably have a small impact on fruit set, unless accompanied by significant wild bee losses.

Temperature affects the rates at which carbamate insecticides penetrate the insect cuticle (Kuhr 1970); lower temperatures generally reduce the cuticle penetration rate. However, Georghiou and Atkins (1964) reported that carbaryl toxicity to honeybees (Apis mellifera) is greater at lower temperatures, probably because the affect of low temperature in lowering the rate of metabolic breakdown more than offsets the decrease in cuticle penetration rate of carbaryl at low temperatures.

Megachile rotundata also exhibits a metabolic resistance mechanism by which carbaryl residues are enzymatically broken down to water soluble forms and excreted (Guirguis and Brindley 1975). This detoxification mechanism has been shown to vary with the age and sex of the bee. Metabolic detoxification

mechanisms have not been studied in other native pollinators; the presence of resistance mechanisms in M. rotundata suggests that other native bees may also possess some form of detoxification mechanism. Temperature effects on wild bee carbaryl resistance remain to be studied.

Pollinators may also contact carbaryl residues on foliage. Carbaryl persists as a surface residue on plants, and little direct penetration into plant tissues occurs (Pieper 1979). Organophosphate insecticides may be taken in through the open stomates of plants; this mode of entrance is favored at high humidities, which stimulate stomatal opening (Korpela and Tulisalo 1974). Though this "absorption" mechanism has not been demonstrated for carbaryl, high humidities (> 70%) favoring stomatal opening occurred during and after all spray applications. In any event, pollinator contact with carbaryl foliage residues would be spotty, and largely a function of forest canopy openings (Struble et al. 1978).

Insecticidal contamination of nectar and pollen can cause significant mortality among foraging pollinators (Johansen 1977, Schneider 1969). Such contamination will be a function of the timing of pollen release, nectar secretion, and flower anthesis relative to spray application. Because these events appear to occur at various times during the day (e.g. Corbet 1978, Thomson et al. 1982), there is probably no general trend in potential for floral contamination among forest plants. However, the nectar and pollen contents of many flowers are probably very low by late afternoon or evening, largely as a consequence of insect foraging (Heinrich 1976). Evening sprays would probably cause very little nectar or pollen contamination in these flowers.

Ambient temperature can be important in initiation and cessation of flower opening, pollen deposition, and nectar flow, and thus temperature at

time of insecticide application could also influence contamination of pollinator forage. Temperature responses differ among plant species, so a general contamination pattern is again not likely. However, low ambient temperatures could limit plant physiological processes (such as nectar production) and thus limited floral contamination could be expected under a low temperature spray regime. In general, floral contamination by insecticide sprays will vary with the intervening forest overstory.

The absence of fruit set reductions in the spray blocks probably reflects the general maintenance of pollinator populations following the block MO-65 and MO-70 carbaryl applications. Fecundity is usually at a very high level in Aralia hispida (Thomson and Barrett 1981), but may be somewhat inflated (Table 2) by our sampling concentration on the highly fecund terminal (primary) umbels and exclusion of damaged flowers and fruit. This species is probably able to exploit the summer emerging bumblebee workers for pollination, though almost any insect visitor is a potential pollinator (Thomson et al. 1982). Maianthemum canadense fruit set was higher in block MO-70 than in adjacent control locations (Table 2). Site differences and plant age can affect flowering and percent fruit set of M. canadense (Silva et al. 1982). These effects may be more noticeable in extensive sampling from a comparatively small area (140 ha for block MO-70), and in general reflect the high degree of variability in the reproductive patterns of forest plants. M. canadense is thought to be pollinated primarily by bumblebees (Thaler and Plowright 1980); however, our observations indicate that other native bees and various species of Diptera may have been more important pollinators in our study areas.

CONCLUSION

Low pollinator mortality can be expected as a consequence of morning carbaryl applications when temperatures are low (< 10°C). Fairly low morning temperatures are typical from late May to mid-June in Maine, the period of time when most spruce budworm insecticide applications are carried out. Late afternoon or evening carbaryl applications can also be expected to cause minimal pollinator mortality and fruit set disruption, probably as a consequence of the activity patterns of native bees and regardless of ambient temperature to a large degree.

Reductions in pollinator populations and resulting depression of fruit set should thus be greatest when carbaryl applications take place on warm mornings (temperatures above 16°C). Many pollinating insects would be flying under these conditions, maximizing insecticide exposure and subsequent mortality. This situation was documented by Miliczky and Osgood (1979), who noted unusually warm morning temperatures during carbaryl application and observed high native bee mortality.

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APPENDIX A.

The flowering and fruiting phenologies of selected forest shrubs and herbs in eastern Maine, spring and summer 1982.

KEY

 Flower Buds

 Flowers

 Immature Fruits

 Ripe Fruits

 Dispersed Fruits

ND No Data

ABUNDANCE

C – Common

L – Locally Common

S – Rare

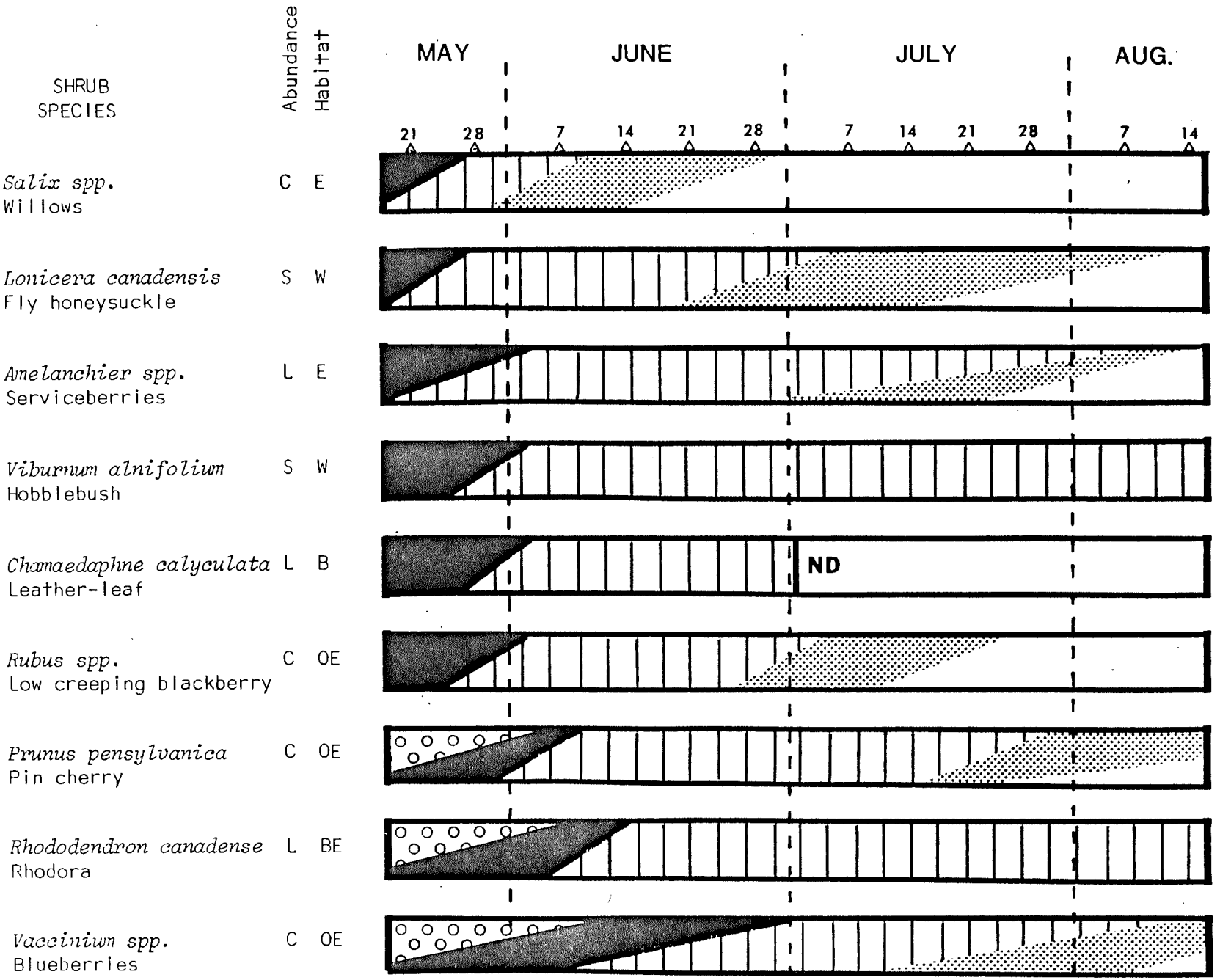
HABITAT

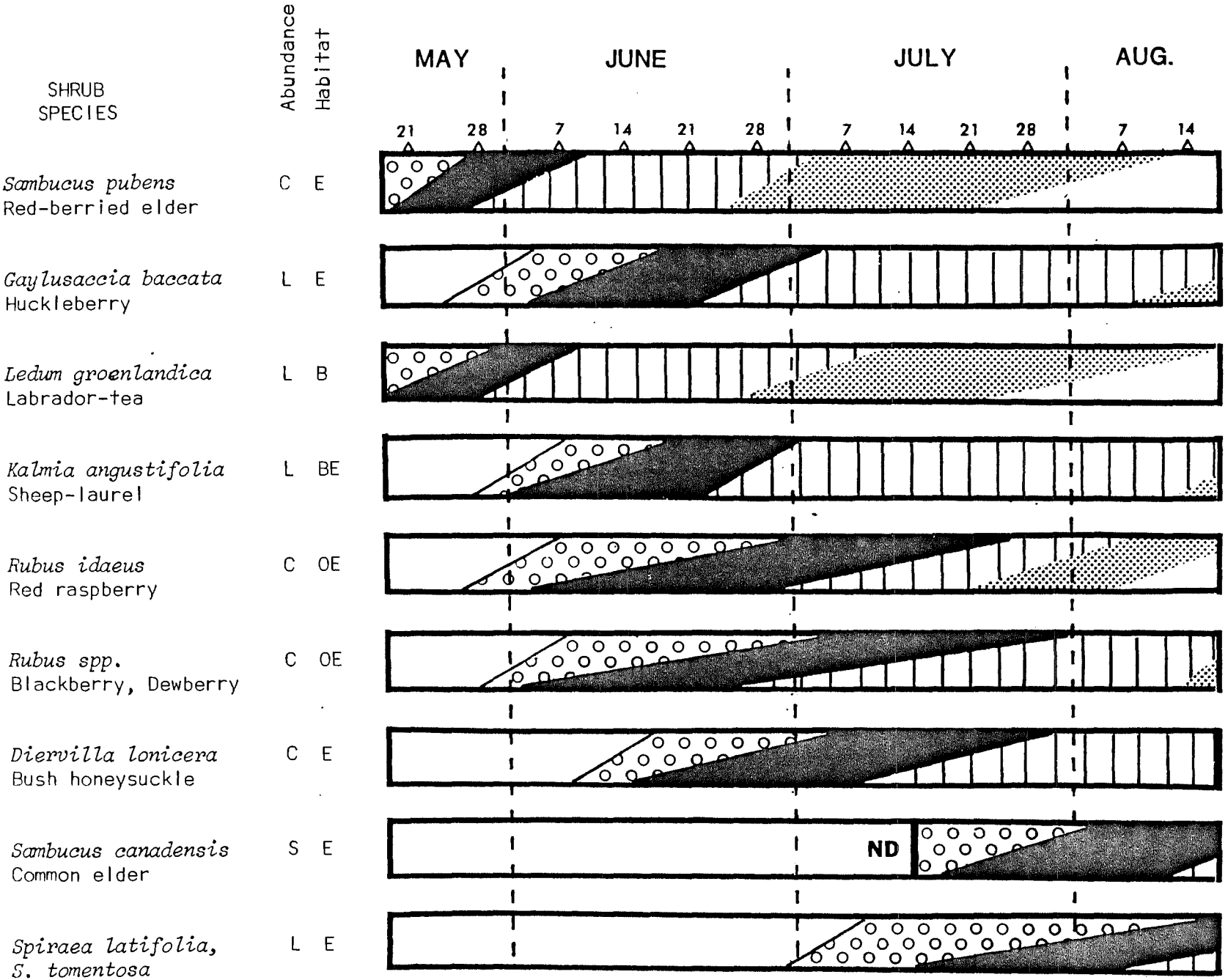
O – Open Areas

W – Wooded Areas

E – Forest Edges

B – Bogs, Wet Areas


SHRUB SPECIES
Abundance
Habitat
MAY
JUNE
JULY
AUG.
21
28
7
14
21
28
7
14
21
28
7
14
Salix spp.
Willows
C E
Lonicera canadensis
Fly honeysuckle
S W
Amelanchier spp.
Serviceberries
L E
Viburnum alnifolium
Hobblebush
S W
Chamaedaphne calyculata
Leather-leaf
L B
ND
Rubus spp.
Low creeping blackberry
C OE
Prunus pensylvanica
Pin cherry
C OE
Rhododendron canadense
Rhodora
L BE
Vaccinium spp.
Blueberries
C OE


SHRUB SPECIES
Abundance
Habitat
MAY
JUNE
JULY
AUG.
21
28
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14
21
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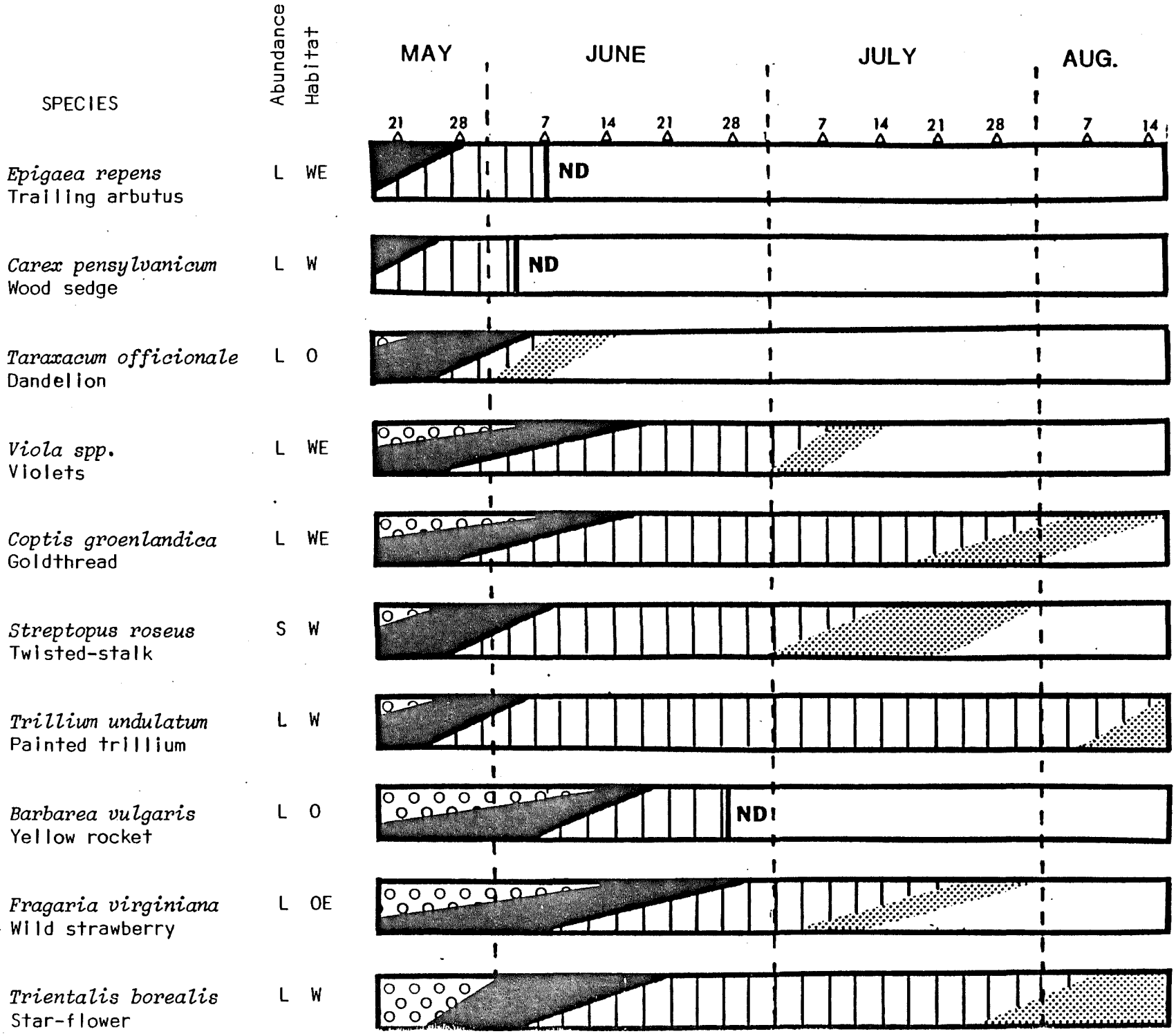
14
21
28
7
14
Sambucus pubens
Red-berried elder
C E
Gaylusaccia baccata
Huckleberry
L E
Ledum groenlandica
Labrador-tea
L B
Kalmia angustifolia
Sheep-laurel
L BE
Rubus idaeus
Red raspberry
C OE
Rubus spp.
Blackberry, Dewberry
C OE
Diervilla lonicera
Bush honeysuckle
C E
Sambucus canadensis
Common elder
S E
ND
Spiraea latifolia,
S. tomentosa
Meadowsweet, Steeplebush
L E


SPECIES
Abundance
Habitat
MAY
JUNE
JULY
AUG.
21
28
7
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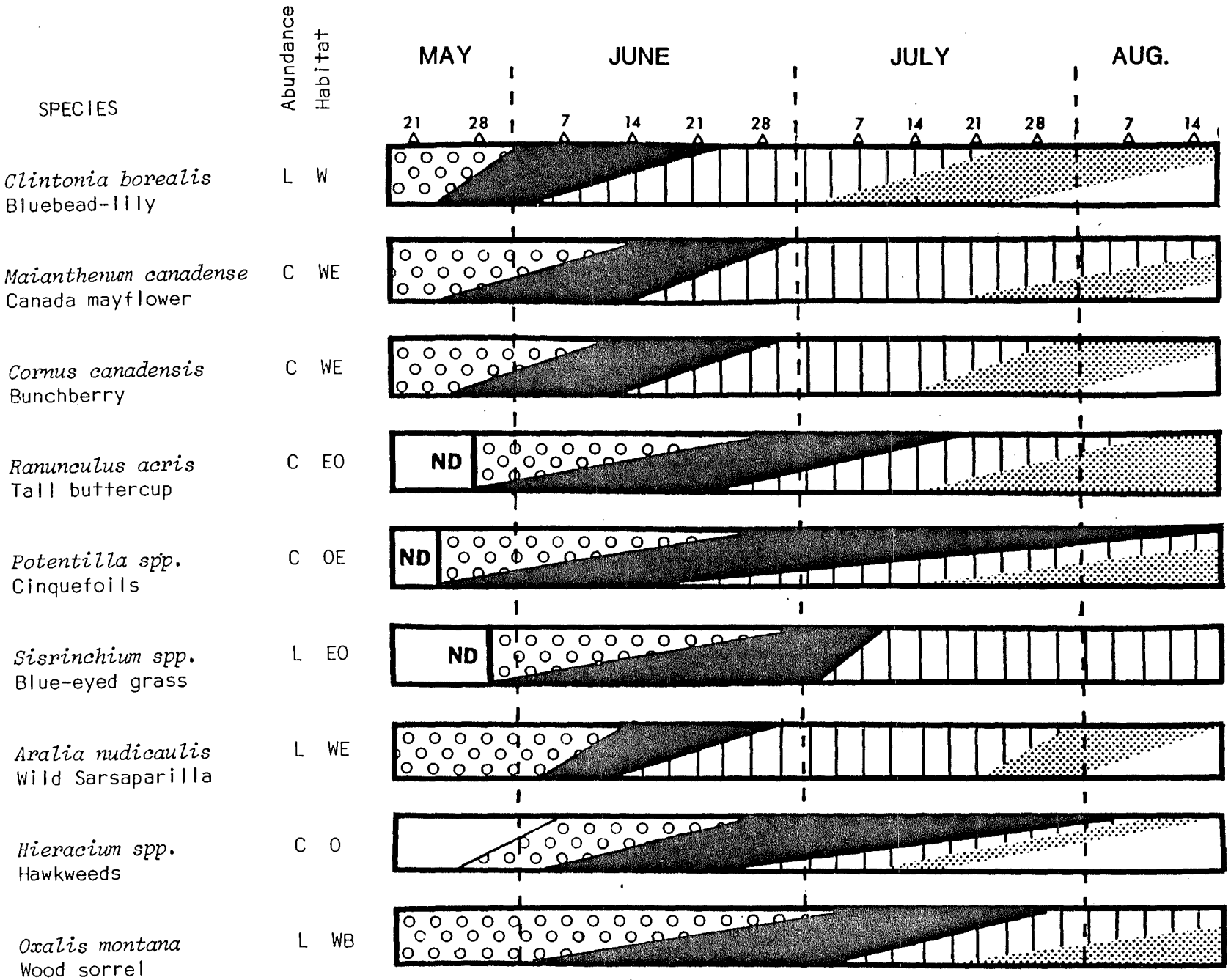
14
21
28
7
14
Epigaea repens
Trailing arbutus
L WE
ND
Carex pensylvanicum
Wood sedge
L W
ND
Taraxacum officionale
Dandelion
L O
Viola spp.
Violets
L WE
Coptis groenlandica
Goldthread
L WE
Streptopus roseus
Twisted-stalk
S W
Trillium undulatum
Painted trillium
L W
Barbarea vulgaris
Yellow rocket
L O
ND
Fragaria virginiana
Wild strawberry
L OE
Trientalis borealis
Star-flower
L W


SPECIES
Abundance
Habitat
MAY
JUNE
JULY
AUG.
21
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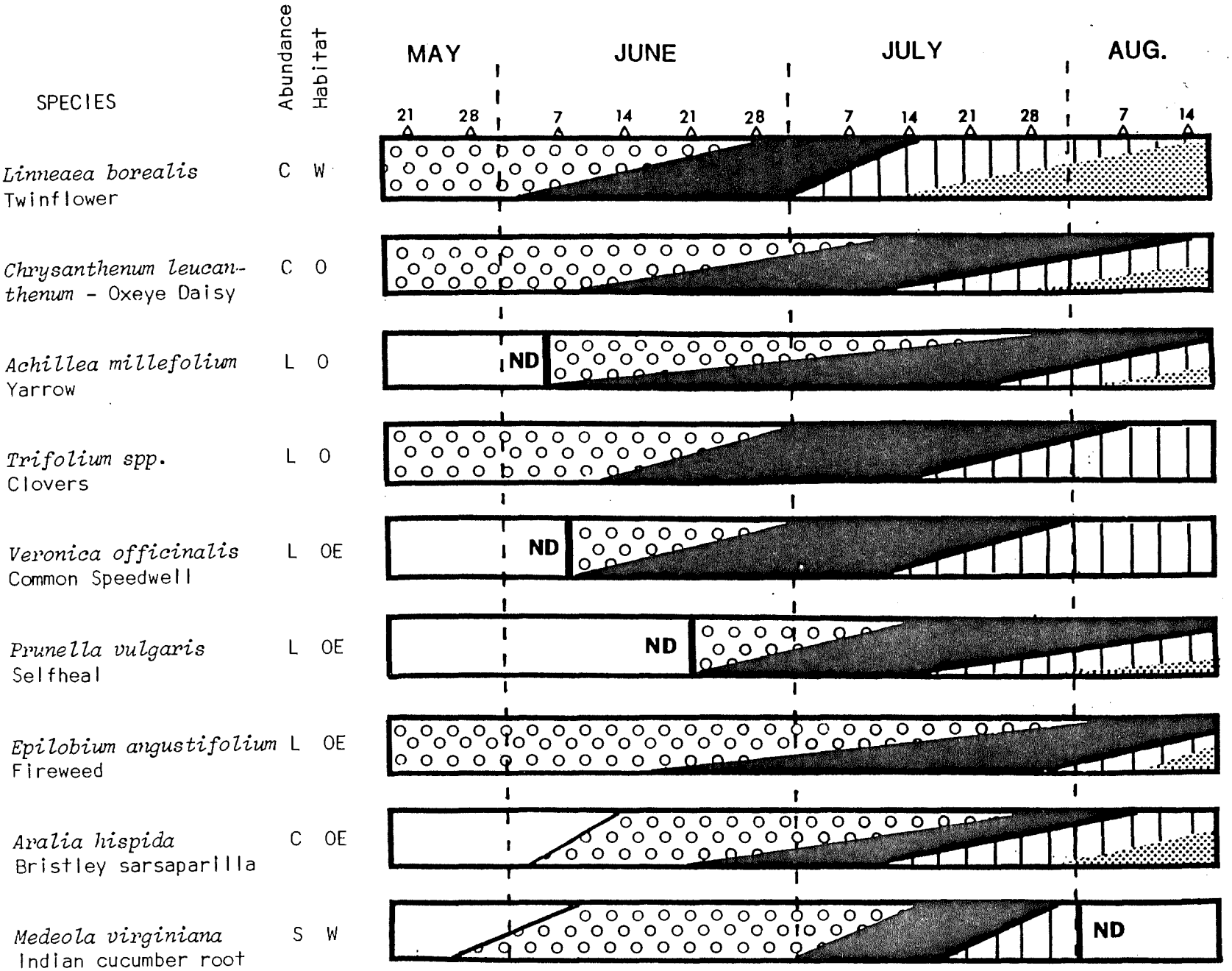
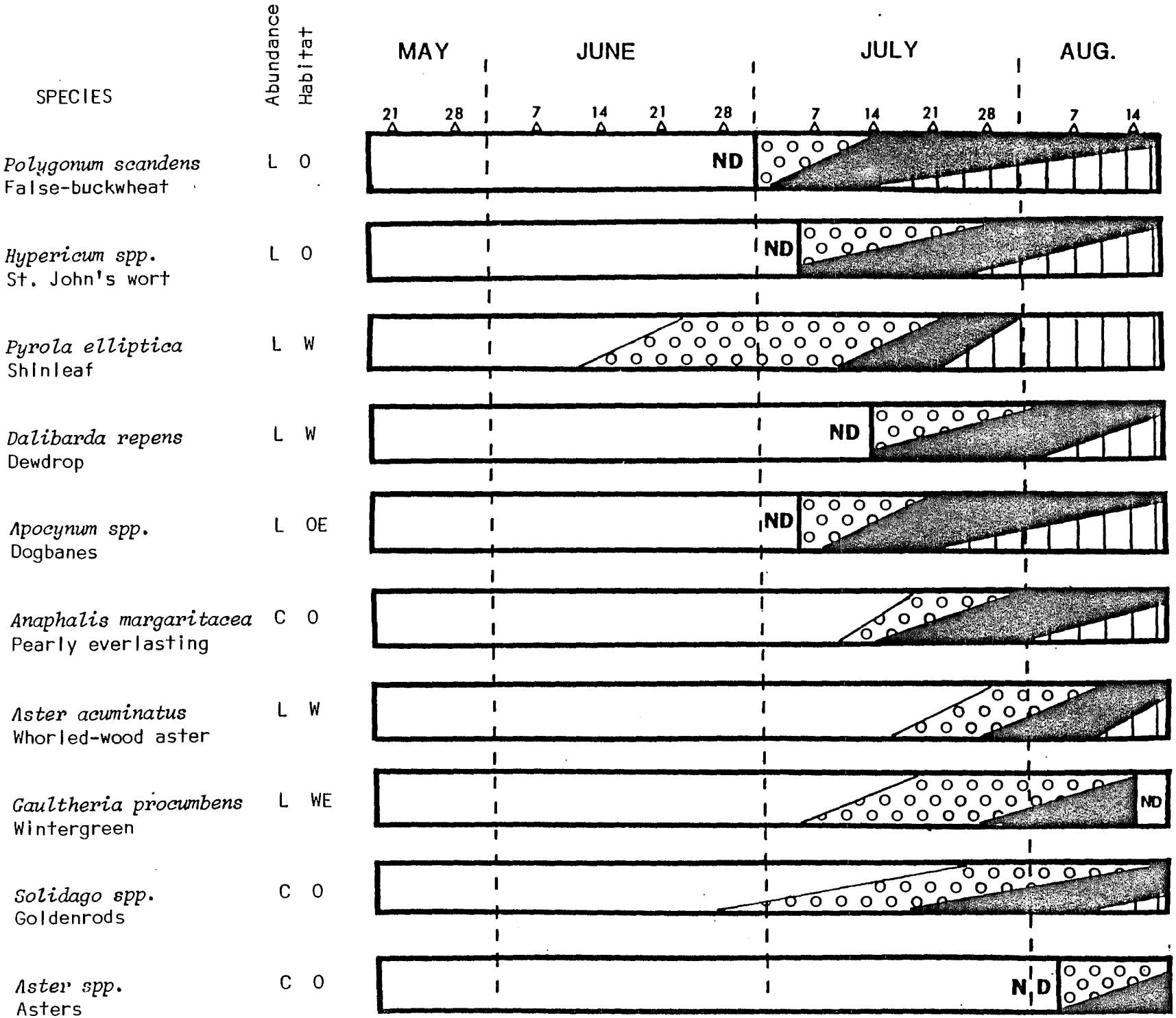
21
28
7
14
Clintonia borealis
Bluebead-lily
L W
Maianthemum canadense
Canada mayflower
C WE
Cornus canadensis
Bunchberry
C WE
Ranunculus acris
Tall buttercup
C EO
ND
Potentilla spp.
Cinquefoils
C OE
ND
Sisrinchium spp.
Blue-eyed grass
L EO
ND
Aralia nudicaulis
Wild Sarsaparilla
L WE
Hieracium spp.
Hawkweeds
C O
Oxalis montana
Wood sorrel
L WB


SPECIES
Abundance
Habitat
MAY
JUNE
JULY
AUG.
21
28
7
14
21
28
7
14
21
28
7
14
Linneaea borealis
Twinflower
C W
Chrysanthenum leucan-
thenum - Oxeye Daisy
C O
Achillea millefolium
Yarrow
L O
ND
Trifolium spp.
Clovers
L O
Veronica officinalis
Common Speedwell
L OE
ND
Prunella vulgaris
Selfheal
L OE
ND
Epilobium angustifolium
Fireweed
L OE
Aralia hispida
Bristley sarsaparilla
C OE
Medeola virginiana
Indian cucumber root
S W
ND


SPECIES
Abundance
Habitat
MAY
JUNE
JULY
AUG.
21
28
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14
21
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7
14
21
28
7
14
Polygonum scandens
False-buckwheat
L O
ND
Hypericum spp.
St. John's wort
L O
ND
Pyrola elliptica
Shinleaf
L W
Dalibarda repens
Dewdrop
L W
ND
Apocynum spp.
Dogbanes
L OE
ND
Anaphalis margaritacea
Pearly everlasting
C O
Aster acuminatus
Whorled-wood aster
L W
Gaultheria procumbens
Wintergreen
L WE
ND
Solidago spp.
Goldenrods
C O
Aster spp.
Asters
C O
ND

ACUTE TOXICITY OF CARBARYL, ALPHA NAPHTHOL AND SEVIN-4-OIL TANK MIX TO *CAMBARUS BARTONI* AND *ORCONECTES VIRILIS*

BY KENNETH A. SIMON
ENVIROSYSTEMS DIVISION
PECK ENVIRONMENTAL LABORATORY, INC.

ACUTE TOXICITY OF CARBARYL, ALPHA NAPHTHOL AND SEVIN-4-OIL^{R} TANK MIX TO CAMBARUS BARTONI AND ORCONECTES VIRILIS

1.0 INTRODUCTION

Control of the spruce budworm in the Maine spruce-fir forest has led to the use of organic pesticides including carbaryl, the active ingredient in Sevin-4-Oil^{R}. This compound, its carriers/solvents and breakdown products have positive benefits in the control of the budworm and potential adverse impacts, including death and alteration of normal behavior, which can in turn have long-term impacts on populations of non-target species. The scope of this program was to document the acute toxicological effects of carbaryl, its primary hydrolytic breakdown product alpha naphthol and the commercial application product (referred to as Sevin-4-Oil^{R} tank mix) on two resident crayfish species Cambarus bartoni and Orconectes virilis. Specific areas included in the investigation were determination of concentrations lethal to half and entire populations (LC-50 and LC-100) plus no effect concentration (LC-0) for both carbaryl and alpha naphthol to C. bartoni and O. virilis. In addition, LC-0, 50 and 100's were established for C. bartoni exposed to the tank mix.

Selection of alpha naphthol as a test compound was based on the degradation of carbaryl. Carbaryl breakdown occurs via a number of pathways with alkaline hydrolysis being a primary route in water (Wolfe et al, 1978). This pathway leads to the production of alpha naphthol plus several other minor compounds. The rate of breakdown of carbaryl via this pathway is dependent upon the pH of the water and to a lesser degree water temperature (Sikka et al, 1975).

Commercial formulations of carbaryl are generally reformulated to produce a product providing better characteristics for aerial spray applications. Sevin-4-Oil^{R}, the product currently used in Maine, is carbaryl suspended in a fuel oil at the rate of 4 pounds carbaryl per gallon of oil. The product applied to Maine forests, referred to as Sevin-4-Oil^{R} tank mix, contains one part kerosene to every 4 parts Sevin-4-Oil^{R} plus unidentified surfactants (Trask, 1982). The combination of oils, kerosene and surfactants has the potential to alter the toxicity of the parent compound and was therefore included in the program.

Use of site specific water and indigenous species were considered as important factors in this program as a means to reduce the number of variables that must be considered when comparing laboratory results with what might be expected to occur in natural environments. Variation in pH and presence of naturally occurring organic compounds can affect degradation rates and breakdown products, through surface adsorption and formation of complexes,subsequently altering toxic effects of the products. Also, radically different responses to a compound can be observed between species and when the same species is evaluated under differing conditions.

The overall goal of the program is to provide the Maine Department of Conservation with information that can be used to determine if existing limits of carbaryl in surface waters are adequate to protect these species plus provide data useful in assessing potential impacts resulting from accidental application or spills of large quantities of the pesticide.

2.1.4 Laboratory Holding

Crayfish delivered to the laboratory were held in fiberglass holding tanks (6' x 2' x 6") after initial culling to remove dead and injured animals. All crayfish were held for a minimum of two weeks or until observed mortality during a week did not exceed 10% of the population to insure any diseased or injured animals had been removed from the test population.

Water used during the holding period was obtained from shallow wells at the laboratory. Flow rates were set to achieve a minimum of 6 changes per day to prevent buildup of metabolic byproducts and insure adequate dissolved oxygen. Water temperature during holding was maintained between 16^{o} and 18.5^{o}C. Water quality parameters checked daily were: temperature, dissolved oxygen and pH. Total organic carbon levels were checked monthly.

Animals were fed daily a ration of either prepared puppy chow or fresh fish. The ratio of puppy chow to fresh fish was establised at 5 days : 2 days. Crayfish were fed ad liberatum and any food not consumed was removed prior to the next feeding.

To reduce injuries from fighting between crayfish, all animals' claws were banded. Bands were utilized during both holding periods and assays. The banding appeared to have no adverse effect on the animals.

2.2 Dilution Water

Dilution water used in all assays was collected in the general area of the crayfish collections. Water was transported to the laboratory in 55 gallon, high density polypropylene drums. At the laboratory pH and total organic carbon levels were measured and the water then stored in a cool room. Prior to use, the water was brought up to test temperature and pH and total organic carbon levels again checked.

2.0 METHODS AND MATERIALS

2.1 Crayfish

2.1.1 Species

Species used to assess the impacts of Seven-4-Oil^{R} were Cambarus bartoni and Orconectes virilis collected from regions of the Maine spruce-fir forest not included in the Spruce Budworm spray program. Identification of the species was confirmed by using keys in Freshwater Invertebrates of the United States (Pennak 1978).

2.1.2 Sources and Collection Techniques

C. bartoni were collected from several locations in the northern section of Maine with the majority of the animals being caught in; Upper Hudson Pond (T11 R10), Farran Pond Stream (T11 R9), plus Deny, Gardner, Perch and Togue Ponds in T15 R9. C. bartoni were taken by hand in the near shore zone during three collection efforts between May and October 1982. O. virilis were taken primarily from more southerly locations than C. bartoni; principal sources: Moosehead Lake (Greenville), Portage Lake (Portage) and Minnehonk Lake (Mount Vernon). As this species ranged into deeper water and was more agile than C. bartoni, baited minnow traps were used for collecting specimens. Traps were baited with either beef bones or fish racks and checked daily. Collections were made on four occasions between late June and October.

2.1.3 Transportation

Crayfish were transported in damp burlap bags within plastic buckets. This prevented the organisms from suffocating in oxygen depleted water during transit. Mortality associated with collection and transportation was minimal throughout the program.

To determine the effect of dilution water and if the laboratory water had an effect on pesticide toxicity, an assay was conducted using laboratory water. The laboratory water was treated in the same manner as the other dilution water.

2.3 General Experimental Protocol

2.3.1 Test Animals

Test animals were selected from the general laboratory population and randomly added to test chambers. C. bartoni selected for testing generally fell between 0.5 and 2.0 grams and ranged from 3 to 4 cm in length (eye socket to tip of telson). O. virilis were larger animals ranging from 5 to 15 grams and 5 to 8 cm in length. Both male and female specimens of C. bartoni were used for testing. All females were checked to insure they were not gravid. Assays with O. virilis were conducted exclusively with males as no females were collected.

2.3.2 Exposure Period

All assays conducted were run in a static culture mode for a period of 96 hours with partial replacement of the test solution at 48 hours. Observations of survival were made at 4, 8, 24, 48, 72 and 96 hours. Water quality checks were made at 24 hour intervals.

2.3.3 Test Chambers and Loadings

Test chambers were either 40 liter, all glass aquaria or 2 liter culture bowls, depending upon species and experimental design. Animal loading rates varied with species; 2 grams per liter for C. bartoni and 5 grams per liter for O. virilis.

2.3.4 Determination of Concentrations

Prior to conducting definitive assays, a series of 96 hour range finding tests were run to establish approximate no effect, LC-50 and LC-100 concentrations. Toxicant concentrations for definitive assays were clustered around these values to provide better estimates of the critical values. Range finding assays used 5 concentrations with 3 replicates each, 6-11 concentrations with 4-6 replicates were utilized in definitive assays. The variation in number of replicates reflected the number of chambers necessary to obtain a minimum number of specimens; 15 per concentration. The number of specimens per concentration ranged from 15 to 37.

2.3.5 Controls and Solvent Blanks

In addition to the test concentration each assay included a set of dilution water controls and as required a dilution water plus solvent carrier blank. The purpose of the solvent/carrier was to insure complete dissolution of the pesticide in the dilution water. The solvent blank contained a quantity of solvent equal to that found in the highest pesticide test concentration. The solvent/carrier used with carbaryl and alpha naphthol was methanol, while N-butanol was used with the Sevin-4-Oil^{R} tank mix, both solvents were certified as pesticide free. In the Sevin-4-Oil^{R} tank mix assays, a set of crayfish were also exposed to kerosene at a concentration equal to that in the highest tank mix treatment.

2.3.6 Critical End Points

Critical end points in the assays were LC-100, LC-50 and no effect concentration (LC-0). LC-50 values were obtained from a computer program developed by the U.S. EPA Environmental Research Laboratory, Duluth, Mn.

(Stephen, 1982). The program computes LC-50 values and 95% confidence intervals using moving average, binomial and probit techniques. LC-100 values were estimated and presented as the highest concentration with no significant surviving animals. The no effect concentration, LC-0, represents a range of values from the lowest value with significant mortality to the highest value with no significant mortality. In addition to establishing the 96 hour end points, test compound effects at shorter periods of exposure were also considered. Data sets from 24, 48 and 72 hour observation periods were evaluated to determine critical LC-100, LC-50 and LC-0 concentrations for these exposure periods.

For all assays an animal was considered to be dead when it showed no response to gentle probing of the eye stalk or movement of mouth parts and swimmerets when they were touched. Animals showing considerable stress were noted, but counted as alive.

2.3.7 Preparation of Test Solution

Stock solutions (10,000 mg/L) of carbaryl and alpha naphthol were prepared from technical grade products (99.8 and 99.7% purity respectively) dissolved in methanol, supplied by the Agricultural Products Division of Union Carbide Corporation. Sevin-4-Oil^{R} tank mix stock solutions were prepared from material supplied by the Maine Department of Conservation, Forestry Service, dissolved in N-butanol. Class A volumetric glassware was used to prepare all stock solution and final solutions for C. bartoni. Final solutions for O. virilis assays were prepared in large volume, calibrated containers. Final solutions were randomly selected and representative samples withdrawn for chemical analysis to ascertain the accuracy of concentrations.

3.0 RESULTS

To reduce the volume of text, LC-50 values computed by the probit technique will be presented in the results unless otherwise noted. All three values will be presented in the summary tables.

3.1 General Findings

3.1.1 Source Water

C. bartoni exposed to carbaryl in water from Maine exhibited a slightly higher LC-50 than animals exposed to carbaryl in well water, 5.73 and 2.36 mg/L respectively (binomial method). As the 95% confidence limits of these two values overlapped, Table 1., the difference was considered to be not significant, ANOVA results were similar.

3.1.2 Gender

Results from an assay exposing male and female C. bartoni to carbaryl are presented in Table 2. LC-50's for males and females were 2.23 and 2.41 mg/L respectively with 95% confidence limits of 1.51-3.30 and 1.56-3.74 indicating no significant difference in response to the pesticide. Further analysis of the data set by analysis of variance techniques showed no significant difference in response related to gender over the concentrations and exposure time evaluated.

An evaluation of this type could not be conducted with O. virilis due to insufficient numbers of female representatives.

TABLE 1. COMPARISON OF SURVIVAL DATA FOR CAMBARUS BARTONI EXPOSED TO CARBARYL IN DIFFERENT DILUTION WATERS.

Comparison of LC-50 with 95% Confidence Intervals
(Mg/L)

Water Source	pH	TOC	LC-50 Technique Binomial		Moving Average		Probit	
Northern Maine Stream	5.5	18 mg/L	5.73	5.0 10.0	2.90	1.6 6.4	3.66	2.00 7.11
New Hampshire Laboratory Well	5.6	25 mg/L	2.24	1.0 5.0	--		--	

Analysis of Variance

Source of Variation	Degrees of Freedom	Sum of Squares	Mean Squares	F_s	
Among Groups (Water Source)	1	3.6	3.6	0.195	ns
Within Groups (Concentration)	8	148.0	18.5		
Total	9	151.6			

$$\text{Expected } F_s = F_{0.05\ (1,8)} = 5.32$$

TABLE 2. COMPARISON OF SURVIVAL DATA FOR CAMBARUS BARTONI EXPOSED TO CARBARYL IN DIFFERENT DILUTION WATERS.

Comparison of LC-50 with 95% Confidence Intervals
(mg/L)

Water Source	pH	TOC	LC-50 Technique Binomial		Moving Average		Probit	
Northern Maine Stream	5.5	18 mg/L	5.73	5.0 10.0	2.90	1.6 6.4	3.66	2.00 7.11
New Hampshire Laboratory Well	5.6	25 mg/L	2.24	1.0 5.0	--		--	

Analysis of Variance

Source of Variation	Degree of Freedom	Sum of Squares	Mean Squares	F_s	
Among Groups (Water Source)	1	3.6	3.6	0.195	ns
Within Groups (Concentration)	8	148.0	18.5		
Total	9	151.6			

Expected $F_s = F_{0.05\ (1,8)} = 5.32$

3.2 Effects of carbaryl

3.2.1 Cambarus bartoni

Three sets of assays, one range finding and two definitive, were conducted with C. bartoni and carbaryl. Results are summarized in Table 3 and Appendices A, B and C. Initial range finding assays indicated an approximate LC-50 of 3.66 mg/L, while the definitive assays generated values of 0.72 and 1.28 mg/L with 95% confidence intervals of 0.54 - 0.89 and 0.83 - 1.85 mg/L respectively. LC-50 values from the three assays were in the same range, varying by less than 3.0 mg/L, but significantly different. Evaluation of time series from the first definitive assays showed decreasing LC-50 values with increased time of exposure. LC-50 values for 24, 48 and 72 hours were 1.66, 1.01 and 0.80 mg/L respectively. Values obtained after 72 hours of exposure were not significantly different from those at 96 hours.

The 96 hour LC-100 value established for C. bartoni exposed to carbaryl was 6.0 mg/L. Evaluation of earlier observations showed 24-hour LC-100 value as 6.0 mg/L. No effect concentrations for carbaryl ranged from 0.1-0.5 mg/L at all time elements evaluated.

Effects of very high concentrations of carbaryl were observed in an assay where concentrations were inadvertently mixed at 10 times proposed levels. Concentrations from 50-100 mg/L had dramatic effects resulting in 100 percent mortality within 2 hours. Near total mortality was observed within 1 hour at 100 mg/L. Animals' behavioral responses were more dramatic than observed in other assays as well. The crayfish were much more aggressive looking, waving their claws about and moving about rapidly. They also made numerous unsuccessful attempts to escape from the chambers.

TABLE 3. SUMMARY OF LC-50, LC-100 AND NO EFFECT CONCENTRATIONS (MG/L) FOR CAMBARUS BARTONI EXPOSED TO CARBARYL.

LC-50 With 95% Confidence Intervals (mg/L)

Assay	Period of Exposure	Technique: Binomial		Moving Average		Probit	
Range Finding	96 hr.	5.73	0.5 10.0	2.90	1.64 5.41	3.66	2.00 7.11
Definitive 1	24 hr.	1.5	1.0 3.0	1.46	1.19 1.80	1.66	1.39 1.98
	48 hr.	1.08	0.5 1.5	0.90	0.72 1.10	1.01	0.83 1.20
	72 hr.	0.75	0.1 1.5	0.76	0.59 0.95	0.80	0.61 0.98
	96 hr.	0.75	0.1 1.5	0.70	0.54 0.89	0.72	0.54 0.89
Definitive 2	96 hr.	0.94		1.32	0.79 1.99	1.28	0.83 1.85

LC-100 (mg/L)

24 hr.	6.0
48 hr.	6.0
72 hr.	6.0
96 hr.	6.0

LC-0/No Effect Concentration (mg/L)

24 hr.	0.1 - 0.5
48 hr.	0.1 - 0.5
72 hr.	0.1 - 0.5
96 hr.	0.1 - 0.5

Evaluation of survival between replicates from definitive assay 1 after 96 hours of exposure, showed no significant difference between the LC-50 values (Appendix C).

3.2.2 Orconectes virilis

A series of two definitive assays were conducted with O. virilis and carbaryl. Results are summarized in Table 4. and Appendices A, B and C. Ninety-six hour LC-50 values generated from the two tests were 2.01 and 2.03 mg/L with 95% confidence intervals of 1.69-2.40 and 1.67-2.40 mg/L. The values were not significantly different. LC-50 values from earlier observations, 24, 48 and 72 hours at 3.98 and 2.28 mg/L, show a consistent trend of decreasing values with increased exposure.

Ninety-six hour LC-100 value for O. virilis was 5.0 mg/L. This value increased to 6.0 mg/L at 72 and 48 hours and to 9.0 mg/L at 24 hours. No effect concentrations ranged from 0.75 to 1.0 mg/L at 72 and 96 hours and 1.5 to 2.0 at 24 and 48 hours.

3.3 Effects of Alpha Naphthol

3.3.1 Cambarus bartoni

Results of acute 96 hour assays for C. bartoni exposed to alpha naphthol are summarized in Table 5. plus Appendices A, B and C. The 96 hour LC-50 for this species was 13.83 mg/L with a 95% confidence interval of 11.83 to 15.68 mg/L. Earlier observations; 24, 48 and 72 hours followed earlier trends of increasing LC-50 with decreased periods of exposure. The 48 hour LC-50 was determined to be 16.06 while no accurate values were obtained for 24 and 48 hour observations as the value exceeded the highest test concentration of 35 mg/L.

TABLE 4. SUMMARY OF LC-50, LC-100 AND NO EFFECT CONCENTRATIONS (MG/L) FOR ORCONECTES VIRILIS EXPOSED TO CARBARYL.

LC-50 (mg/L)

Assay	Period of Exposure	Technique: Binomial		Moving Average		Probit	
Definitive 1	24 hr.	4.42	1.5 7.5	3.85	3.22 4.63	3.98	3.25 4.87
	48 hr.	2.61	1.5 6.0	1.96	1.59 2.45	3.25	2.16 3.02
	72 hr.	2.28	1.5 6.0	1.80	1.47 2.24	2.28	1.92 2.71
	96 hr.	2.23	1.0 3.0	1.61	1.31 1.99	2.01	1.69 2.40
Definitive 2	96 hr.	2.00	1.0 3.0	1.89	1.36 2.54	2.03	1.67 2.40

LC-100 (mg/L)

24 hr.	9.0
48 hr.	6.0
72 hr.	6.0
96 hr.	5.0

LC-0/No Effect Concentration (mg/L)

24 hr.	1.5 - 2.0
48 hr.	1.5 - 2.0
72 hr.	0.75 - 1.0
96 hr.	0.75 - 1.0

TABLE 5. SUMMARY OF LC-50, LC-100 AND NO EFFECT CONCENTRATIONS (MG/L) FOR CAMBARUS BARTONI EXPOSED TO ALPHA NAPHTHOL.

LC-50 (mg/L)

Assay	Period of Exposure	Technique: Binomial	Moving Average	Probit
Definitive	24 hr.	35	35	35
	48 hr.	35	35	35
	72 hr.	16.95 (10.0 – 25.0)	15.02 (12.69 – 18.13)	16.06 (13.55 – 18.65)
	96 hr.	14.06 (10.0 – 20.0)	12.86 (10.77 – 15.11)	13.83 (11.83 – 15.68)

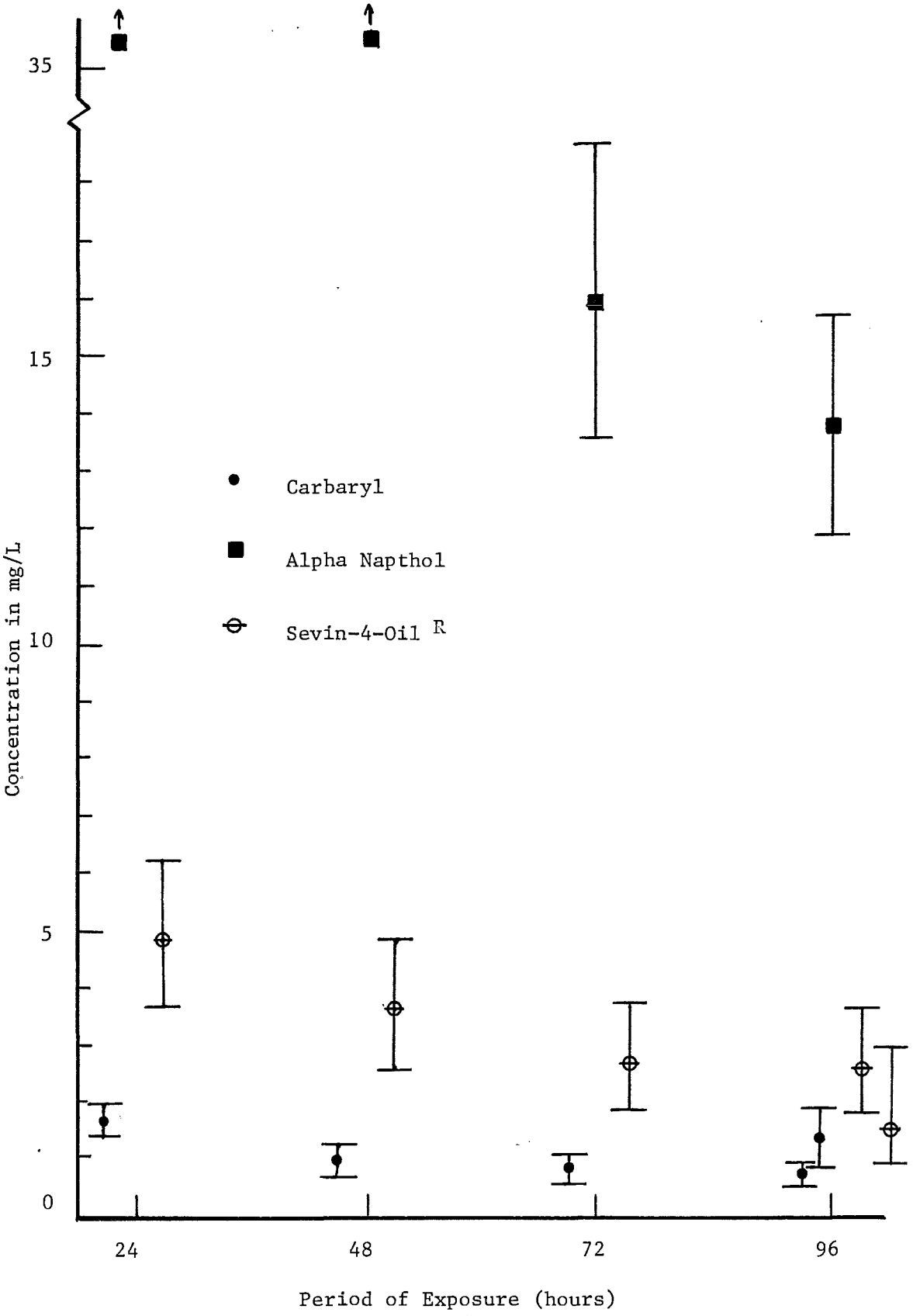
LC-100 (mg/L)

24 hr.	> 35
48 hr.	> 35
72 hr.	> 35.0
96 hr.	25.0

LC-0/No Effect Concentration (mg/L)

24 hr.	> 35.0
48 hr.	20.0-25.0
72 hr.	5.0-10.0
96 hr.	5.0-10.0

FIGURE 1. LC-50's AND 95 CONFIDENCE INTERVALS FOR CAMBARUS BARTONI EXPOSED TO CARBARYL, ALPHA NAPTHOL, AND SEVIN-4-OIL^{R}



LC-100 values decreased from 35.0 mg/L or greater from 24 through 72 hours to 25.0 mg/L at 96 hours. No effect concentration equaled 35.0 mg/L at 24 hours and decreased to between 5.0 and 10.0 mg/L by 96 hours.

3.3.2 Orconectes virilis

Ninety-six hour acute assay results for O. virilis exposed to alpha naphthol are summarized in Table 6. plus Appendices A, B and C. LC-50's were 30.98 and 32.67 mg/L with 95% confidence intervals of 28.39 - 33.80 and 30.28 - 35.23 respectively. LC-50's computed from observations at 24, 48 and 72 hours of exposure ranged from greater than 75 to 40.48 mg/L, the concentration at each observation being significantly different.

LC-100 values showed little change at the four observations; ranging from 75.0 mg/L at 24 hours to 50-75.0 mg/L at 96 hours. No effect concentrations decreased steadily from 50.0 - 75.0 mg/L at 24 hours to 15 - 20.4 mg/L at 96 hours.

3.4 Effect of Sevin-4-Oil^{R} Tank Mix

Results of acute exposure assays conducted with C. bartoni and Sevin-4-Oil^{R} tank mix are summarized in Table 7. Ninety-six hour LC-50 values ranged from 1.55 (moving average) to 2.66 mg/L with 95% confidence intervals of 0.85 - 3.01 mg/L and 1.87 - 3.63 mg/L respectively. LC-50's for shorter periods of exposure decreased from 4.86 to 2.73 mg/L at 72 hours. Values for the 48, 72 and 96 hour observations were not significantly different. The 96 hour LC-100 was calculated to range from 7.5 to 10 mg/L while the no effect concentration at that time ranged from 0.5 to 0.1 mg/L.

TABLE 6. SUMMARY OF LC-50, LC-100 AND NO EFFECT CONCENTRATIONS (MG/L) FOR ORCONECTES VIRILIS EXPOSED TO ALPHA NAPHTHOL.

LC-50 (mg/L)

Assay	Period of Exposure	Technique: Binomial	Moving Average	Probit
Range Finding	96 hr.			
Definitive 1	24 hr.	75.0	75.0	75.0
	48 hr.	54.46 (35 – 75)	52.09 (48.72 – 55.84)[1]	51.88 ±
	72 hr.	40.25 (30 – 50)	42.81 (40.45 – 45.32)	40.48 (34.42 – 49.10)
	96 hr.	32.17 (20 – 50)	31.03 (28.57 – 33.92)	30.98 (28.39 – 33.80)
Definitive 2	96 hr.	32.17 (20 – 50)	33.01 (30.38 – 35.73)	32.67 (30.28 – 35.23)

LC-100 (mg/L)

24 hr.	75.0
48 hr.	75.0
72 hr.	75.0
96 hr.	50 - 75.0

LC-0/No Effect Concentration (mg/L)

24 hr.	50.0 - 75.0
48 hr.	35.0 - 50.0
72 hr.	30.0 - 35.0
96 hr.	15.0 - 20.0

1 - Bracketed values have a significant potential to under or over estimate the actual LC-50.

TABLE 7. SUMMARY OF LC-50, LC-100 AND NO EFFECT CONCENTRATIONS (MG/L) FOR CAMBARUS BARTONI EXPOSED TO SEVIN-4-OIL^{R} TANK MIX.

LC-50 With 95% Confidence Intervals (mg/L)

Assay	Period of Exposure	Technique: Binomial		Moving Average		Probit	
Definitive 1	96 hour	2.69	1.0 5.0	1.55	0.85 3.01	1.56	0.0 +
Definitive 2	24 hour	6.12	5.0 2.5	4.26	3.44 5.36	4.86	3.70 6.21
	48 hour	4.46	2.5 5.0	3.43	2.68 4.34	3.58	2.60 4.80
	72 hour	2.97	2.5 5.0	2.87	2.14 3.69	2.73	1.92 3.76
	96 hour	2.01	1.0 2.5	2.80	2.07 3.60	2.66	1.87 3.64

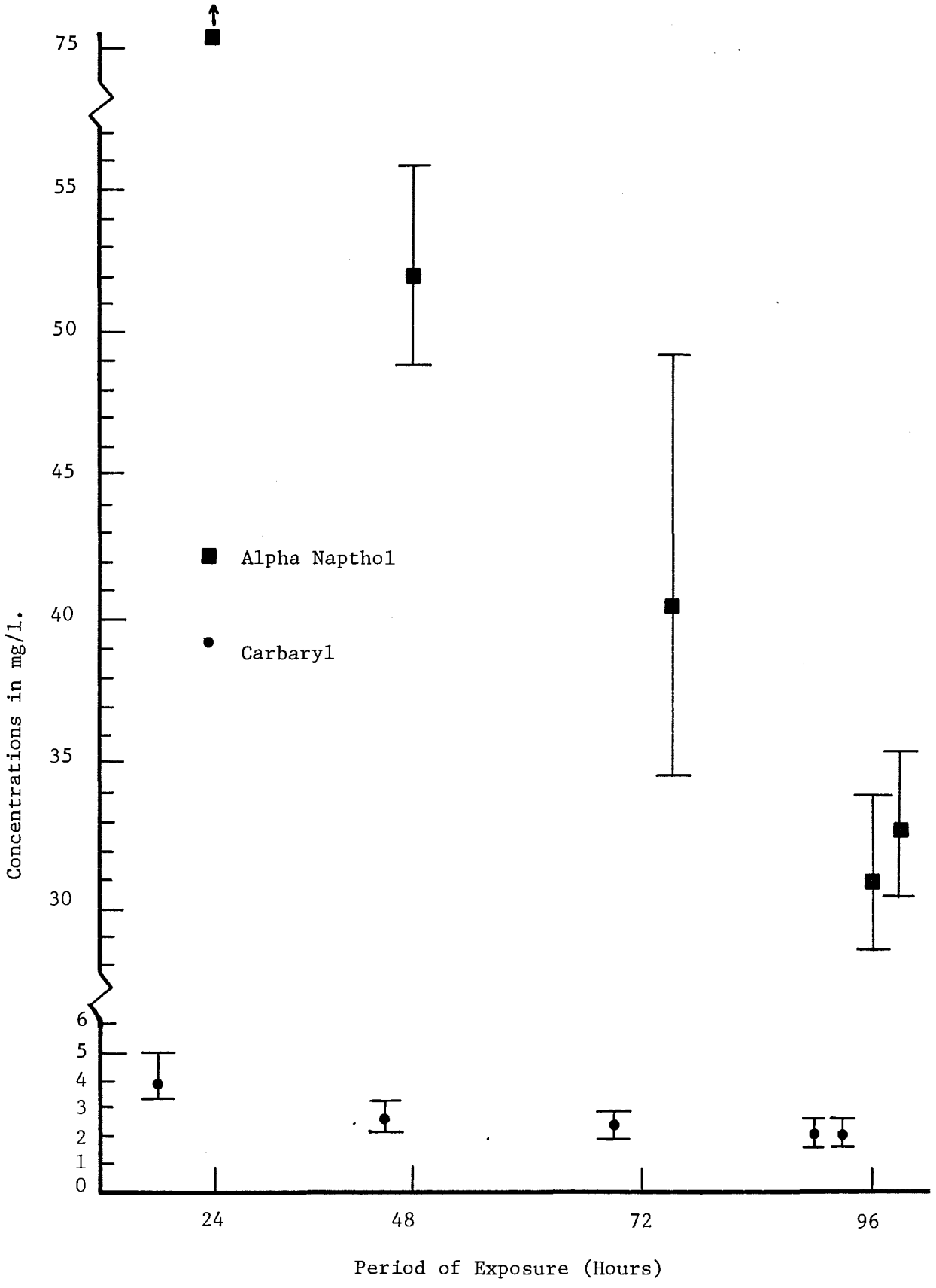
LC - 100 (mg/L)

24 hour	7.5
48 hour	7.5
72 hour	7.5
96 hour	7.5

LC-0/No Effect Concentration (mg/L)

24 hour	0.1 - 0.5
48 hour	0.1 - 0.5
72 hour	0.1 - 0.5
96 hour	0.1 - 0.5

FIGURE 2. LC-50s and 95% CONFIDENCE INTERVALS FOR ORCONECTES VIRILIS EXPOSED TO CARBARYL AND ALPHA NAPTHOL.



Evaluation of the kerosene/solvent blank showed that a kerosene concentration of 10 mg/L had no significant effect on C. bartoni survival during the 96 hour period of exposure.

4.0 DISCUSSION

4.1 Overview

- Comparison of sensitivities of the two test species, C. bartoni and O.virilis showed C. bartoni to be the more sensitive (Table 8).
- Comparative toxicities of the compounds were; Carbaryl = Sevin-4-Oil^{R} > Alpha Naphthol.
- The current limit of 0.03 mg/L carbaryl in surface waters is adequate to protect adult C. bartoni and O. virilis from increased mortality during short periods of exposure.

4.2 Preliminary Considerations

Prior to the start of definitive assays impacts on LC-50 values associated with effects of; holding water, gender and partial replacement of toxicant solutions were evaluated. Results of a series of tests comparing survival of C. bartoni exposed to carbaryl in holding water and water from northern Maine yielded no significant difference in response. This lack of a significant difference indicated either the overall composition of the two water sources to be similar or that water chemistry has little effect on carbaryl's toxicity. Based on these findings it was felt that maintaining crayfish stocks in laboratory well water prior to the assays would not significantly alter results of definitive assays.

With respect to test animal gender, Champ (1981) in a review of toxicological studies reported differences, of up to one order of magnitude, in LC-50 values between males and females of the same species. As collection of only female representatives was not practical, the effect of gender on response had to be documented. The lack of significant differences in response (mortality) between male and female C. bartoni exposed to carbaryl was considered as adequate support to conduct future assays with mixed

TABLE 8. SUMMARY OF ACUTELY LETHAL CONCENTRATIONS (MG/L) OF CARBARYL, SEVIN-4-OIL[R] AND ALPHA NAPHTHOL FOR CAMBARUS BARTONI AND ORCONECTES VIRILIS.

Compound	Species					
	Cambarus bartoni			Orconectes virilis		
	96 hour			96 hour		
	LC-0	LC-50	LC-100	LC-0	LC-50	LC-100
Carbaryl	0.1-0.5	0.72[1]	6.0	0.75-1.0	2.01	5.0
Sevin-4-Oil[R]	0.1-0.5	1.56	7.5	-	-	-
Alpha Naphthol	5.0-10.0	13.83	25.0	15.0-20.0	30.98	50.0-75.0

1 - When more than one value for a given parameter was available the lowest value was selected for this summary table.

populations.

The final set of preliminary studies indicated that replacement of half the test solution every 48 hours had no significant impact. A review of available literature indicated the breakdown rate of carbaryl was primarily controlled by solution pH and to a lesser degree, temperature (Trask 1982). Wolfe et.al. (1978) reported carbaryl to have a half life of 1500 days at a pH of 5.0 and 27^{o}C; Khasawinah (1977) reported carbaryl to be stable at pH's between 3 and 6 at 25^{o}C. Reports also show that biological breakdown and photodegradation of carbaryl were not as significant as pH in product breakdown (Trask 1982). As the pH of dilution water used in definitive assays ranged from 5.2-5.7 and assays were conducted at 16-18^{o}C the test products were considered to be stable over the 48 hour period. In addition to losses of carbaryl through breakdown, losses from the system by adsorption were also considered. Carbaryl was reported to be readily transported from surface waters to sediments (Union Carbide 1981, Gibbs et. al. 1981) suggesting another route by which pesticide concentrations might be altered during testing. Analysis of water samples collected from 48 and 96 hour intervals in the program (Appendix D) showed the level of the pesticide to remain relatively constant indicating little adsorption to the surfaces of the test chambers. It was not possible to document the breakdown rate of carbaryl to alpha naphthol as the analytical technique used required the derivatization of carbaryl to alpha naphthol prior to extraction and analysis.

A final test performed prior to the definitive assays was an evaluation of loading levels. Several aquaria were stocked with C. bartoni at a rate of 20 grams per liter and held for over two weeks. During the period mortality did not exceed that of the remainder of the laboratory stocks,

in addition, no changes in behavior were noted. It was noted that both species were very hardy and survived very well in conditions of high density and poor water quality. Of the two species C. bartoni was the more sensitive to overcrowding, low dissolved oxygen and poor water quality. Based on these findings the high densities in holding tanks and densities higher than 1 gram per liter in definitive assays had no significant impact on final results.

4.3 Effects of Carbaryl

Carbaryl was found to be more toxic to C. bartoni having a significantly lower LC-50 than O. virilis at all observation periods. Comparison of LC-0 and LC-100 values, with a single exception, show C. bartoni being more sensitive. The exception noted was attributed to the range of concentrations selected for the two sets of assays and not to differences in response. Comparison of these data with that reported in other studies, summarized in Table 9, shows C. bartoni and O. virilis having responses similar to Procambarus clarkii, the Louisiana red crayfish. At 48 hours, LC-50's for the three species were 1.01, 2.55 and 3.0 mg/L respectively. Comparison with other crustaceans showed smaller species, stone flies and water fleas, to be more sensitive than the large crayfish by up to three orders of magnitude. Review of available literature did not provide a direct assessment as to the reason for the observed difference between the two size groups. It is possible that the difference was due to greater surface to volume ratio of the small organisms as compared to larger species resulting in a more rapid uptake of the pesticide. As stated earlier by Weiden and Moorehead (1964) carbaryl acts by reducing the levels of acetylcholinesterase activity and subsequently blocking nerve impulses. This was evident in all assays. As test animals neared death they entered a period during

TABLE 9. COMPARISON OF LC-50 VALUES (MG/L) FOR CRUSTACEANS EXPOSED TO CARBARYL.

Species	Habitat	24-Hour LC-50 (mg/L)	48 Hour LC/50 (mg/L)
Pteronarcella badia[1] (Stone Fly)	Aquatic	0.005	--
Claassenia sabulosa[1] (Stone Fly)	Aquatic	0.012	--
Pteronarcys californiaca[1] (Stone Fly)	Aquatic	0.030	0.015
Gammarus lacustris[1] (Amphipod)	Aquatic	0.040	0.022
Callianassa californiensis[1] (ghost shrimp)	Marine	0.130	0.060
Daphnia pulex[1] (water flea)	Aquatic	--	0.006
Cancer magister[1] (Dungeness Crab)	Marine	0.62	--
Hemigraspus ovegonensis[1] (Shore Crab)	Marine	0.49	--
Procambrus clarkii[1] (Red Crayfish)	Aquatic	--	3.0
Cambarus bartoni (Crayfish)	Aquatic	1.66	1.01
Orconectes virilis (Crayfish)	Aquatic	3.98	2.55
Gamarus pseudocalamalus[2]	Aquatic	--	0.016 @ 96 hours

1 - Union Carbide 1982
2 - Schoettger and Manch 1976

which they had little control of their appendages followed by reduced activity and subsequent death. During this period the animals moved about in an extreme frenzy, waving claws and legs and did not respond to external stimuli in the normal manner. The response to carbaryl showed a sharp break between the LC-50 and LC-0 values and a relatively small range from LC-0 to LC-100 as compared to that observed for toxicants such as some metals and organics which do not interfere with the nervous system. This was attributed to carbaryl's mechanisms for action. It appears that the level of carbaryl in the animal's system has no effect until it approaches a critical limit, beyond that point death is quick. Weiden and Moorehead (1964) showed that animals exposed to sublethal concentrations quickly recovered from adverse effects and that the overall reaction was reversible if animals which had not died were transferred to fresh water. With respect to long term effect of carbaryl on crayfish Hendrick et. al. (1966) showed that Procambarus clarkii was not adversely affected by sublethal concentrations of carbaryl. Data from rice fields sprayed with carbaryl, at an unspecified rate, had total yields of crayfish similar to untreated fields; also the size and weight of individual crayfish were not affected.

Results from an unplanned test provided insight into effects associated with extremely high levels of carbaryl, similar to those associated with an accidental spill. Concentrations used in the study were 150, 100, 75 and 50 mg/L with a period of exposure of 24 hours. Animals in the 150 and 100 mg/L concentrations immediately began to lose control of their appendages and were dead within one hour. Animals exposed to 75 mg/L showed signs of stress within one hour of the exposure and 100% mortality within 4 hours. Concentrations of 50 mg/L produced 100% mortality between 12 and 24 hours. Results from the experiment show that at concentrations similar to those associated with a spill on the ground or accidental bulk dump of Sevin-4-Oil^{R} over a body of water will have a sudden dramatic effect.

4.4 Effects of Alpha Naphthol

Results from definitive assays showed alpha naphthol to be less toxic than carbaryl to C. bartoni and O. virilis by approximately an order of magnitude. As with carbaryl, C. bartoni were more sensitive than O. virilis when exposed to alpha naphthol.

Little data on the mode of action of alpha naphthol in crustaceans was reported in the literature. Based on the reaction of crayfish exposed to the compound it operates in a manner similar to that of carbaryl. Animals exposed to test concentrations above the LC-50 value were observed to lose coordination of their appendages prior to death, plus the range between LC-0 and LC-100 was again small indicating that if the compound exceeds a threshold value the animal is likely to die. Those animals exposed to concentrations below the threshold are only slightly impacted.

No comparative data was found for alpha naphthol and crustaceans closely related to crayfish. Butler et. al.(1968) evaluated the response of the cockle clam, Chinocardium nuttalli, to alpha naphthol and reported a 96 hour LC-50 value of 0.56 mg/L as compared to 0.8 mg/L for carbaryl. Butler reported that marine fish and shellfish were more sensitive to alpha naphthol than carbaryl, a situation not observed in these assays or in other literature concerning freshwater and marine crustacean species.

4.5 Effect of Sevin-4-Oil^{R}

Animals exposed to the commercial formulation of carbaryl, Sevin-4-Oil^{R} showed responses very similar to those of carbaryl. The sensitivity of C. bartoni was similar for both products as were the responses of test animals. As in the carbaryl assay animals exposed to higher concentrations 5-10 mg/L, exhibited a loss of coordination subsequently followed by death.

Animals exposed to Sevin-4-Oil^{R} at less than 1 mg/L showed little response. The data indicate that oils, kerosene and surfactants added to carbaryl in the reformulation process have no significant effect on the toxicity of the product when applied to C. bartoni.

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A COMPARISON OF BIRD POPULATIONS IN MORIBUND AND HEALTHY SPRUCE-FIR STANDS IN MAINE

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ABSTRACT

Bird populations were compared in two spruce-fir forest plots. Total numbers and species richness were greater in a moribund plot which had experienced some budworm caused defoliation in past years. This plot was characterized by high fir mortality and development of herbacaous ground cover and shrubs. A nearby plot, characterized by healthy spruce and some living fir, supported fewer numbers of birds. Greater habitat diversity in the moribund plot accounts for the differences in bird populations.

ACKNOWLDGEMENTS

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INTRODUCTION

As a result of eastern spruce budworm defoliation, many spruce and balsam fir stands have become moribund in northern Maine. The environmental impact of such widespread tree mortality has not been fully investigated. Although many components of the spruce-fir ecosystem are likely to be adversely affected, birds are excellent indicators of habitat changes and, because of their high visibility and audibility are well suited to field work in dense spruce-fir forests.

This study compares forest bird populations in a moribund and a relatively healthy spruce-fir stand and examines the habitat modifications resulting from spruce budworm induced tree mortality.

Since 1970, more than 40 research projects have focused upon birds which inhabit the spruce-fir forests of Maine and eastern Canada. Most studies have attempted to document perturbations of forest bird populations resulting from insecticide application for suppression of the eastern spruce budworm. The primary concern of these studies has been immediate post-spray effects caused by acute toxicity of the insecticides to the birds. However, there is now general agreement that the insecticides used in Maine for budworm suppression (carbaryl, acephate, aminocarb and Bacillus thuringiensis) are not acutely toxic to birds when applied at the operational rates.

Recently, Hunter (1981) and Hunter and Witham (1982) shifted this focus by searching for more subtle, indirect effects caused by food supply depletion. There reports indicate that short-term insecticide induced food reductions do not adversely affect the majority of insectivorous birds during a single breeding season. Birds appear able to compensate for short-term food supply depletions by consuming insects which were not

affected or by temporarily expanding their foraging ranges. Only when a species has a restricted foraging niche, and effects within that niche are severe, is there likely to be an adverse impact (USDA Forest Service 1982).

Spruce budworm induced conifer mortality represents an obvious niche disruption for species adapted to forage and nest in spruce and fir. However, the extent of these alterations has not been fully investigated. Drury et al (1980) detected minor population differences in areas of varying spruce-fir composition but did not include areas of extensive mortality in his survey of northern Maine. Gage and Miller (1978) showed population changes for several species in New Brunswick forest stands which had 80% mortality of balsam fir but attributed these changes to decreases in budworm density and did not document habitat alteration. Also in New Brunswick, MacDonald and Webb (1963) documented some changes in species composition as the coniferous overstory died as a result of budworm feeding.

Many authors, (e.g. Kendeigh 1947, Mook 1963, Germain 1980) have shown that some species of birds exhibit a positive numerical response during a severe budworm outbreak. The most commonly cited species are Tennessee warbler, Cape May warbler, bay-breasted warbler, evening grosbeak and yellow-bellied flycatcher. Lloyd-Evans (1982) demonstrated a collapse in populations of two of the species, bay-breasted and Cape May warblers, as budworm populations in parts of their breeding ranges declined. It is reasonable to assume that these, as well as other species which show a less obvious functional response, will be affected not only by long-term declines in budworm populations but declines in preferred budworm hosts, ie. spruce and fir, as well.

The principle objective of this study was to measure and compare bird populations within two habitats; a spruce-fir stand in moribund

condition due to budworm defoliation, and a stand of similar age class, composition and density in a relatively healthy condition due to past successful budworm suppression treatment.

METHODS

Site Selection

An aerial survey of Baxter State Park was flown in May, 1982 to search for moribund stands of sufficient size and accessibility. Adjacent townships were searched for stands of comparable age and composition in a healthy condition. Areas with excessively high budworm populations and areas contained in or adjacent to 1982 spray blocks were avoided. Since some temporary displacement of warblers occurs in carbaryl spray blocks (Hunter 1981) care was taken to locate study sites at least one mile from 1982 spray blocks. Logging operations were also avoided.

Field visits to finalize site selection were made in late May and early June. At this time the areas were mapped and census grids laid out. Each study site contained one rectangular 10 hectare grid, with numbered flags along grid lines at 50 meter intervals.

Stands were characterized using methods adapted from Lawrence and Houseweart (1981). Five plots were randomly selected, with a grid marker as the center of the plot. Concentric circular plots of .0004 ha (.001a), .008 ha (.02a) and .02 ha (.05a) were used to tally regeneration, undergrowth, and mature trees by counting the number of stems in each category in the respective plots.

Census Procedures

Spot-mapping was developed by Williams in 1936 and has since been used many times in studies of spruce-fir forest avifauna. Recommended standard procedures developed by the International Bird Census Committee (IBCC) (1970) were used to map bird territories.

Each plot was censused eight times during the breeding season. Censuses began at dawn and observers varied the starting and ending points on the grid so that all parts of the plot were encountered at different times.

RESULTS AND DISCUSSION

Study Sites

Two study sites were selected for comparison; spruce-fir stands in moribund and healthy condition. The species composition of the two stands was not identical; the healthy stand has a preponderance of spruce--70%, whereas the moribund stand had a higher percentage of fir--62%. However, it has often been reported that habitat selection by birds is more closely associated with vegetation structure, rather than with particular plant species (Peterson 1975).

The moribund plot was located in Baxter State Park in T4R10 WELS, immediately north of Nesowadnehunk field along the west side of the perimeter road. Known spray history, easy access, and proximity to non-moribund stands were principal selection factors. It was also large enough to preclude repeated visits by smaller species of birds nesting in non-moribund areas in adjacent townships. This area had not been sprayed for budworm suppression since 1973.

The healthy plot was located in T4R11 WELS, approximately 5 miles west of the moribund plot on land owned by Great Northern Paper Company. This stand consisted primarily of living spruce and fir, was only lightly infested by spruce budworm in 1982 and had good accessibility. It had been sprayed in 1979 and 1980 with Sevin-4-Oil^{R}.

Moribund Plot

The species composition based on the number of stems greater than 3 inches DBH, in this area is 32% spruce, 62% fir and 6% intolerant hardwoods (paper birch, grey birch, pin cherry). The stand is even

aged and mature with 95% of the overstory either dead or moribund. A few scattered red spruce constitute the only softwoods that are still alive. Blowdown is common in some areas, but many dead trees are still standing.

Fir regeneration is well established and dense; spruce seedlings are rare. There are some shade tolerant hardwood seedlings, primarily mountain ash and striped maple along with a mixture of blueberry and other woody shrubs in areas where the canopy is relatively closed. The ground beneath open canopy areas is dominated by dense clusters of raspberries and blowdown. Open areas are well interspersed throughout the stand.

Live Plot

Although this plot is considered healthy, it is so only relative to the moribund site and cannot be considered a vigorous stand. It is composed of 70% spruce (primarily red and black) and 24% balsam with minor components of other softwoods (white pine, northern white-cedar and hardwoods, (paper birch, yellow birch) making up the remaining 6% of the stand. This stand was also even aged and mature with 67% of the trees alive. Most of the mortality in the stand is fir, with 75% of all fir over 3 inches DBH dead and another 10% in a moribund condition. Most of the spruce--85%, is alive. The spruce occurs in two components. One component is red spruce in an even mix with balsam fir and the other is a nearly pure patch of black spruce.

Regeneration is more evenly split between spruce and fir, although it is much sparser than in the moribund plot. There are some hardwood seedlings (red and striped maple) and a mixture of woody shrubs (rhodora and sheep laurel) which are confined primarily to the moist soils of the black spruce patch.

The canopy is closed throughout the stand with the exception of 4 narrow strip cuts about 25 meters in width and varying in length.

Raspberries are not established, except in the strip cuts, and the forest floor is covered primarily with herbaceous plants or duff. There is little slash or woody ground cover except in the vicinity of the strip cuts.

Bird Populations

Fifty-four species of birds were encountered on the study sites during the breeding season. Of these, 27 were territorial on one or both plots and 27 were recorded only at transient visitors. The status of all 54 species is shown in Table 1.

Despite the obvious habitat differences, the two plots shared many common species. Table 2 lists the 15 species that were territorial on both plots. Mose of these species are characteristically associated with mature softwood stands. The exceptions are the hermit thrush and Nashville warbler, which are more characteristic of mixedwood stands; the magnolia warbler, which is generally associated with young softwoods; and the white throated sparrow and common yellow throat, both of which are typically found in early successional stages of disturbed areas. The latter two species were restricted, in the live plot, to the strip cuts (Appendix).

A comparison of bird species diversity indices (Tramer 1969) of the two sites reveals that both sites are about equally diverse, the moribund site having a diversity index of 2.82 versus 2.58 for the live site. These values are comparable to those described in other northeastern softwood stands. Most species were represented approximately equally and no one species dominated either plot.

The species richness, that is the total number of bird species, of the two areas was similar. The live plot had 19 territorial species while the moribund plot had 23. However, the total number of territories was greater on the moribund plot, 64 or 256/40 ha, than on the live plot, 45 or 180/40 ha. Since there were no repetitions of study sites, it is

TABLE 1. STATUS OF ALL SPECIES ENCOUNTERED ON STUDY SITES.

V = Visitor T = Territorial - = Not encountered

SPECIES	LIVE PLOT	MORIBUND PLOT
broad-winged hawk	V	V
ruffed grouse	-	T
common flicker	-	V
pileated woodpecker	V	-
yellow-bellied sapsucker	-	V
hairy woodpecker	V	-
downy woodpecker	V	-
black-backed three-toed woodpecker	V	T
northern three-toed woodpecker	V	-
yellow-bellied flycatcher	T	T
eastern wood pewee	-	V
olive-sided flycatcher	V	-
blue jay	V	V
gray jay	T	-
boreal chickadee	V	V
red-breasted nuthatch	-	V
brown creeper	V	T
winter wren	T	T
American robin	-	V
wood thrush	-	V
hermit thrush	T	T
Swainson's thrush	T	T
golden-crowned kinglet	T	T
ruby-crowned kinglet	-	V

SPECIES	LIVE PLOT	MORIBUND PLOT
cedar waxwing	V	T
solitary vireo	T	-
red-eyed vireo	-	T
Tennessee warbler	T	T
Nashville warbler	T	T
northern parula warbler	-	T
magnolia warbler	T	T
Cape May warbler	T	T
yellow-rumped warbler	T	T
black-throated green warbler	T	-
blackburnian warbler	T	T
chestnut-sided warbler	V	-
bay-breasted warbler	T	-
blackpoll warbler	V	-
ovenbird	-	T
common yellowthroat	T	T
mourning warbler	V	T
Canada warbler	-	V
American redstart	-	V
common grackle	-	V
scarlet tanager	V	-
rose-breasted grosbeak	-	V
evening grosbeak	V	V
purple finch	T	T
pine grosbeak	V	-

SPECIES	LIVE PLOT	MORIBUND PLOT
pine siskin	V	V
red crossbill	V	V
dark-eyed junco	T	T
chipping sparrow	-	V
white-throated sparrow	T	T
TOTALS:		
Number of species encountered	37	41
Visiting species	18	18
Territorial species	19	23

Total number of species encountered, both plots: 54

TABLE 2. SPECIES WHICH WERE TERRITORIAL IN BOTH STUDY AREAS

MS = mature softwood
MW = mixedwood
IS = immature softwood
ES = early successional stage

SPECIES	GENERAL HABITAT ASSOCIATION
yellowed-bellied flycatcher	MS
winter wren	MS
hermit thrush	MW
Swainson's thrush	MS
golden-crowned kinglet	MS
Tennessee warbler	MS
Nashville warbler	MW
magnolia warbler	IS
Cape may warbler	MS
yellow-rumped warbler	MS
blackburnian warbler	MS
common yellowthroat	ES
purple finch	MS
dark-eyed junco	MS
white-throated sparrow	ES

impossible to ascertain if these numbers are representative of other, similar stands. However, species richness and total number of territories compare favorably to those reported by Crawford and Titterington (1979) in a review of spruce-fir forest bird censuses. In the reported censuses, the number of territorial pairs per 40 hectares varied from 112 in a pure, uninfested balsam fir forest to 350 in a spruce-fir forest harboring epidemic population levels of spruce budworm. Spruce fir forests with endemic budworm population levels were reported to support from 131 pairs per ha. to 249. Likewise, bird species richness ranged from 19 species in a pure balsam fir forest in Saskatchewan to 31 species in a spruce-fir forest with epidemic budworm populations in Maine, and 36 under similar condition in Ontario. Crawford and Titterington concluded that numbers of spruce budworm and diversity of horizontal and vertical stand structure were important influences on spruce-fir forest bird populations. Neither plot had large populations of spruce budworm in 1982, but it is apparent that the greater habitat diversity in the moribund plot allowed greater territory stratification among the species, and accounted for the larger number of bird territories.

It is even more enlightening to partition the bird species into associations. These associations, based on habitat preferences are shown in Table 3. These associations are not rigid; some species are less specific in their habitat requirements or show some degree of variation in habitats selected from one region to another. However, the associations in Table 3 hold true for these 2 study sites.

Mature Softwood Association

In the mature softwood association, the most obvious difference is in the bark gleaning guild composed of the black-backed three-toed woodpecker and the brown creeper. The numerous dead trees in the moribund plot

TABLE 3. NUMBERS OF TERRITORIES WITHIN HABITAT ASSOCIATIONS

HABITAT ASSOCIATION		SPECIES	NUMBER OF TERRITORIES	
			Live Plot	Moribund Plot
Mature Softwood				
a.	bark gleaning species	black-backed three-toed woodpecker	0	2
		brown creeper	0	1
		SUBTOTAL	0	3
b.	species primarily associated with the upper canopy	golden-crowned kinglet	1	2
		northern parula warbler	0	1
		Cape May warbler	2	3
		yellow-rumped warbler	8	9
		black-throated green warbler	1	0
		blackburnian warbler	9	9
		bay-breasted warbler	1	0
		purple finch	1	1
		SUBTOTAL	23	25
c.	species generally dwelling below the canopy	yellow-bellied flycatcher	3	2
		gray jay	1	0
		winter wren	1	1
		Swainson's thrush	1	2
		Tennessee warbler	1	1
		dark-eyed junco	5	4
		SUBTOTAL	12	10

TABLE 3. (cont.)

HABITAT ASSOCIATION	SPECIES	NUMBER OF TERRITORIES	
		Live Plot	Moribund Plot
Young Softwood	solitary vireo	1	0
	magnolia warbler	2	5
	SUBTOTAL	3	5
Early successional stage	mourning warbler	0	2
	common yellowthroat	1	1
	white-throated sparrow	3	7
	SUBTOTAL	4	10
Mixedwood	ruffed grouse	0	1
	cedar waxwing	0	1
	hermit thrush	2	1
	red-eyed vireo	0	1
	Nashville warbler	1	4
	ovenbird	0	3
	SUBTOTAL	3	11

provided ample foraging opportunities to support the woodpeckers, which typically have large territories. The loose bark, characteristic of standing dead balsam fir, provided a nest site for a brown creeper pair. The number of woodpecker species visiting the live plot (Table 1) was actually greater than the moribund plot. Even the rare northern three-toed woodpecker was sighted twice. But none of these visiting woodpeckers were encountered often enough to delineate a territory. Undoubtedly, the plot was included in the territories of many of these woodpeckers. However, the large size of woodpecker territories, and the lack of concentration of foraging sites (i.e. dead trees) precluded numerous repeat observations in the live plot. In contrast, the territorial black-backed three-toed woodpeckers were present daily on the moribund plot probably due to the greater concentration of dead trees which resulted in more numerous foraging opportunities.

The other species associated with mature softwood were about equally represented on both plots. The total number of territories in both the canopy and sub-canopy guilds was similar.

The species representing the greatest number of territories, the yellow-rumped and blackburnian warblers, along with the dark-eyed junco were about equally represented on both plots. The strong presence of the blackburnian warbler in the moribund plot is surprising in light of the poor condition of the softwood canopy. One possible explanation is that, even though habitat quality has declined, the number of birds has not yet begun to follow. This may be due to saturation of the surrounding healthy areas, forcing some birds into less than optimum sites, or it may be that site affinity has caused birds to return to areas where they had previously nested, or had been fledged. In the latter case, only when breeding success in the moribund area is greatly reduced will the effects of

site affinity decline. In either case it may be expected that the decline in spruce-fir canopy associated species will lag somewhat behind habitat decline. If surrounding areas remain healthy and produce surplus birds the surplus will compensate for decreased productivity on the moribund site (Stewart and Aldrich 1952). Surrounding areas may remain saturated and some individuals will continue to be forced into sub-optimum habitat until it has declined to the point of losing all structural similarity to living stands.

The softwood associated species that were not found on both plots may have been missed because of the small size of the plots and the lack of replication of study sites. In all cases where a species was absent on 1 plot there was only one territory of that species in the other plot, indicating low expected populations.

It is in the 3 remaining habitat associations that the real difference in species composition is apparent.

Young Softwood Association

The solitary vireo is more characteristic of a softwood understory, whereas the magnolia warbler is generally found in advanced regeneration that is not overtopped by mature trees. The greater degree of openness in the moribund plot probably accounts for the higher number of magnolia warblers (Table 3).

Early Successional Stage Association

In this association there is an obvious difference in bird species composition. This difference is even greater if the edge effect, produced by narrow strip cuts in the live plot, is discounted. The territory maps for the common yellow throat and white-throated sparrow (Appendix) show that these species were restricted to the strip cuts in the live plot. These species, along with the mourning warbler, are more evenly distributed in the moribund plot.

Mixedwood Association

The greater number of species of this association in the moribund plot is evident from Table 3. The mixed character of the moribund plot is not necessarily a result of budworm caused mortality to softwoods, although release of suppressed hardwood has occurred. As hardwoods temporarily replace softwoods in many locations within this site, the mixedwood association should continue to be strongly represented.

CONCLUSIONS

Both plots possessed avifauna of a diverse nature. The number of territories found was comparable to the numbers reported in other studies on similar sites.

Mature softwood associated species were well represented on both plots, even the moribund plot in spite of the extremely poor condition of the spruce and fir. The principal differences were in the early successional stage species (common yellow-throat, mourning warbler and white-throated sparrow) which were well represented in the moribund plot, but only poorly represented in the live plot. Mixedwood associated birds were also present in greater numbers in the moribund plot, as were the mature softwood associates that specialized in bark-gleaning. However, the sample size was too small to allow statistical comparisons. A greater number of territories, 256/40 ha was found in the moribund plot versus 180/40 ha on the live plot. Greater habitat diversity, especially the presence of dense ground cover and released hardwoods, in the moribund site accounts for these differences, and is the direct result of severe defoliation by the spruce budworm in recent years.

It is likely that the moribund site will continue to support more species and individuals until the softwood canopy deteriorates completely. Although bird species which prefer the canopy may continue to establish

territories for a few more years in the moribund plot, their reproductive success will probably be low, due to the sub-optimum nature of the habitat. Eventually the dead trees will be removed through the actions of wind and decay. Early successional species and mixedwood species will increase, but without the overstory stratum this plot will probably not be as rich in species as it now is.

As long as the overstory spruce remains healthy on the live plot, little change in avifauna can be expected. An increase in spruce budworm population could result in temporary increases for several species which are known to respond numerically to budworm infestations, such as the Cape-may, bay-breasted, and Tennessee warblers.

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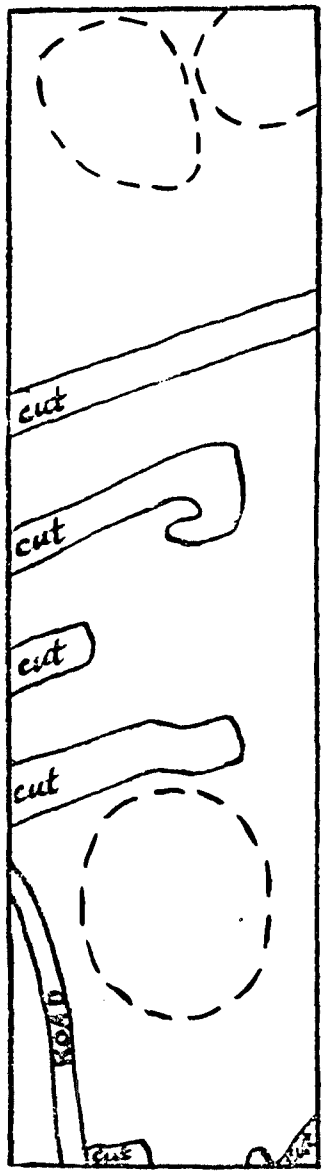
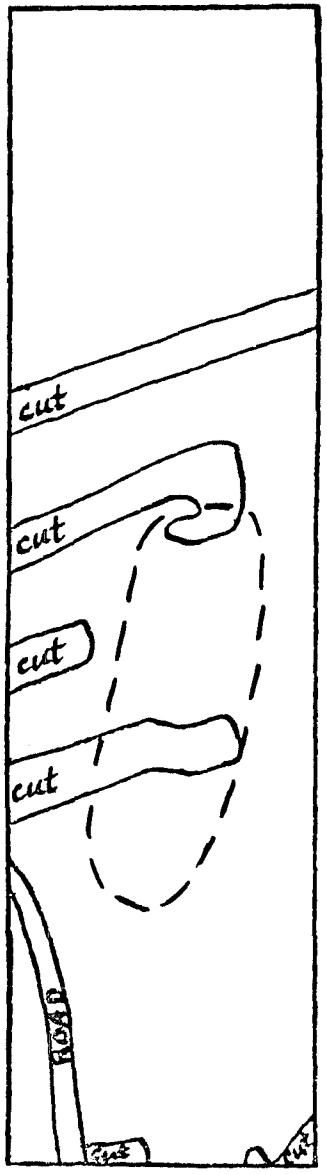
APPENDIX

BIRD TERRITORIES ON LIVE AND MORIBUND STUDY PLOTS

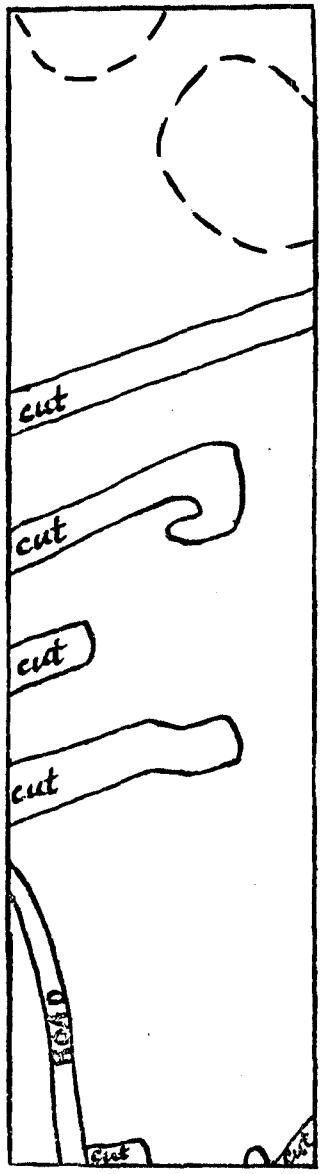
Bird territories. Live plot



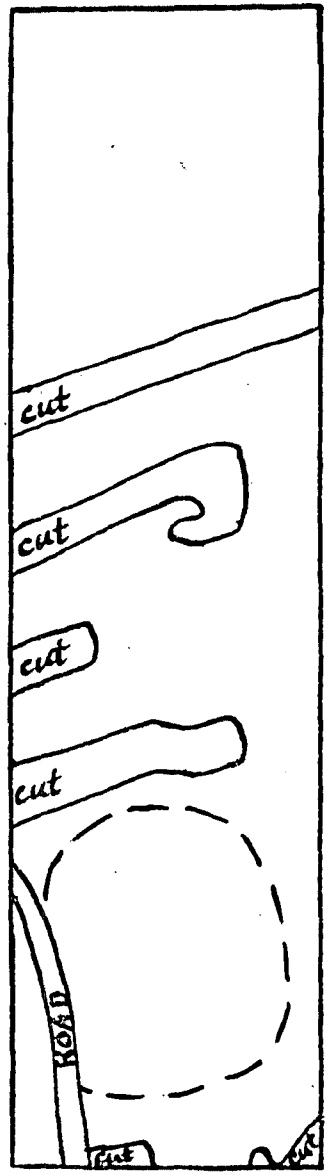
Yellow-bellied fly-catcher



Winter wren

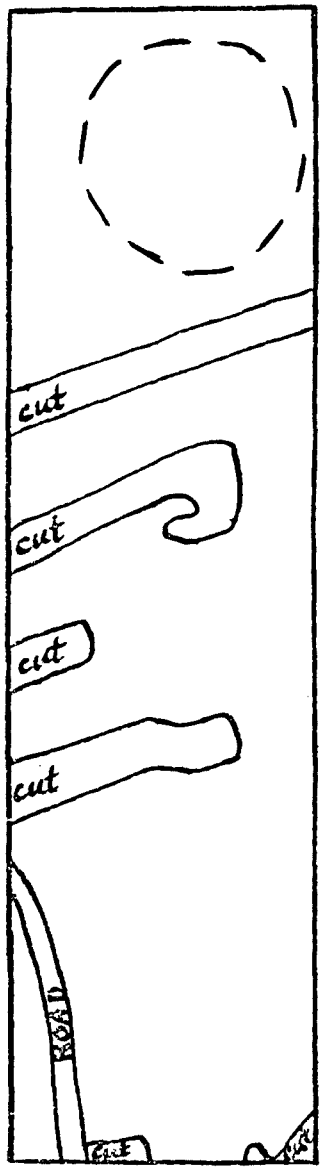


Hermit thrush

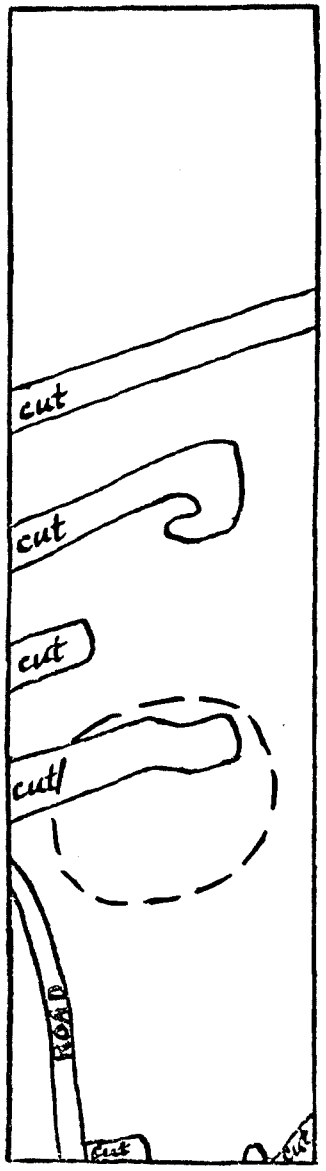


Swainson's thrush

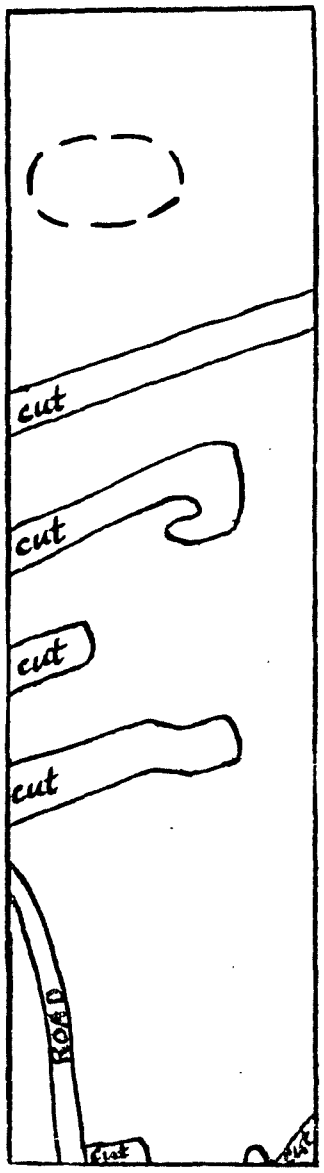
Bird territories. Live plot



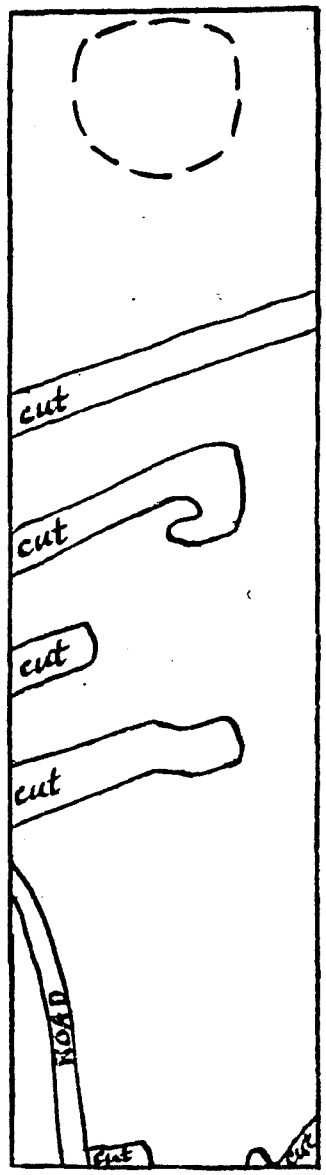
Golden crowned king-let



Solitary vireo

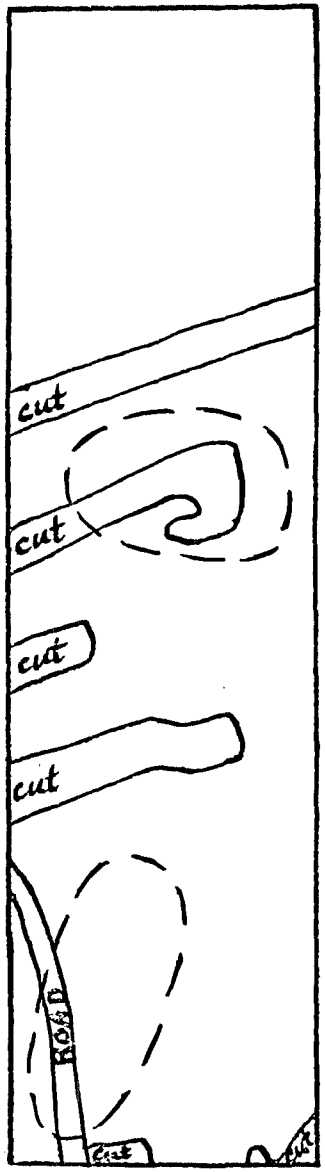


Tennessee warbler

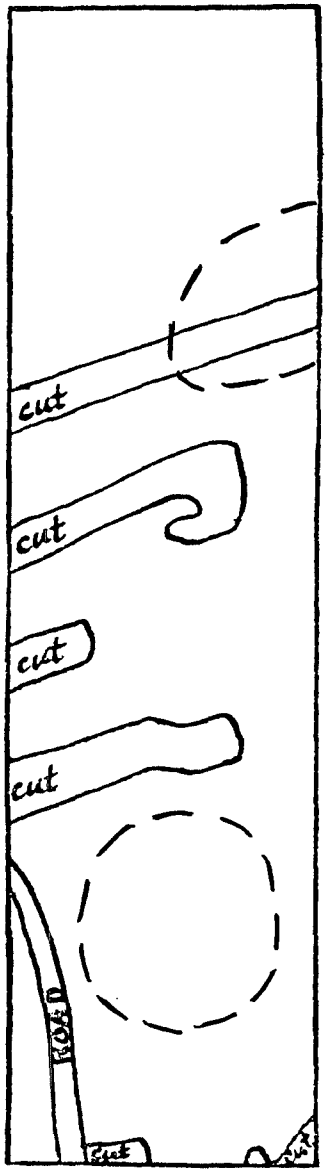


Nashville warbler

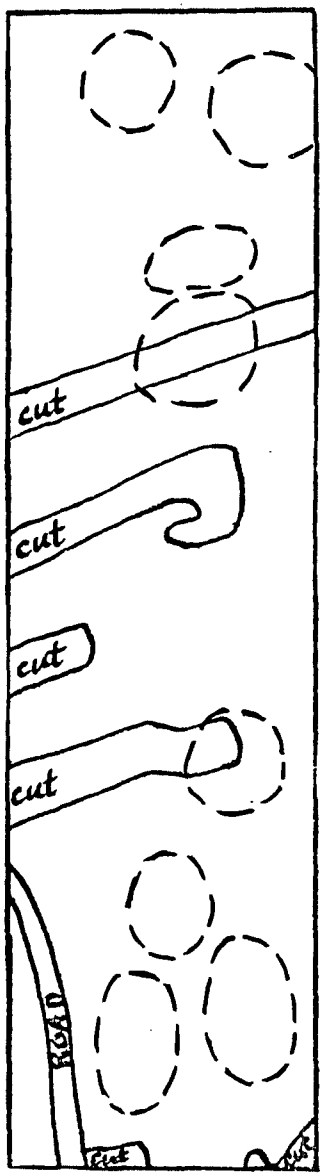
Bird territories. Live plot



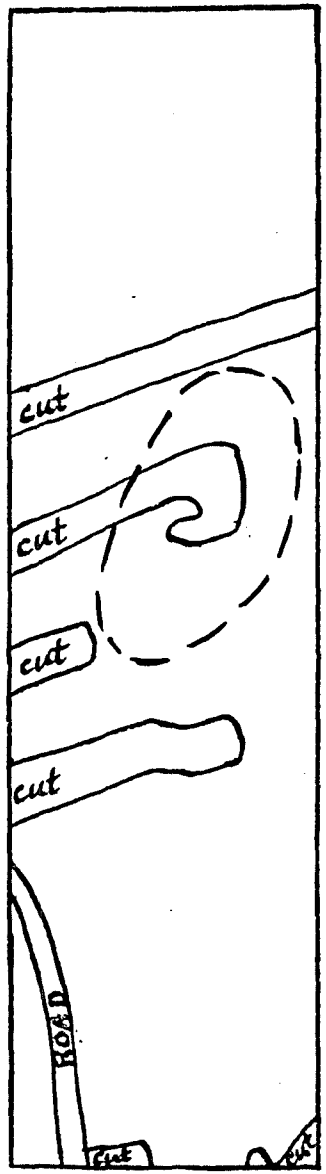
Magnolia warbler



Cape May warbler

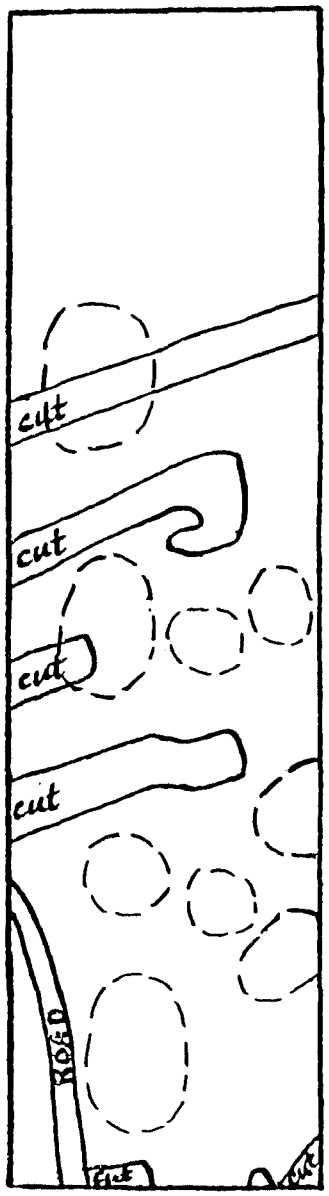


Yellow-rumped warbler

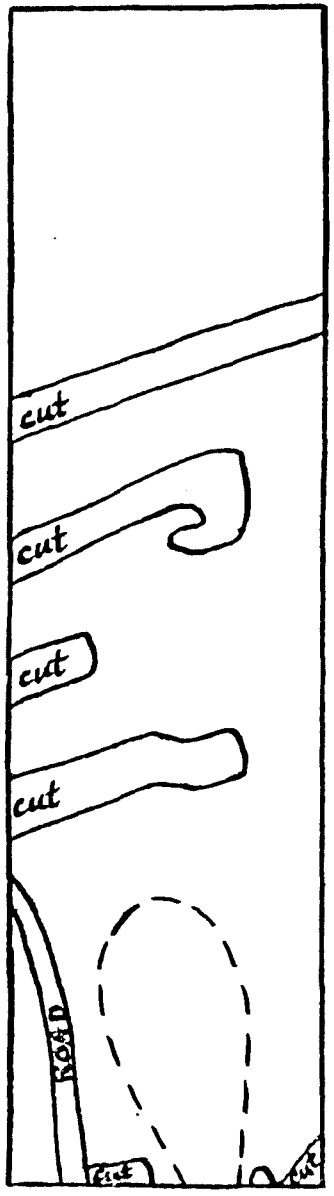


Black throated green warbler

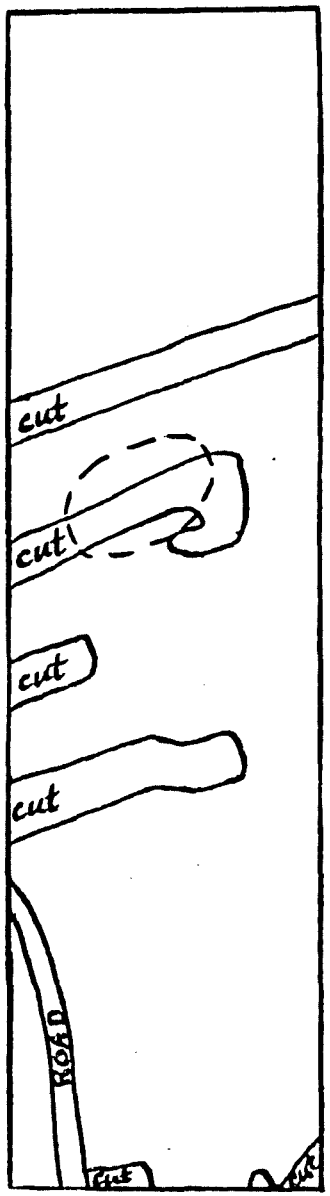
Bird territories. Live plot. Continued



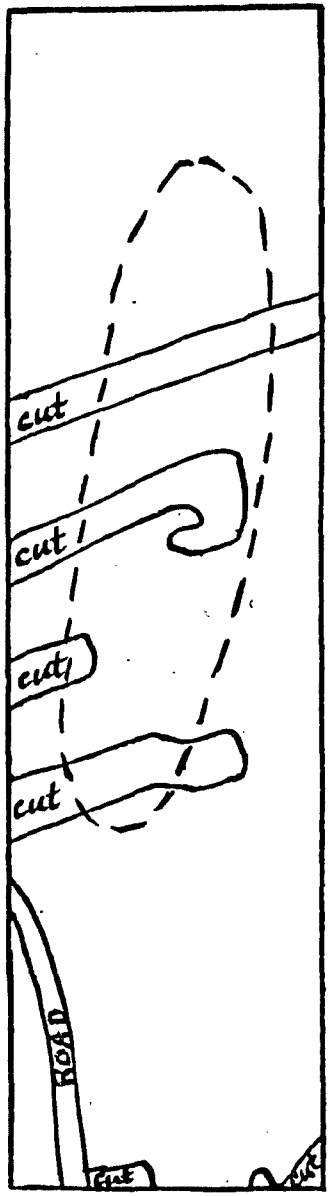
Blackburnian warbler



Bay-breasted warbler

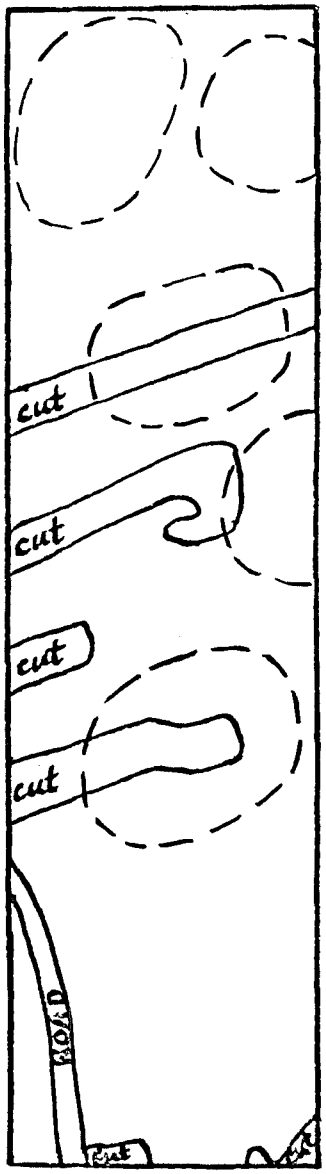


Common yellowthroat

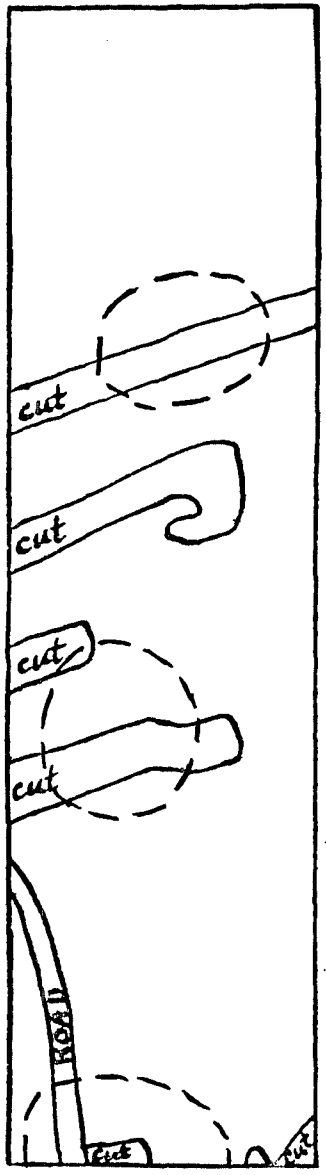


Purple finch

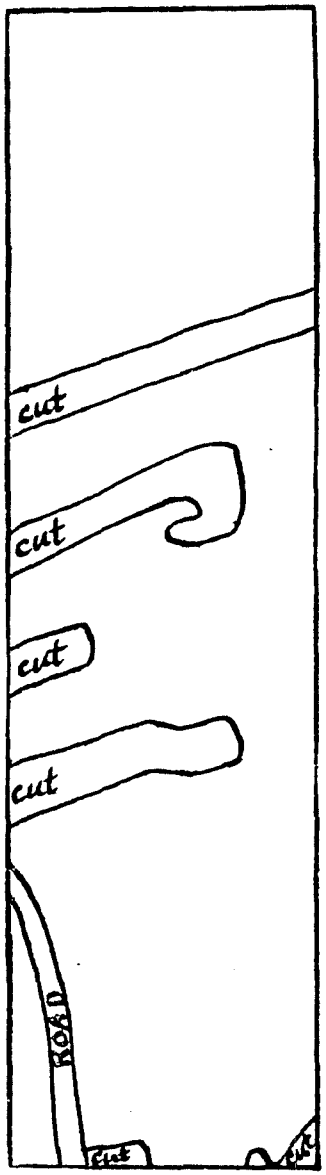
Bird territories. Live plot.

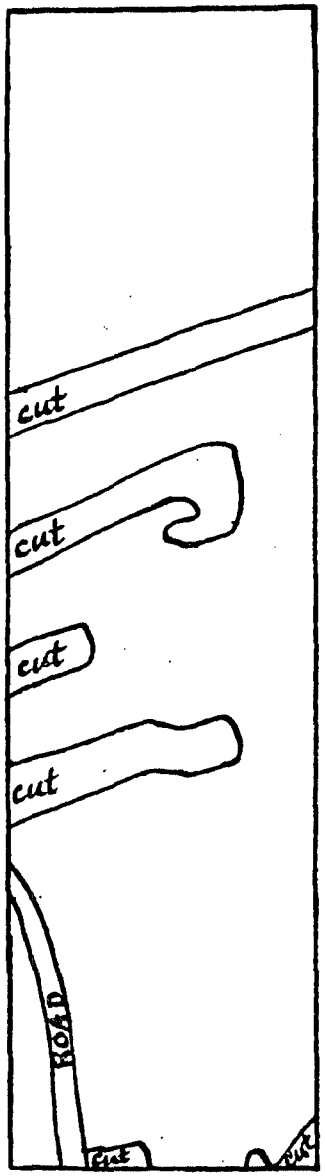


Dark-eyed junco

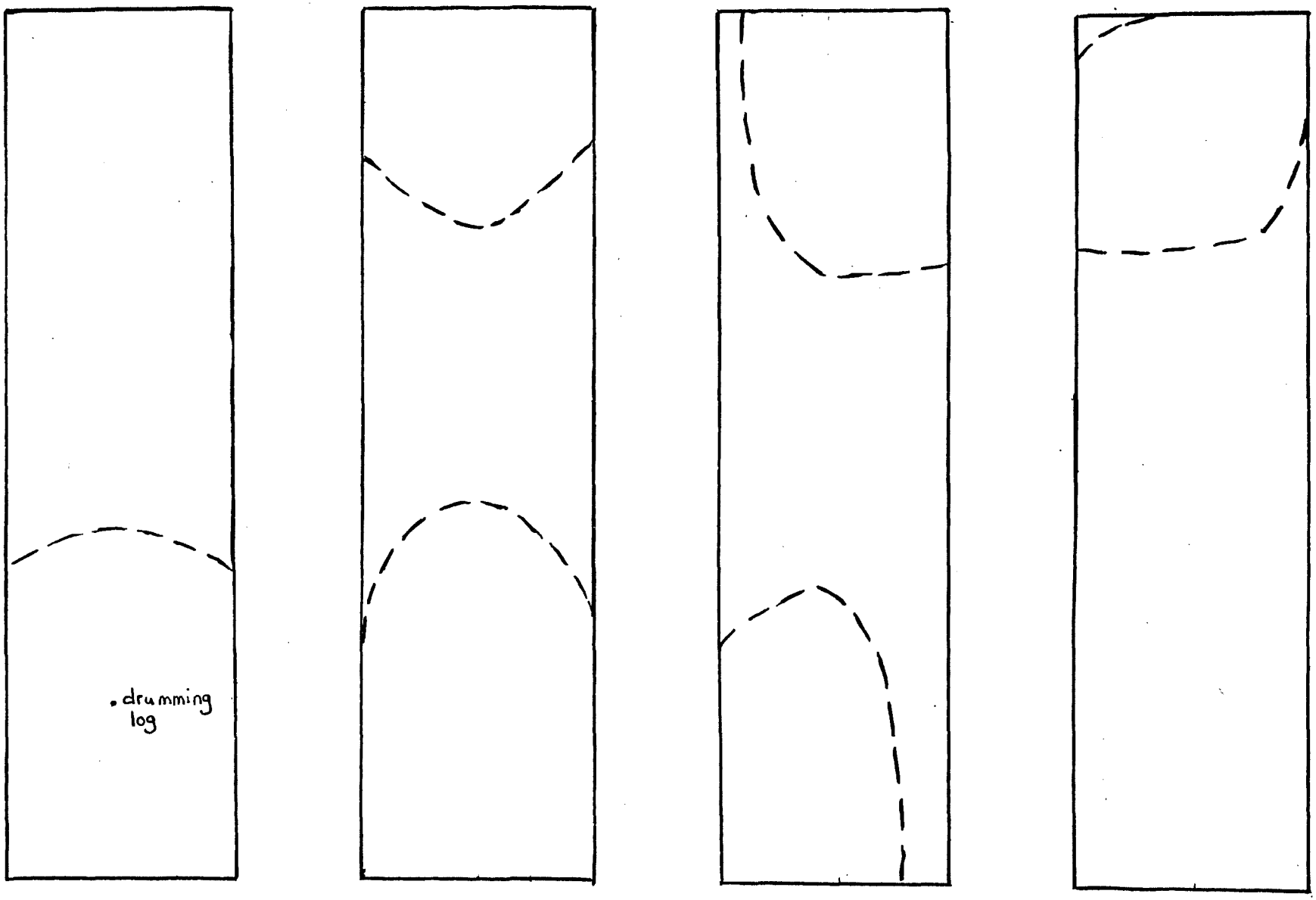


White-throated sparrow





Bird territories. Moribund plot.



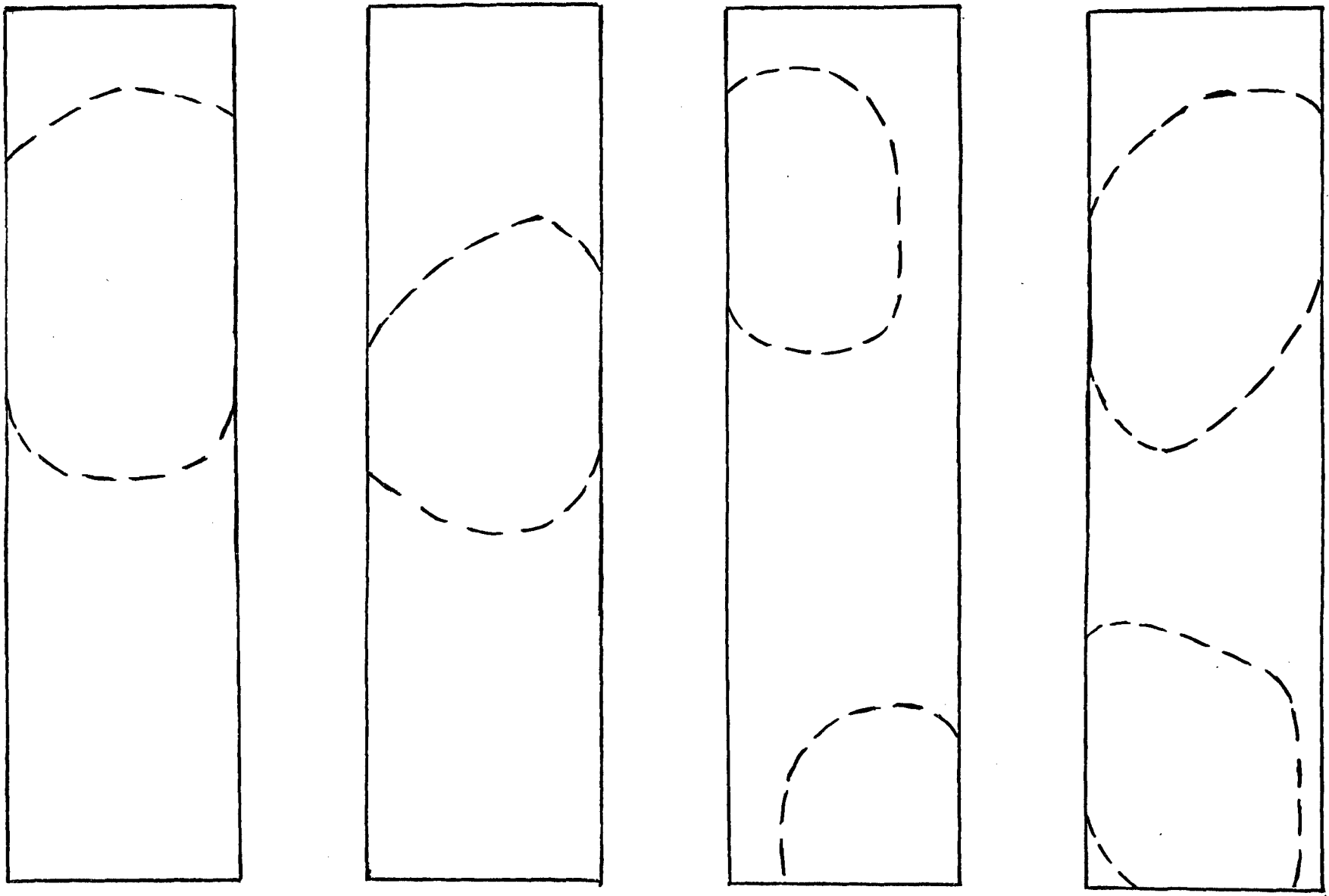
Ruffed grouse

Black-backed three toed woodpecker

Yellow-bellied fly-catcher

Brown creeper

Bird territories. Moribund plot.



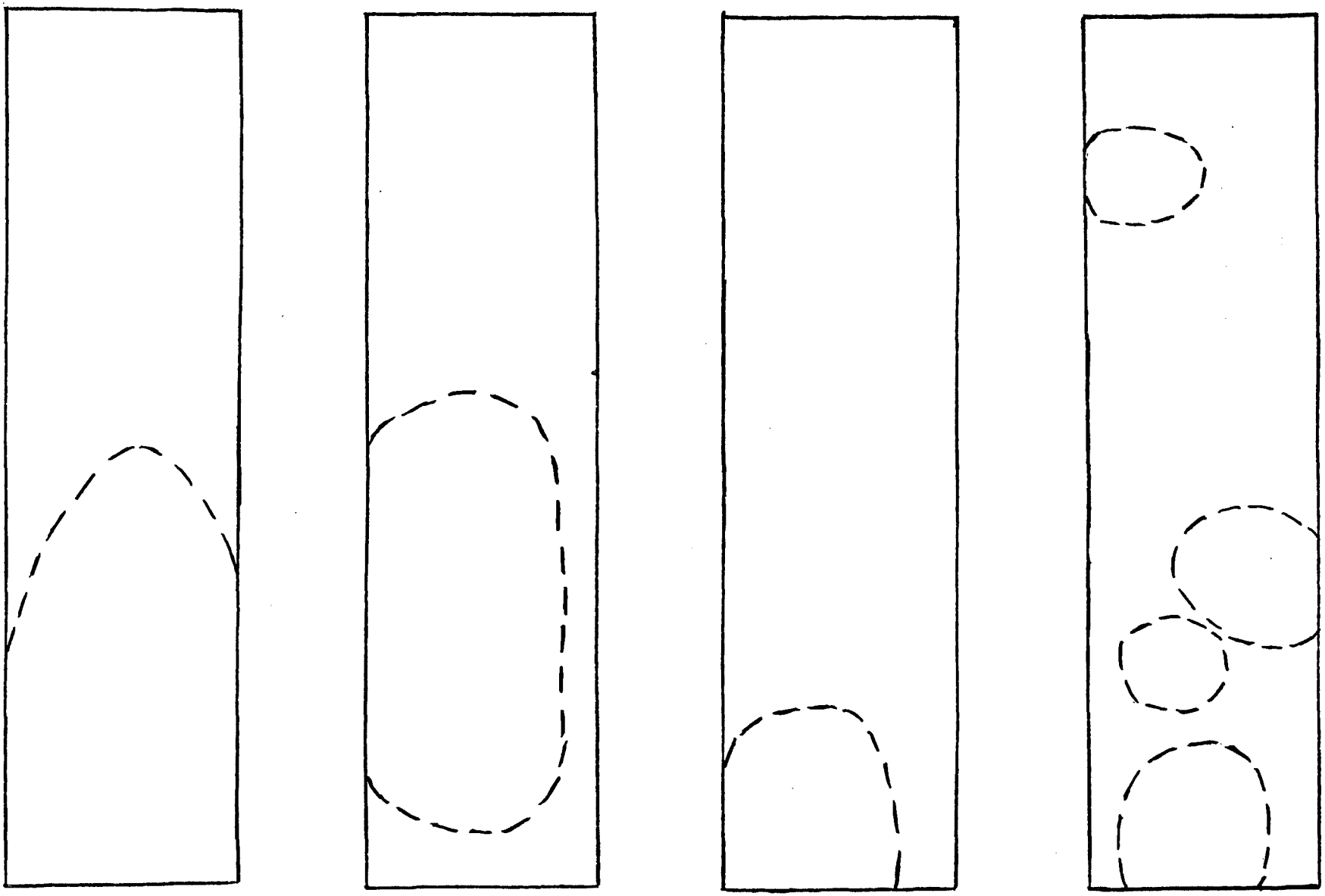
Winter wren

Hermit thrush

Swainson's thrush

Golden crowned king-let

Bird territories. Moribund plot.



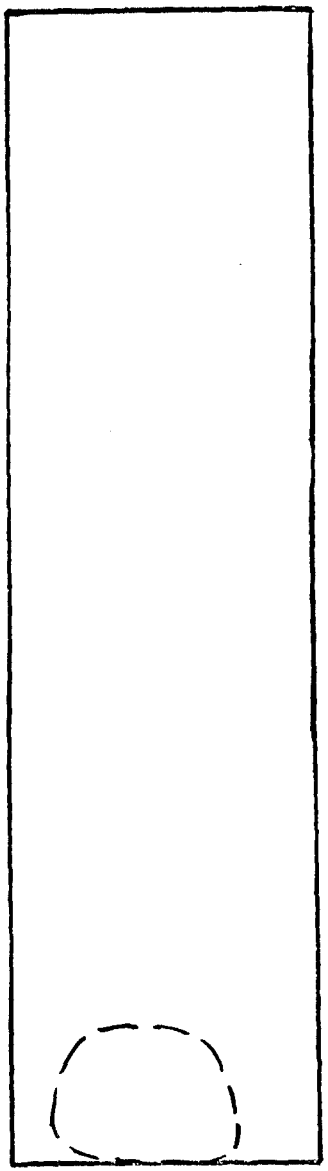
Cedar waxwing

Red-eyed vireo

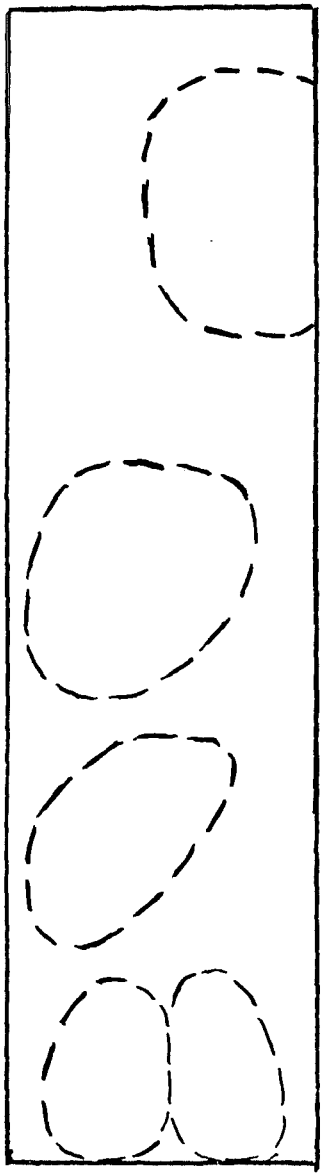
Tennessee warbler

Nashville warbler

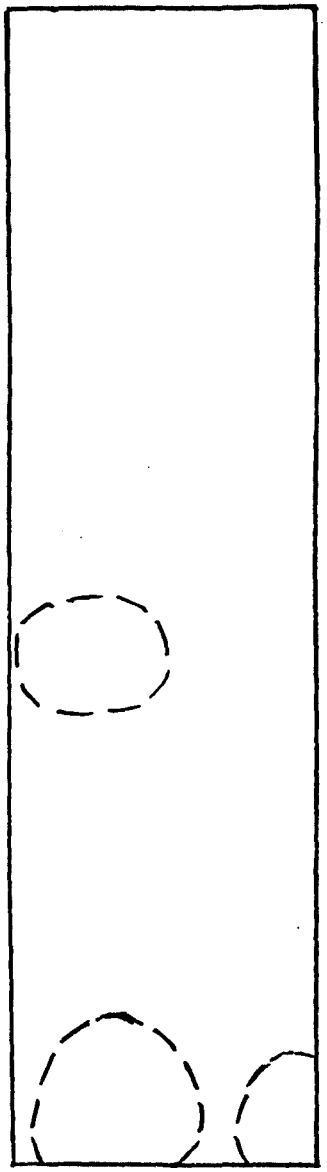
Bird territories. Moribund plot.



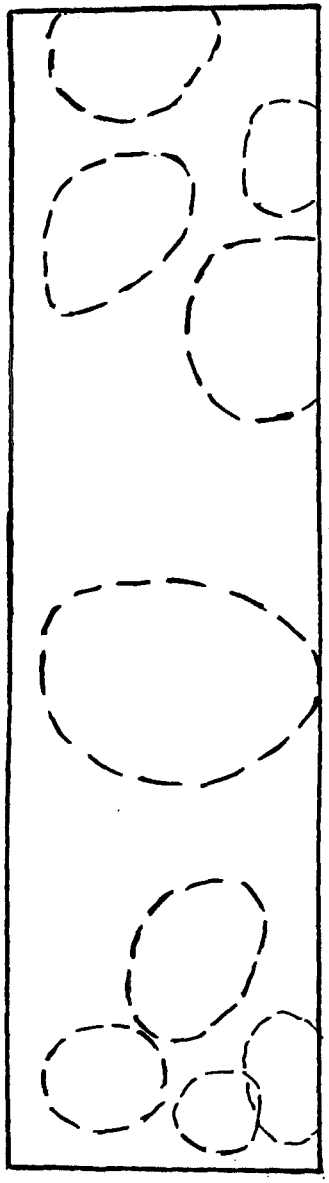
Northern parula warbler



Magnolia warbler

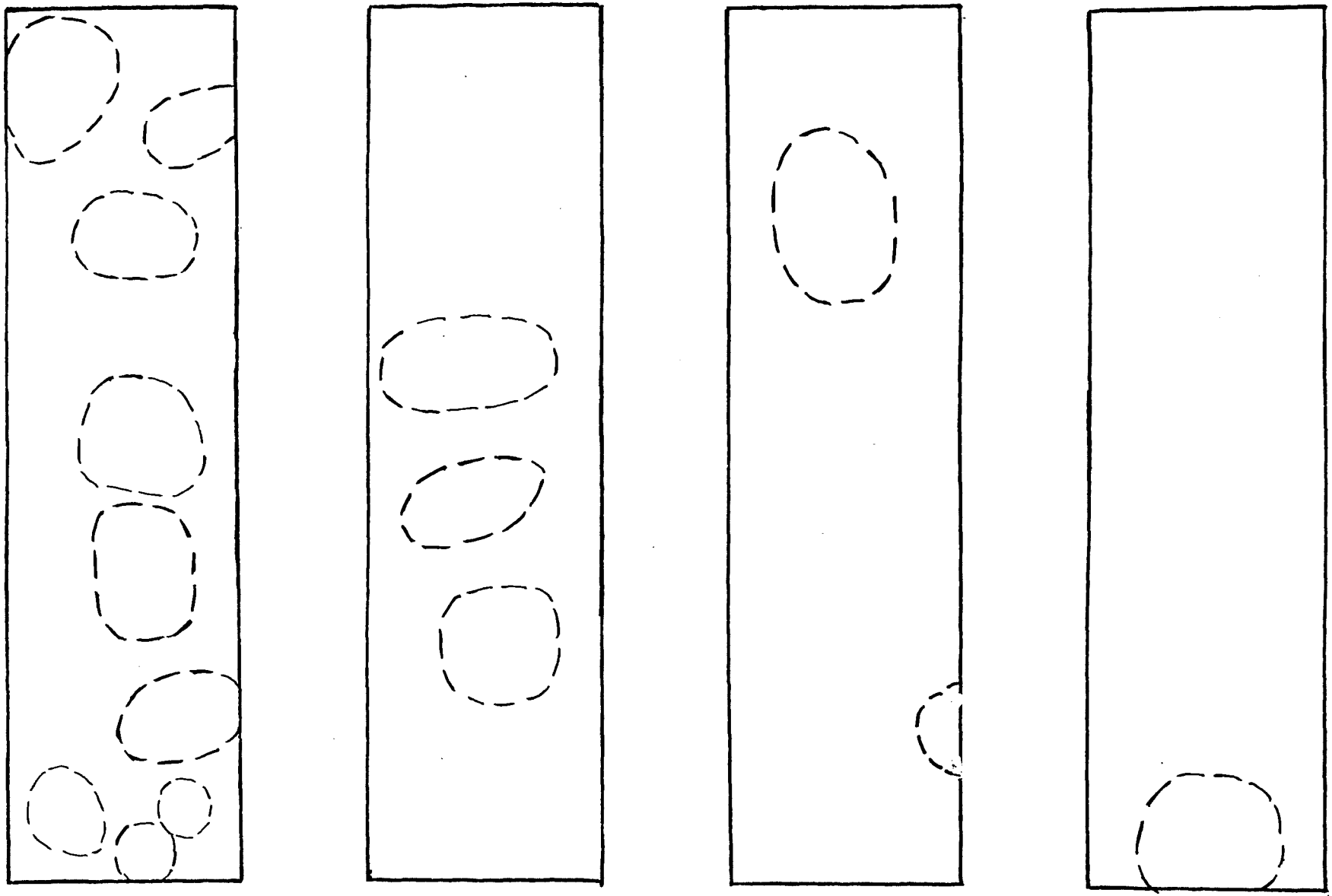


Cape May warbler



Yellow-rumped warbler

Bird territories. Moribund plot.



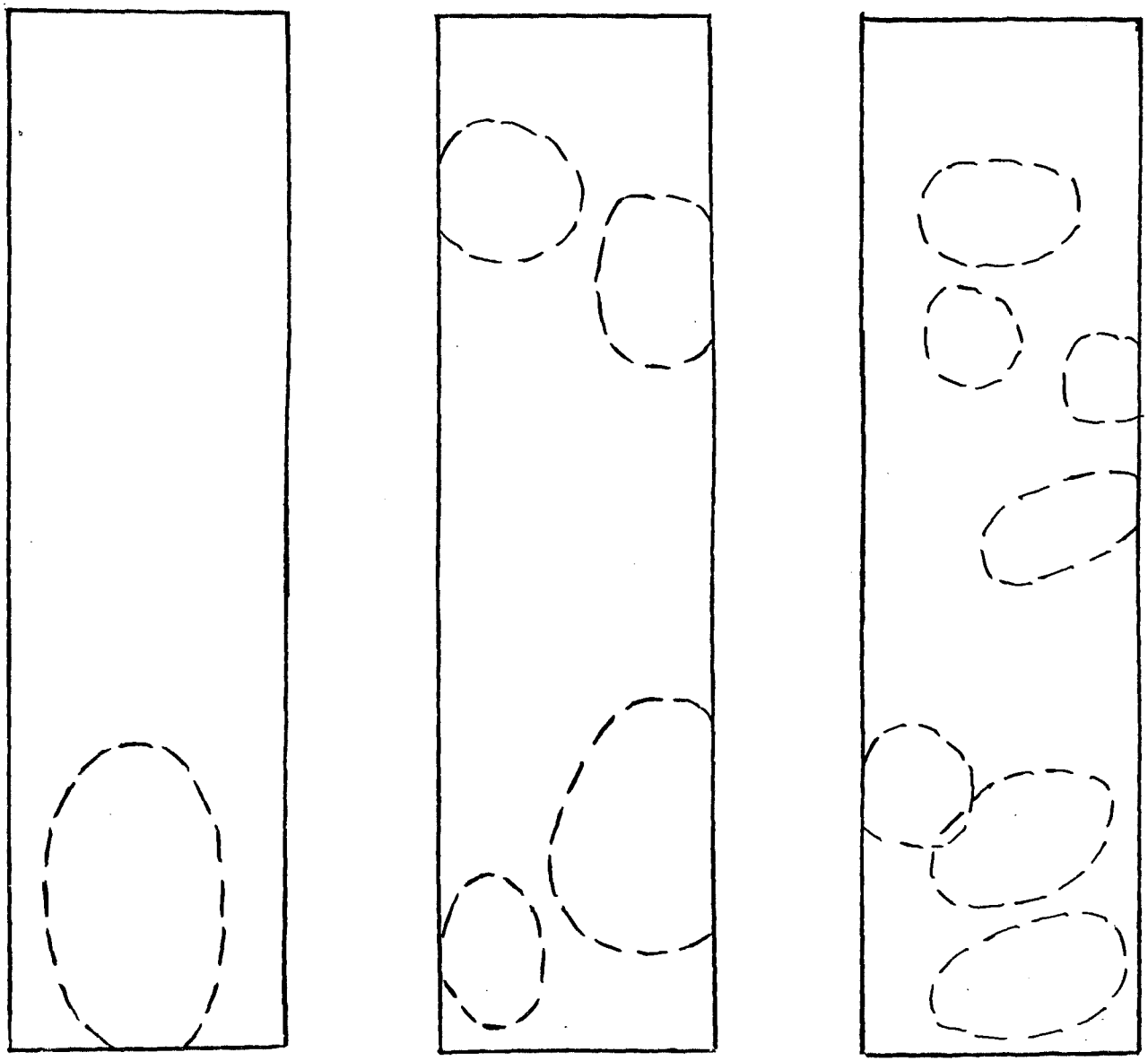
Blackburnian warbler

Ovenbird

Mourning warbler

Common yellowthroat

Bird territories. Moribund plot.



Purple finch

Dark-eyed junco

White-throated sparrow

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