SEASONAL OCCURRENCE AND ABUNDANCE OF MAYFLIES, OR EPHEMEROPTERA, FROM A RESTRICTED AREA OF GULL LAKE

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ABSTRACT

SEASONAL OCCURRENCE AND ABUNDANCE OF GRYLLIDS,

[illegible] ORTHOPTERA,

FROM A RESTRICTED AREA OF GULL LAKE

by

Phyllis E. Vinton

Light trapping was conducted from March 20, 1967, to September 15, 1967, at Gull Lake, in Kalamazoo and Barry Counties of southern Michigan. Four species of gryllids (Orthoptera) were taken from May through August. Graphs of the occurrence and abundance of each species are included. Air temperature, water temperature, incident radiation, and wind speed are evaluated as possible parameters operating as modifying factors in the emergence pattern and activity of the gryllids. Weather conditions which prevailed on nights with unusually high or low light catch are compared. A discussion of the sex ratio of [illegible] (Serville) in relation to abundance is presented. Suggestions are made concerning further investigations of this type.

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By

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INTRODUCTION

Mayflies living under natural conditions are exposed to a continually changing combination of environmental factors. The physical environment is comprised partly of climatic factors, which are relatively stable, and weather factors which, like biological factors, are continually varying, although they usually vary about climatic means which change slowly.

Relative population estimates may be used for making population comparisons in space and time. Biological interpretation of such estimates is difficult, however, since the sample size is influenced by changes in actual numbers of individuals, changes in their activity, the degree to which a species or sex is responsive to the trap stimulus, and changes in efficiency of the trap.

Prevailing climatic conditions, as well as biological factors, greatly determine the species which may be present, and the season during which adults are likely to be active, while changes in weather have immediate effects on the number of individuals caught. Williams (1939, 1940) approached the problem of analyzing long range effects of climate and more immediate effects of weather by making comparisons between the same months of different years, of the number of insects trapped. Similar studies, conducted at the specific level, are few.

The objectives of this investigation were (1) to report the numbers and seasonal occurrence of mayflies (Ephemeroptera) emerging from a restricted area of Gull Lake, Michigan, and, (2) to evaluate several environmental parameters as possible elements operating as modifying factors in the emergence pattern of the mayflies.

LITERATURE REVIEW

Historical Review

A few species of large conspicuous mayflies often come to the general attention every year when they emerge in enormous numbers. Adults of many species appear consistently year after year in the same localities, on approximately the same dates for those localities, often forming vast swarms near the water. The earliest published records concerning American mayflies were descriptions of such swarms. In 1749, Philadelphia botanist John Bartram (1750) made observations which were published in the Transactions of the Royal Society of London, being communicated as follows:

> May the 4th, 1749, Mr. Bartram perceived many May-flies had attained wings, and were very thick spread on the bushes and grass, and by the river side. The second day after their leaving their aquatic abode they cast another skin, after which their tails are longer, and their wings drier and more transparent. The 5th and 6th was rainy, the 7th windy; so very few came out. The 8th was cool; so very few were seen: but many swarmed late in the evening; and on the 11th, 12th and 13th, they swarmed abundantly. What he calls swarming, was their gathering thick as bees, near the rivers to lay their eggs in the water.

Numerous papers, including keys and descriptions of the mayflies of a particular region, have been published. Eaton's Monograph of the Recent Ephemeridae, issued 1883-1888, still serves for the

generic and specific identification of much of the then known fauna of the world.

Most North American species were described by Traver (1935) and in a long series of papers published by McDunnough (1926, 1943) from 1921-1943. Needham, Traver and Hsu (1935) published a detailed account of the biology of mayflies and keys to North American mayflies. Two excellent references for mayflies of the Michigan area are: The Mayflies, or Ephemeroptera, of Illinois (Burks 1953), and Mayflies of Michigan Trout Streams (Leonard and Leonard 1962).

Insects and Weather

Early investigations made before statistical methods were developed were frequently descriptive in nature. The earliest extensive study of insects and their relation to climate was conducted by B. P. Uvarov (1931). In studying the responses of insects to environmental factors, Uvarov said that it was necessary to apply the analytical method and to investigate the influence of each factor separately. He indicated that it would be incorrect to assume that the response of an insect to the combined action of several factors will represent a sum of the responses to each factor involved.

C. B. Williams (1939, 1940), with the aid of R. L. Fisher, both working at the Rothamsted Experiment Station, Harpenden, England, analysed four years' capture of insects in a light trap. Most analyses were made by methods of partial regressions and

analysis of variance. Williams' works from 1935 to present constitute the most comprehensive studies to date dealing with meteorological factors and their effect upon the total insect population and activity. Williams investigated large heterogeneous populations about which he assumed the total changed slowly, and hence, daily changes in the catch were due to changes in activity of the insects. Utilizing several years information, he was able to correct the mean total catch of each month for its departures from the normal (of the four years) in meteorological conditions (i.e., weather and climate), obtaining a value for what he believed would have been the catch had conditions been normal. The differences remaining he called the population effects, and these values were calculated. In his analyses he showed meteorological factors accounting for 50-60 percent of the variance of the total population.

The present study, dealing with Ephemeroptera at the specific level, does not lend itself to similar analyses. The population of a single species of mayflies is not constant as was the general population studied by Williams. It can and does change very rapidly. The adult life span of mayflies is so short that population and activity are not easily separated.

In 1962, Williams conducted a similar study which was confined to a single group, the black flies (Williams 1962, Davis and Williams 1962).

Other workers have investigated one to several weather factors

as they affect abundance of a species or group of insects. Most work conducted to date at the specific level remains quite descriptive. Leonard and Leonard (1962) recorded the seasonal occurrence of winged mayflies over a single gravel riffle on the Pere Marquette River in Michigan.

Temperature

Williams (1940) believed temperature was the most important single climatic factor in a cool temperate zone. On nights when the catch of all insects was high, maximum day and minimum night temperatures were higher. He indicated that the effect of maximum temperature alone was of less significance than the effect of minimum temperature.

Cook (1924) noted that Lepidoptera catch increased with increasing air temperatures, the effect being much greater when humidity was low. Uvarov (1931) concluded that air temperature is the chief environmental factor influencing insect flight activities, such activities beginning about 10°C, with an optimum range between 20-25°C. With one exception, Scott and Opdyke (1941) found no general correlation between aquatic insect emergence and air temperature.

In his black fly studies, Williams found that maximum and minimum temperatures on days preceding the three nights of highest catch were 1°C above the monthly mean, with nights of high activity occurring at a minimum temperature above 9°C.

Chant and Mcleod (1952) found temperature range to have a close inverse relation to earwig abundance. This is in agreement with Davidson and Andrewartha (1948) who found temperature range to have a definite influence on the abundance of thrips.

Taylor (1963) believed there were both an upper and lower temperature threshold for insect flight. In a study of aerial insects, J. A. Freeman (1945) collected most species at a temperature above 61°F (16°C), but believed that appearance of many species in the air is more closely associated with their life history than with immediate effects of temperature. Further, that "regular daily catches of an aerial insect population would throw more light on the problem."

Incident Radiation

The source of heat which alters air temperature is radiation from the sun. There is a tendency for good catches to follow sunny days (Williams 1940).

Moisture

Williams (1940) found rain did not have a great effect on the catch, although the catch was usually lower after a rainy day. He found relative humidity to have no effect on catch. Uvarov (1931) believed relative humidity had an effect on the

activity of Lepidoptera, there being an inverse relation between relative humidity and activity above 54 percent relative humidity and a direct relation below 54 percent relative humidity.

Other Meteorological Parameters

Atmospheric pressure.--Chant and Mcleod (1952), Williams (1940) found atmospheric pressure to have no significant effect on insect abundance.

Cloud cover.--In addition to indicating high humidity, cloud cover prevents radiation of heat from the ground at night, thereby keeping night temperature higher, and partly blocks radiation from the sun, thereby lowering maximum temperature. Cloudy days usually have a lower maximum and higher minimum temperature than clear days (Williams 1940, Chant and Mcleod 1952).

Wind.--An analysis of the effect of wind is difficult due to its rapid variation in strength and its interaction with other weather factors. It is perhaps for this reason that this parameter has been incompletely investigated.

Moonlight.--Prior to 1950 Williams claimed that moonlight had a definite effect on nocturnal insects and that low catches in a light trap, at full moon, are not merely due to a physical reduction in efficiency of the trap. After evaluations utilizing suction traps were conducted from 1951 to 1953, Williams, Singh, and El Zaidy (1956) concluded that the 1950 cycle, on which they had based

their claims, was accidental and of no biological significance. Further, that there was no evidence relating the effect of moonlight to the activity or distribution of night flying insects. They did indicate an exception in the case of some aquatic species, where light appears to influence emergence from the water.

Scott and Opdyke (1941) caught far more emergent aquatic insects in light colored than dark colored emergence traps. They hypothesized that when about to emerge, pupae or nymphs must be strongly phototactic to light of rather weak intensity.

<u>Lunar periodicity</u>.---A lunar rhythm has been associated with the changes in activity of certain animals, but most of the established cases are marine, and the effect may be partly due to tides. Hora (1927) noted in India that swarms of several species of mayflies usually appeared during the full moon period. Hartland-Rowe (1955) suggested that swarming in an African mayfly (*Povilla adusta* Navas) is related to the lunar cycle. He hypothesized that the lunar rhythm may only be maintained near the equator where there is little annual variation in day length and air temperature.

Sex Ratio

Williams (1939) found in *Agrotis exclamationis* and several other species of Noctuidae that females formed a smaller proportion

of the catch on nights when the species was abundant. According to Davis and Williams (1962) several species of black flies show a similar trend.

METHODS AND MATERIALS

Study area

Gull Lake is located in Kalamazoo and Barry Counties, T.1S. and 1 N.; R. 9 and 10 W., in the southwestern section of Lower Michigan. The study was conducted at the W. K. Kellogg Biological Station, located on the northeast side of the lake.

Gull Lake is among the deeper and larger of the inland lakes in southern Michigan. The surface area is 825 hectares. A major part of the lake is over 13 meters in depth, with a maximum depth of 34 meters. It is classified as a cold-water lake. The water is alkaline (pH 7.4-8.4).

Sand, gravel, and rubble are the principal bottom types on the shoals. Marl, muck, and pulpy peat are found in the deeper areas. Twenty-four species of aquatic plants were recorded when a biological survey of the lake was made in 1941.

The climate at Gull Lake alternates between Continental and Semimarine, due to prevailing westerly winds crossing Lake Michigan. The air temperature falls to -20°C during most winters; there are approximately 15 days each summer when the temperature reaches 33°C or above. Average dates of the first freezing temperature in fall and the last in spring are October 6 and May 8, respectively.

About 6[illegible] percent of the annual total precipitation occurs from April to September, with rainfall heaviest in June.

Meteorological Records

An official weather station is located at the W. K. Kellogg Biological Station. Air temperature and relative humidity were obtained utilizing a continuous recording Hygro-Thermograph. A continuous record of water temperature was obtained utilizing a Taylor temperature recorder (76 J type recorder). A log was maintained for weather conditions throughout the study period. Air temperature and relative humidity were recorded at a distance of 2 meters from the trap and 1 meter above ground level. Water temperature was recorded at a depth of 15-30 centimeters and at a distance of 3 meters from the lake shore in proximity to the light trap. Thus, measurements of the daily physical environment were available for comparison with light trap captures.

Records of the average air temperature, total precipitation, and departures of each from the normal during the past 33 years were obtained from A. H. Eichmeier, State Climatologist, Weather Bureau Office, Lansing.

Species studied, with notes on their biology

General biology.--Mayflies have a life cycle of 4 stages: egg, aquatic nymph, aerial subimago and imago. Hereafter the imago and subimago will be referred to as "adults."

Nymphs of nearly all Michigan species require a year to mature (Leonard and Leonard 1962). Often an overlap in broods results in a long seasonal appearance by these species. A few species have a shorter life cycle with two broods per year, and the large ephemerids usually require two years to mature (Burks 1953).

Duration of the winged stage is usually 2-3 days, but varies somewhat with the species, individuals, and probably with weather conditions (Needham, Traver and Hsu 1935, Burks 1953). Subimagos usually emerge in late afternoon or evening, spend the subimaginal stage resting near the water, and make the final molt a day or so later; then males swarm, mating occurs, and females deposit eggs soon afterward (Burks 1953).

Collecting at lights usually yields the largest number of adults. Subimagos are often strongly attracted to light (Needham, Traver and Hsu 1935, Burks 1953, and Leonard and Leonard 1962).

Species present.--It is assumed that adults of all species caught emerged from Gull Lake.

Hexagenia limbata (Serville)

Habitat: Mole-like legs of the nymphs enable them to burrow into

bottom sediments of streams and larger lakes (Leonard and Leonard 1962).

Life cycle: Two years are usually required, although the cycle is completed in a year in some of the warmer southern Michigan lakes (Hunt 1953). The winged stage often lasts three days (Hunt 1953). Emergence and swarming are greatest from dusk to midnight (Hunt 1953).

Ephemera simulans (Walker)

Habitat: Like H. limbata, mole-like legs of nymphs enable them to burrow into the substrate. They inhabit streams and lakes with considerable wave action, and are most abundant in waters having a sand and gravel substratum (Leonard and Leonard 1962). They are less common in silt and mud bars where H. limbata predominates (Leonard and Leonard 1962).

Life cycle: The cycle usually takes two years to complete (Burks 1953). Emergence is during the evening and swarming occurs over the water at dusk (Leonard and Leonard 1962). According to Leonard and Leonard (1962) heavy emergence of E. simulans usually takes place about ten days before that of H. limbata.

Stenonema rubrum (McDunnough)

Habitat: Legs and body of the nymphs are flattened, offering little resistance to water movement or action as they cling to stones and other submerged objects. They frequently occur in the shallow water (less than 15 centimeters) of streams and lakes with strong current or wave action (Leonard and Leonard 1962).

Life cycle: The cycle is completed in a year. Emergence occurs from afternoon through evening (Burks 1953, Leonard and Leonard 1962).

<u>*Caenis simulans*</u> (McDunnough)

Habitat: The operculate gilled nymphs inhabit quiet waters where silt and debris collect. Adults are assumed to have emerged from a lagoon area at the Biological Station, as well as from Gull Lake.

Life cycle: The life cycle is completed in a year with heaviest emergence and swarming occurring at darkness (Burks 1953). The subimago stage is greatly abbreviated, as evidenced by Burks (1953), who observed the subimaginal exuviae being shed during flight immediately after emergence.

<u>Sampling techniques</u>

<u>Description of Traps</u>.--A New Jersey type light trap was utilized for the collections from March 29, 1967 to July 29, 1967. At this time the trap became inoperable, and was replaced with a Spinsect Night Flying Insect Trap, which operated from July 30, 1967 to September 15, 1967. Both traps combine light (New Jersey: incandescent, Spinsect: black light fluorescent) and suction (rotary fan) and, therefore, are especially useful for weak fliers. Information is not available to determine the effect that changing traps had on the number and types of insects collected.

Trap site.--The trap was located at the W. K. Kellogg Biological Station, in an open area 3 meters from the lake shore, 1.3 meters above water level, and 1 meter above ground level. Nearby trees, shrubs and surrounding hills afforded some protection from high winds sufficient to alter natural dispersion of the insects.

Method of determining number of mayflies per catch.-- A Mettler balance was utilized to determine the dry weight of *Caenis simulans*. The number trapped was estimated by comparing the dry weight of each daily sample to the known dry weight of 600 individuals. All other species were counted directly. Imagos and subimagos were counted as adults. Several times the trap was not emptied for two or three days; 1/2 or 1/3 of the catch was arbitrarily assigned to each day.

RESULTS

<u>Use of logarithms</u>

In comparing the number of mayflies caught, logs of the numbers were used, as suggested by Williams (1936, 1961).

Night to night variation in numbers was more geometrical than arithmetical, i.e., high emergence periods were associated with a multiplication of the catch by some factor, not the addition of some number to the catch. It was necessary to convert the catch to a log scale, so that geometric changes became linear and normal statistical formulas could be used. Since catches were zero on many nights, logarithm of the number caught plus one [log. (n + 1)] was used.

Any increase of .301 in the log. catch indicates that the catch is doubled.

Statistical analysis of log. catch in relation to meteorological factors was limited to events during the emergence peak of a species. Only then can adults of that species be expected to be present. Due to biological factors, one would not expect to find *E. simulans* in August, hence there is no point in considering weather conditions in August as they directly influence the occurrence of *E. simulans* adults.

Seasonal emergence of the species studied

Two major widely separated peaks of emergence were observed for *S. rubrum*. Emergence patterns for other species were too equally close and therefore considered as one peak.

Hexagenia limbata

Emergence: June 23 to August 30 (Figure 1)

Peak emergence period: July 29 to August 30

Ephemera simulans

Emergence: May 31 to June 9 (Figure 1)

Note: Emergence of *E. simulans* was 15 days prior to the emergence of *H. limbata*.

Stenonema rubrum

Emergence: May 26 to August 24 (Figure 2)

Peak emergence period: May 31 to June 11, July 29 to August 24

Caenis simulans

Emergence: June 16 to July 24 (Figure 3)

Peak emergence period: June 16 to July 11

Stenonema rubrum adults which emerged during the first peak were noticeably larger than those from the second peak.

Water temperature, maximum and minimum air temperature, and incident radiation on days during the June and August peaks when

the log. catch was 1.00 or greater were compared. Using the Mann-Whitney test, no significant difference was found between June and August maximum air temperatures $[.10 < P(U \leq 48)]$; no significant difference was found between June and August minimum air temperatures $[.10 < P(U \leq 46)]$; but a highly significant difference was found between June and August water temperatures $[P(U \leq 19.5) < .002]$.

Comparisons between nights of high and low catch

Prior to a more detailed survey of single factors, it is of interest to note the weather conditions that prevailed on nights with unusually high or low log. catch. Average and minimum air temperatures were generally higher when the log. catch was high (Figures 1-6). Maximum air temperature and temperature range appeared to have little direct effect on the log. catch (Figures 7, 8). Days prior to numerous nights of high log. catches had more sunshine. High emergence occurred during many periods of rainy weather, although prolonged rain at the time of emergence peaks usually coincided with a tapering off in number of individuals captured (Figures 4-6). The effect of rain was more apparent during non peak periods. High as well as low numbers of individuals were taken when there was rain at night, but day rain was often followed by a low catch (Figures 4-6). No emergence was observed until the water temperature averaged 17°C (Figures 1-3).

[≥ >]

[≥ >]

[> ≥]

<u>Meteorological Parameters</u>

Meteorological parameters investigated were:

1. Temperature
2. Incident Radiation
3. Moisture

Temperature

<u>Air temperature</u>.--

Table 1.--Average temperature and departure from the normal, May-September, 1967

Month	Av. temp.	Departure from normal*
May	12.1°C (53.7°F)	-2.4°C (-4.3°F)
June	21.3°C (70.3°F)	+1.1°C (+2.0°F)
July	37.6°C (63.6°F)	-1.7°C (-3.0°F)
August	20.4°C (68.7°F)	-1.4°C (-2.5°F)
September	17.1°C (62.7°F)	-0.3°C (-0.6°F)

* Normal of the past 33 years.

Table 1 shows that average temperatures for all months except June were below the normal of the previous 33 years.

<u>Maximum air temperature</u>.--The daily maximum temperature was usually recorded about 3 p.m. It increased from 10-12°C in early May to 23°C by late May, when several exceptionally warm

days preceded the first mayfly emergence. Figure 7 shows that the maximum temperature was 19-26°C during most mayfly emergence, but within this range, maximum temperature had no effect on catch.

Minimum air temperature.--The daily minimum was usually recorded about 6 a.m. It increased from 1-3°C in early May to 11°C before any mayflies emerged. High minimum temperatures often accompanied periods of high mayfly emergence (Figures 1-3).

Hexagenia limbata was most frequently taken when a minimum temperature of 11-17°C was recorded (Table 2). Within this range, there was no significant correlation between size of the log. catch and minimum temperature [Spearman Rank Correlation: .10 < P ($r_s \geq .253$)].

Ephemera simulans was taken at all minimum temperature ranges considered (Table 2). The log. catch was about the same for each range.

Stenonema rubrum also was taken at all ranges considered (Table 2) but, using a Kruskal-Wallis One Way Analysis of Variance by Rank, there was a highly significant difference shown among log. catches at each minimum temperature range [$P(\chi^2 \geq 23.3) < .001$]. Ranges III and IV were combined for testing because of the small Range IV sample. Inspection of these data shows that the log. catch size was greatest from 14-19°C and decreased with decreasing minimum temperatures. There appeared to be a correlation between log. catch size and minimum temperature except on those nights with an unusually

high log. catch (Figure 2). At this time a minimum temperature of 27°C would have been required for temperature to remain proportional to the increase in log. catch. Omitting these three observations, there was a significant correlation shown between the log. catch size and minimum temperature [Spearman Rank Correlation : $P(r_s \geq .4[illegible]) < .0[illegible]$].

[illegible] was taken at 11-1[illegible]°C minimum temperature (Table 2). Most mayflies emerged (Figure 3) during cool weather in early June, although large catches were also taken at higher minimum temperatures.

Average air temperature.--Usually the 6 p.m. temperature approximated the daily average temperature. Early day temperatures averaged 5°C, and increased to the 17°C prior to the earliest mayfly emergence (Figures 4-6).

Hexagenia limbata was most frequently taken when the average temperature ranged between 11-21°C. Within this range there was no significant correlation between size of log. catch and average air temperature [Spearman Rank Correlation : $.05 < P(r_s \geq .3[illegible]) < .10$].

Hexagenia rigida was taken at all average temperatures considered. When the three nights of unusually high log. catch were omitted from the test, (see the above explanation) using a Spearman Rank Correlation test, there was a significant difference shown between size of log. catch and average temperature [$P(r_s \geq .473) < .02$].

Table 2.--Log. catch of each species at increasing minimum temperature ranges.

Species	Range I (less than 10°C)		Range II (11 - 13°C)		Range III (14 - 16°C)	Range IV (17 - 19°C)
Hexagenia			.70			
limbata	1.30		.48	1.65	1.26	1.38
				1.66	0.00	
	1.90		2.63	1.66	2.22	
	2.11		1.96	2.66	0.00	
			1.93	.81	.70	
	.95		.43	.81	.70	
			1.11	0.00	1.26	
			1.73	2.55	1.81	
Ephemera	.30					2.27
simulans	2.73		2.37		2.19	1.20
	2.73				1.73	
Stenonema	.30		1.42		3.59	
rubrum	1.35		.78		3.57	1.52
	1.35		1.16		2.51	1.58
	.78		0.00		1.15	1.43
	.78		1.30		1.26	1.61
	.85		1.52		1.41	
	.70		.95		0.00	
	.95		0.00		1.30	
	.30		1.68		1.48	
			1.76		1.66	
			.48		1.68	
			.48			
			.46			
Caenis	3.73	3.72	3.72		3.73	
simulans	3.73	3.73	3.73		1.15	
	3.71	3.46	3.77		0.00	
	3.70	2.84	.78		1.85	
	3.79	2.93	2.83			
	3.71	3.22	1.90			
	3.73	.85				

Range in air temperature.--Temperature range varied irregularly throughout the study period and had no apparent relation to log. catch (Figure 8).

Average water temperature.--Since daily temperature fluctuated less than 3°C, only average temperatures were reported. Ice left the lake on April 1, 1967. A water temperature of 17°C was recorded in late May, at which time the first mayfly emergence was observed (Figures 1, 2). Water temperature continued increasing to 25°C, varied between 23°C and 26°C until early August, then slowly declined (Figure 1).

Temperatures recorded in this study were obtained in the littoral zone of the lake. Water temperature information for all strata of the lake as well as substrate temperatures might allow for a more detailed analysis of the temperature more closely experienced by the mayflies.

Hexagenia limbata

Water temperature decreased from 25 to 20°C during the July and August emergence peak.

Ephemera simulans

Water temperature during the June emergence peak steadily increased from 17 to 22°C.

Stenonema rubrum

Water temperatures increased from 17 to 24°C during the June emergence, and fell from 25 to 20°C during the August emergence.

Caenis simulans

Water temperature during C. simulans emergence was 24 to 26°C.

Incident Radiation

Sunlight does not directly affect the catch since trapping is between sundown and sunrise.

Peaks in incident radiation often occur during the day of, or a day or two prior to, an observed increase in log. catch. One marked exception did occur when the S. rubrum catch was high during a period of cloudy, rainy weather (Figure 5). A period of very high radiation, however, immediately preceded the emergence peak. At low log. catch levels there appeared to be a linear relation between log. catch and incident radiation, but the relation became geometric, even though logarithms were used, during periods when great numbers of individuals emerged.

Incident radiation and Ephemera simulans log. catch appeared to correspond very closely (Figure 4), but the number of days of emergence was too small to warrant statistical analysis. The log. catch appeared to increase geometrically in relation to incident radiation during very high emergence periods of the other three species, therefore normal statistical tests assuming linearity could not be used.

Table 3.--Total precipitation and departures from the normal

Month	Total Precipitation	Departure from normal*
May	5.94cm(2.34 in)	-4.90cm(-1.39 in)
June	15.32cm(6.03 in)	+4.57cm(+1.80 in)
July	7.32cm(2.88 in)	+ .03cm(+.01 in)
August	4.83cm(1.90 in)	-4.5cm(-1.76 in)
September	7.82cm(3.08 in)	- .03cm(- .01 in)

* Normal of the past 30 years.

Table 3 shows that total precipitation was about normal in July and September, but well above normal in June, and well below normal in May and August.

In standard weather records rain is recorded from 9:00 a.m. to 9:00 a.m. Rain falling up to 9:00 a.m. is credited to the previous day. During this study, day rain was recorded from 6:00 a.m. to 6:00 p.m., and night rain recorded from 6:00 p.m. to 6:00 a.m. (Figure 4).

The effects of rain have been discussed previously (page 7).

Relative humidity.--Maximum relative humidity commonly reached 80 to 92 percent about 6 a.m. There appears to be no relation between log. catch and maximum relative humidity (Figure 9).

Minimum relative humidity varied from 13 to 92 percent, and was usually recorded about 3 p.m. No relation between log. catch and minimum relative humidity was apparent (Figure 10). Average relative humidity was usually 45 to 75 percent with no apparent relation to log. catch (Figure 11).

Lunar periodicity.--Days of full and new moon were noted. Lunar periodicity in emergence was not apparent. The time span of the study was too short, however, to warrant any conclusions.

Sex ratio of Hexagenia limbata in relation to abundance.-- Table 4 shows the number of individuals of each sex caught during periods of high emergence and low emergence.

Using the Wilcoxon sum test, a significant difference is shown between the numbers of each sex caught on nights of high emergence $[.01 < P(h \leq 9) < .02]$. The data show that the number of males greatly exceeds the number of females on these nights.

Table 4.--Numbers of each sex taken on nights of high and low *Hexagenia limbata* (Serville) emergence.

Date	Males number	Males log. (n+1)	Females number	Females log. (n+1)
High emergence (over 40)				
August 1, 1967	159	2.20	10	1.00
August 6, 1967	378	2.58	51	1.72
August 7, 1967	55	1.75	35	1.56
August 8, 1967	74	1.88	10	1.00
August 15, 1967	17	1.26	26	1.43
August 18, 1967	26	1.43	38	1.59
August 19, 1967	26	1.43	18.3	1.29
August 20, 1967	26	1.43	18.3	1.29
August 21, 1967	26	1.43	18.3	1.29
August 24, 1967	123	2.09	5	0.78
August 25, 1967	433	2.64	18	1.28
August 26, 1967	303	2.48	54	1.74
Low emergence (under 40)				
June 23, 1967	2	0.48	2	0.48
June 24, 1967	1	0.30	0	0.00
July 2, 1967	1	0.30	0	0.00
July 8, 1967	0	0.00	1.5	0.41
July 9, 1967	0	0.00	1.5	0.41
July 19, 1967	1	0.30	3	0.60
July 24, 1967	0	0.00	1	0.30
July 25, 1967	0	0.00	2	0.48
July 27, 1967	0	0.00	1	0.30
July 29, 1967	4	0.70	0	0.00
July 30, 1967	9	1.00	9	1.00
August 2, 1967	7	0.90	16	1.23
August 4, 1967	4	0.70	2	0.48
August 5, 1967	2	0.48	0	0.00
August 9, 1967	2	0.48	0	0.00
August 11, 1967	1	0.30	0	0.00
August 14, 1967	5	0.78	7	0.90
August 16, 1967	1	0.30	5	0.78
August 17, 1967	1	0.30	16	1.23
August 22, 1967	13	1.15	6	0.85
August 23, 1967	1	0.30	14	1.18
August 26, 1967	5	0.78	0	0.00
August 27, 1967	5	0.78	1	0.30
August 29, 1967	5	0.78	3	0.60

DISCUSSION AND CONCLUSIONS

The catch on any one night is assumed to be a representative sample of mayflies flying in the vicinity of the trap. The area from which they are attracted is not known, and probably differs for each species, for the same species on different nights, and possibly differs between both sexes of the same species.

The catch is proportional to both the population available for sampling, and activity of the individuals. In turn, population and activity are affected by biological factors such as habits and life history of the species, and meteorological factors, i.e., climate and weather.

Williams' study (1940) of the effects of meteorological conditions on the abundance of insects dealt with population and activity. This is because a continuous succession of insects results in a fairly constant total population. When considering insects at the specific level, however, the habits of that species dictate that there will be periods of high and low numbers of individuals. Since the life span of the aerial stage is short, light trap catches will indicate the relative size of the adult population, provided that the adults are active.

Climate greatly influences the occurrence of a given species, and the time of year during which the adults are likely to be active.

Variation in weather conditions can be expected to influence the daily emergence and activity of the mayflies.

<u>Sources of error</u>

<u>Error from using a single trap</u>.--More reliable results might be obtained by using several traps simultaneously. Williams (1940) used a second trap, set up under nearly identical conditions to the first, to test the reliability of a single trap. Correlation between traps for insects caught was .86-.92, showing that the error was small. Using but one trap may introduce only a negligible error.

<u>Error from trap efficiency and shape of traps</u>.--Traps with fans are more efficient in catching mosquitoes than traps without fans (Frost 1957). The same is probably true for mayflies, since they also are weak fliers.

Briggs, Glick, and Graham (1961) found traps shielded from prevailing winds to be more efficient than traps in exposed locations.

Moonlight may alter trap efficiency, since it causes a reduction in the relative light intensity of the trap (Williams 1936, Williams and Singh 1951, Williams, Singh, and El Ziady 1956). Several studies (Williams 1951, Williams, French and Hosni 1955, Verheyens 1960, Barr *et al.* 1963) indicate that an increase in intensity or size of the lamp frequently brought about by the substitution of an ultra-violet lamp for an incandescent lamp usually led to an increased catch.

It is likely that the traps used in the study did vary

somewhat in efficiency. However, log. catch data collected during the operation of the first trap were not compared to those collected during operation of the second trap.

Error from unit of measurement.--A single mayfly, which is the unit of measurement, is small in comparison to the total catch if many individuals were caught. When the catch is small, the unit of measurement is high in comparison to the total, so small changes have a greater effect.

An estimate, rather than a direct count, should have no effect on the results, since estimates were made only when thousands of *C. simulans* were caught.

Meteorological parameters

The number of insects present is affected by weather conditions prevailing at the time of activity and by the effect of previous weather conditions on the level of the population (Williams 1962). Since nymphs are aquatic, past and immediate aquatic environmental factors, and immediate terrestrial weather conditions, probably most influence the occurrence and relative abundance of adults.

Temperature

Air temperature.--With few exceptions, the adults of all four species studied were caught at a temperature range of 8-26°C. These temperatures fall within the range of 6-28°C at which Freeman (1945) expected to find an increase in density of population and

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Several studies have shown that air temperature is the environmental factor most influencing flight activity (Cook 1924, Uvarov 1931, Taylor 1963).

The log. catch was usually higher when minimum and average air temperatures were high, but maximum temperature and temperature range had no apparent effect as shown by Figures 7 and 8. Maximum temperature showed no effect probably because it was analyzed as a single factor, and normally occurred about 3 p.m., a time when mayflies are inactive (Needham, Traver and Hsu 1935). But since the catch tended to be higher on nights following warm days, maximum temperature probably had an indirect effect through average and minimum temperatures. Emergence and swarming activity of mayflies is usually highest from dusk to midnight, when the air temperature is usually less than the average daily temperature and greater than the minimum temperature. (About 6 p.m., the air temperature generally approximates the daily average; the minimum temperature is most often recorded about 6 a.m.)

The log. catch was often higher when minimum and average temperatures were higher.

Leonard and Leonard (1962) observed the subimaginal stage to be prolonged by daytime temperatures of 10°C or lower, but temperatures at Gull Lake during the emergence periods remained above 10°C. Minimum temperature throughout the study period remained above 6°C, a temperature above which Williams (1962) captured the greatest numbers of emergent black flies.

Since biology of the species as well as factors other than temperature influence the catch, and since extremely unfavorable conditions may act as a limiting factor to daily catch, exceptions occurred, in which the catch was sometimes low when temperature conditions seemed favorable, and vice versa.

The air temperature at which activity of the adults was noted varied somewhat with the species; _S. rubrum_ and _E. simulans_ were active at a greater range in average and minimum temperatures than _H. limbata_ or _C. simulans_. This may be advantageous for _S. rubrum_ and _E. simulans_, since their emergence peaks are earlier in the spring, when a greater fluctuation in temperature is likely.

Water temperature.--Water temperature increased steadily to 17°C before mayfly emergence was noted.

A comparison of weather parameters at the time of _S. rubrum_ emergence peaks in June and in August showed no significant difference between any of the factors investigated, except water

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Water temperature.--Water temperature increased steadily to 17°C before mayfly emergence was noted.

A comparison of weather parameters at the time of S. rubrum emergence peaks in June and in August showed no significant difference between any of the factors investigated, except water temperature, which was higher during the August peak. Adults which emerged in June were larger than adults which emerged in August. Perhaps lower early season water temperatures had postponed emergence, resulting in a larger nymph and larger adult.

It appears that water temperature may trigger or postpone mayfly emergence. Laboratory studies and field data for several years would be needed before any such conclusions could be made with certainty.

Incident Radiation

Sunlight did not directly affect the catch, because trapping was done between sundown and sunrise. Sunny days often occurred immediately before or a day or two prior to nights with increased log. catch, but this is likely due to an indirect effect through the effect on air temperature. Radiation also influences the water temperature, but its effect is more gradual. Figure 4 shows that a high average air temperature very often coincides with high incident radiation.

Moisture

Rain did not greatly affect the catch of any of the species evaluated. Its effects were more noticeable during low emergence periods, but during emergence peaks, the catch was high regardless of rain, although emergence tapered off during periods of prolonged rain. Needham, Traver and Hsu (1935), and Burks (1953) indicated that rain possibly hinders mating flight. Apparently, however, mayflies temperature, which was higher during the August peak. Adults which emerged in June were larger than adults which emerged in August. Perhaps lower early season water temperatures had postponed emergence, resulting in a larger nymph and larger adult.

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Moisture

Rain did not <u>greatly</u> affect the catch of any of the species evaluated. Its effects were more noticeable during low emergence periods, but during emergence peaks, the catch was high regardless of rain, although emergence tapered off during periods of prolonged rain. Needham, Traver and Hsu (1935), and Burks (1953) indicated that rain possibly hinders mating flight. Apparently, however, mayflies are able to fly during most rainy weather, regardless of the size of the individual.

The effects of rain are probably closely related to those of temperature, since day rain seems to reduce the catch more than night rain, which might be expected to have the greater effect. Rainy days are usually cooler, and followed by cool nights. Rainy nights generally have a higher temperature due to cloud cover (Williams, 1940, Chant and Mcleod 1952). It appears that some effects of rain tend to oppose those of temperature.

There was no apparent difference between maximum, minimum, or average relative humidity between nights of high and low log. catch. It might be inferred then, that there is no selection of damp or dry nights for activity or emergence. But relative humidity is dependent on temperature, and the actual moisture content of the air is much greater on warm nights than on cool nights of the same relative humidity. Since the catch is generally higher on warm nights, and since there is no difference in relative humidity between nights of high catch (warm) and nights of low catch (cold), it follows that moisture content of the air is higher on warm nights. Therefore, higher catches are associated with damp, warm nights, and lower catches are associated with dry, cool nights.

According to Leonard (1962), mayflies, especially subimagos, are very vulnerable to desiccation. Relative humidity at night generally reached 80-90 percent, and should not have been critical ture is usually positively associated with minimum and average tempera- tures, and sunshine, but is negatively associated with day rain and cloud cover. Minimum temperature is positively associated with cloud cover and night rain. A decrease in barometric pressure is generally associated with the occurrence of rain.

Many closely related meteorological factors are synergistic or antagonistic, thus it is extremely difficult to assess their in- dividual effects.

For a discussion of meteorological factors other than those con- sidered in this study, see pages 8 and 9 of the literature review.

Sex ratio of *H. limbata* in relation to abundance

The higher proportion of male mayflies on nights when *H. limbata* was abundant may reflect an actual change in the sex ratio. This disproportionate number of males might result from a rapid in- crease in emergence of males, decrease in death rate of males, or the activity of one sex may be governed by biological or environ- mental factors not affecting the other sex.

If no real difference in the sex ratio exists, the apparent difference might result from a different sensitivity of each sex to factors affecting the catch. Williams ([illegible]) suggested that in the Noctuidae, the smaller proportion of females in high catches could be explained if females were less sensitive to the light stimulus of the trap. Further, if the light trap attracts males from a greater area than females on nights of high activity when females might be engaged in egg laying, a difference in catch might result. [illegible]ettle ([illegible]) found an actual variation in the sex ratio in *Culicoides* caught by several different methods.

FUTURE WORK

The results described were based on one year of continuous trapping of insects with a single light trap. Most calculations were made for all the species of adult mayflies obtained at Gull Lake. If further studies of this type are done, the following suggestions are made:

1. There should be several traps working simultaneously under as similar conditions as possible. This will give large numbers of a species and reduce the sampling error.

2. The study should be extended over several years so data can be used for comparisons of nights from year to year as well as nights within years. This will allow the use of more powerful statistical tests.

3. A selected species should be considered, rather than all species of any one group. Sorting the thousands of delicate (3-4 mm in length) Caenis simulans from all of the other insects in each day's catch was an overwhelming task.

4. Hexagenia limbata is suggested for such an investigation on the basis of its following characteristics:

   a. It has relatively long periods of both peak and low emergence.

   b. It is readily attracted to light.

   c. It is easily distinguished from other insects caught in the trap.

   d. Sexes are easily distinguishable.

SUMMARY

The objectives of this investigation were (1) to report the numbers and seasonal occurrence of mayflies (Ephemeroptera) emerging from a restricted area of Gull Lake, and (2) to evaluate several environmental parameters as possible elements operating as modifying factors in the emergence of the mayflies.

An account was given of the aquatic environment, and of the climate and daily weather conditions of the area.

A light trap was operated from March 29, 1967, to September 13, 1967, at Gull Lake, in Kalamazoo and Barry Counties, Michigan. Four species of Ephemeroptera were caught from late May through August. A summary of emergence and peak emergence periods for each species follows:

> Hexagenia limbata: Emergence was from June 23 to August [illegible], with the peak period of emergence from July [illegible] to August [illegible].
>
> Ephemera simulans: A continuous emergence was noted from May 31 to June 8.
>
> [illegible]: Emergence was from May 26 to August [illegible]. The first peak period was from May 31 to June 11; the second peak period occurred from July [illegible] to August 24.
>
> Caenis simulans: Emergence was from June 15 to July 24, with the peak period of emergence from June 16 to July 11.

The daily catch was assumed to be dependent upon the adult population and activity. The catch was considered in logarithmic proportions.

Analysis of the effect of each weather factor on the occurrence and abundance of a species is made more difficult by the complex interaction of many of the factors.

A comparison of weather conditions on nights of high and low log. catch of a species showed that minimum and average air temperatures were usually higher on nights when the catch was high, and that a low log. catch was usually associated with a lower minimum and average air temperature. The maximum air temperature apparently had no direct effect, but probably had an indirect effect on the average and minimum air temperatures. A water temperature of 17°C was recorded in the littoral zone at the time of the first mayfly catch. Throughout the remainder of the study period, water temperature remained above this level. Water temperature may possibly have triggered or postponed emergence. Further studies would need to be conducted before any conclusions could be made with certainty.

Sunny days often preceded an increased log. catch, but this was likely the result of an indirect effect through temperature.

Rain tended to lower the log. catch somewhat, although not greatly. The log. catch often was lower following rainy days than it was on rainy nights, possibly because rainy days were cooler. High log. catch was usually associated with warm, damp nights, and a low log. catch was often associated with dry, cool nights.

On nights when H. limbata was abundant, males were taken in far greater numbers than females.

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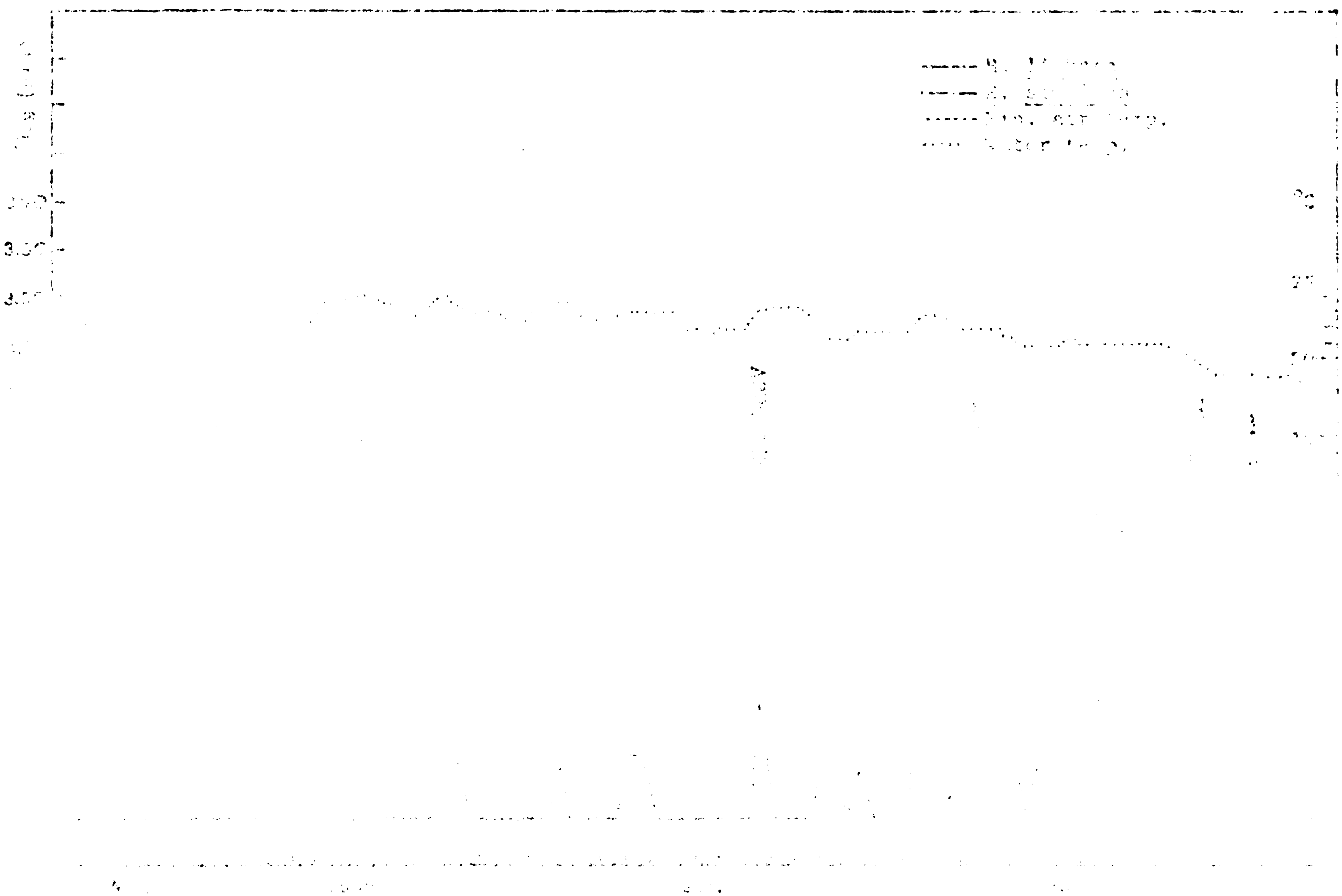

Figure 1.-- [illegible]

Figure 1.-- The relationship of log. catch to minimum air temperature and average water temperature.

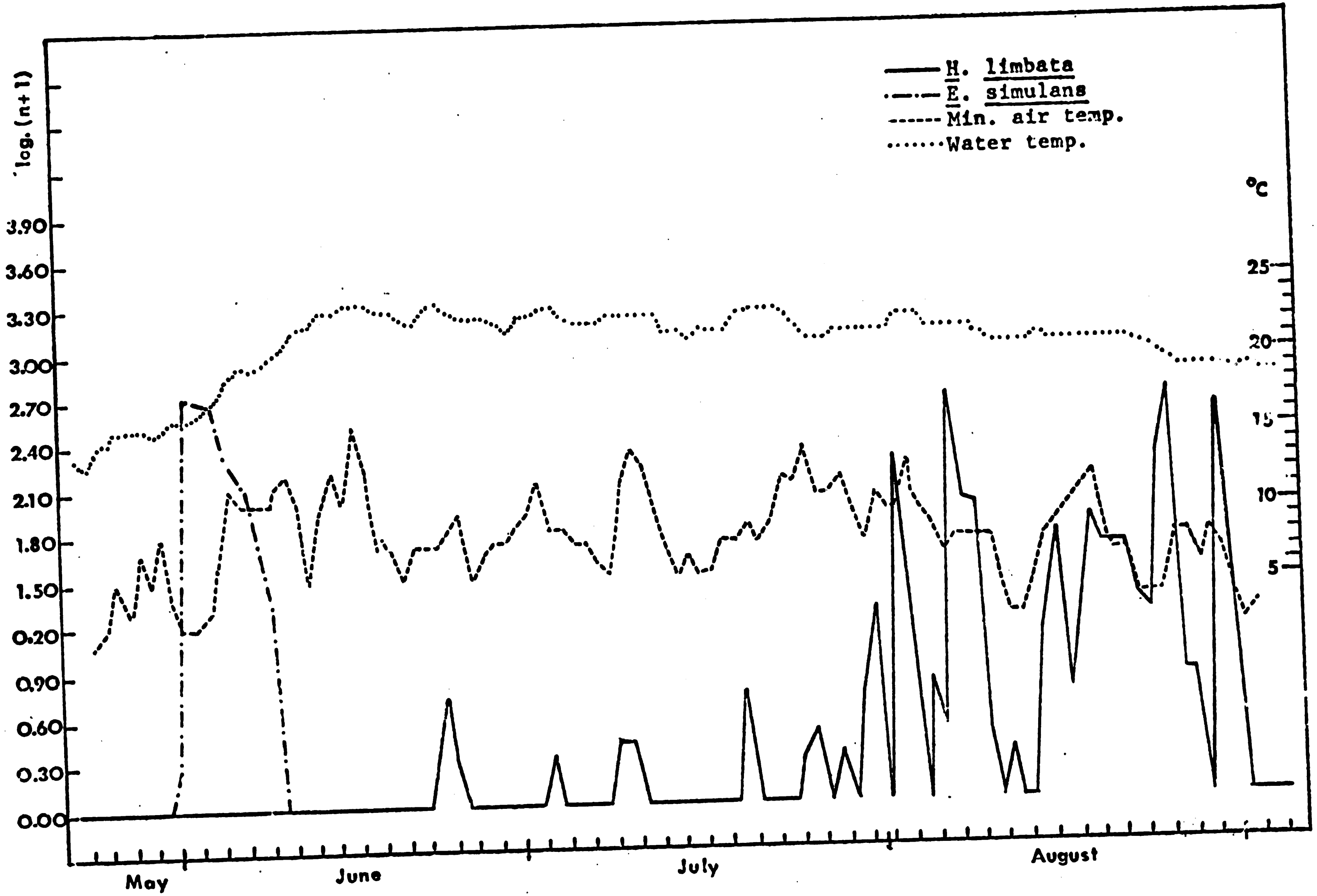

Figure 2.-- The relationship of log. catch to minimum air temperature and average water temperature.

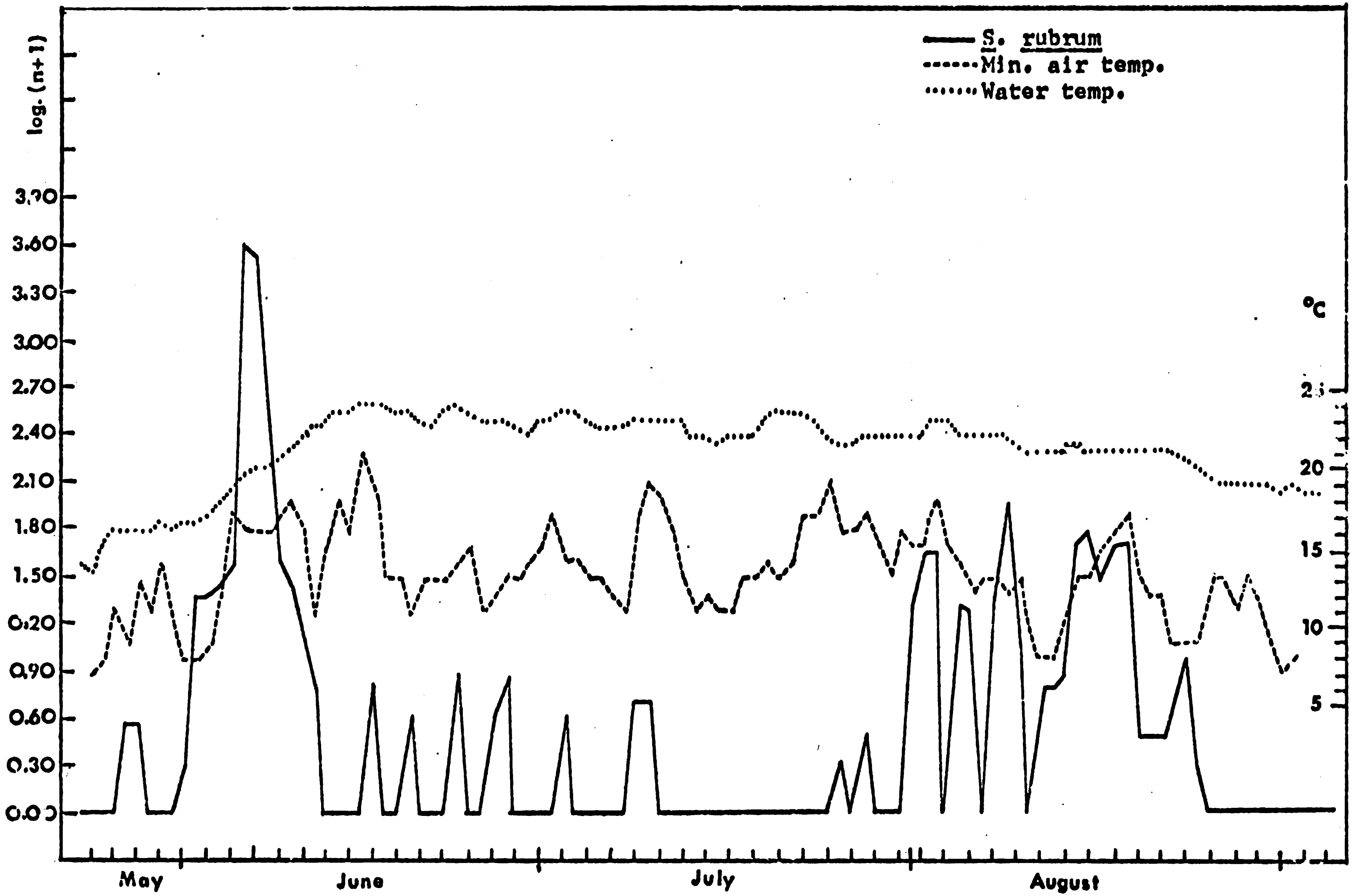

Figure 3.-- The relationship of log. catch to minimum air temperature and average water temperature.

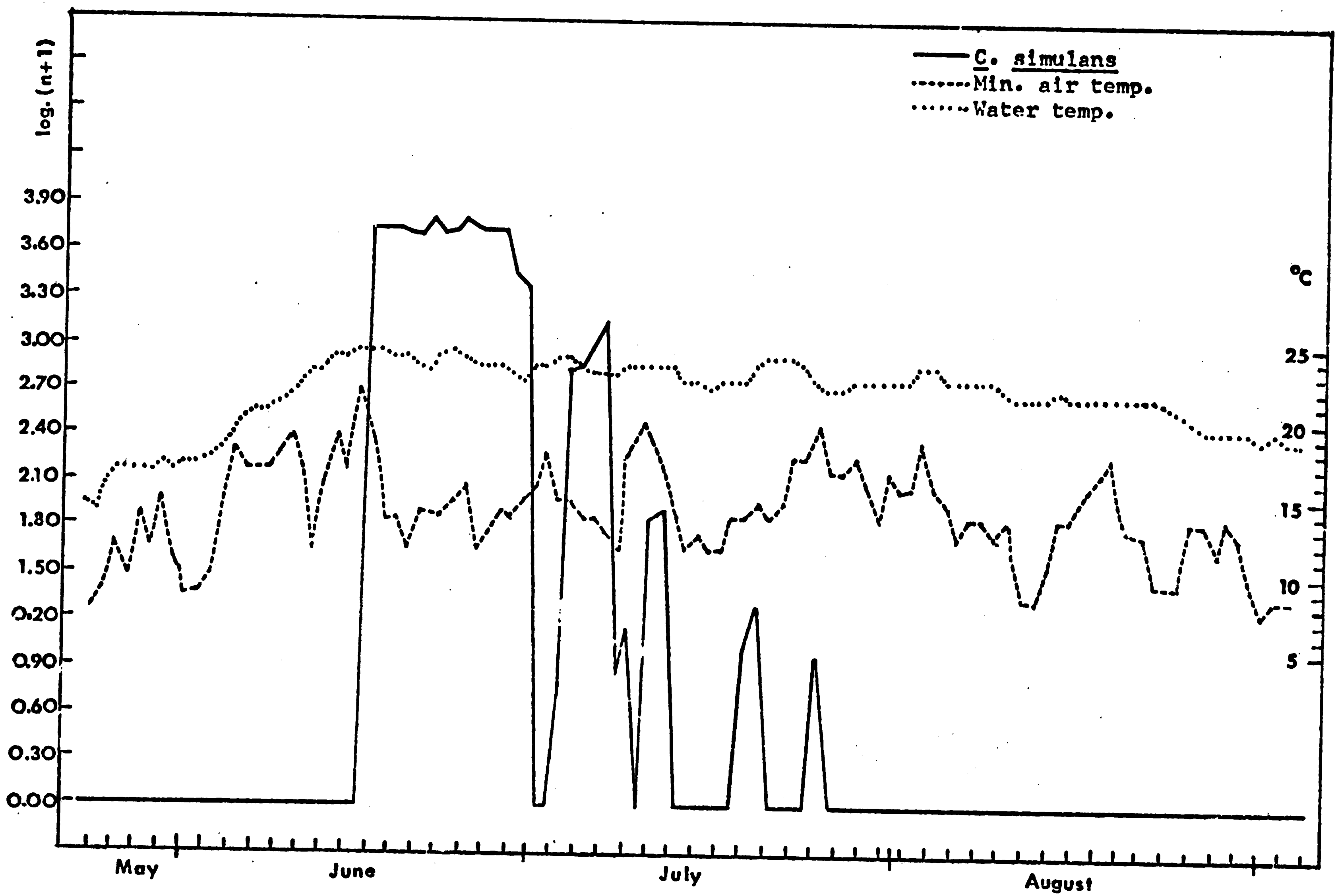

Figure 4.-- The relationship of log. catch to average air temperature, incident radiation, day rain, and night rain.

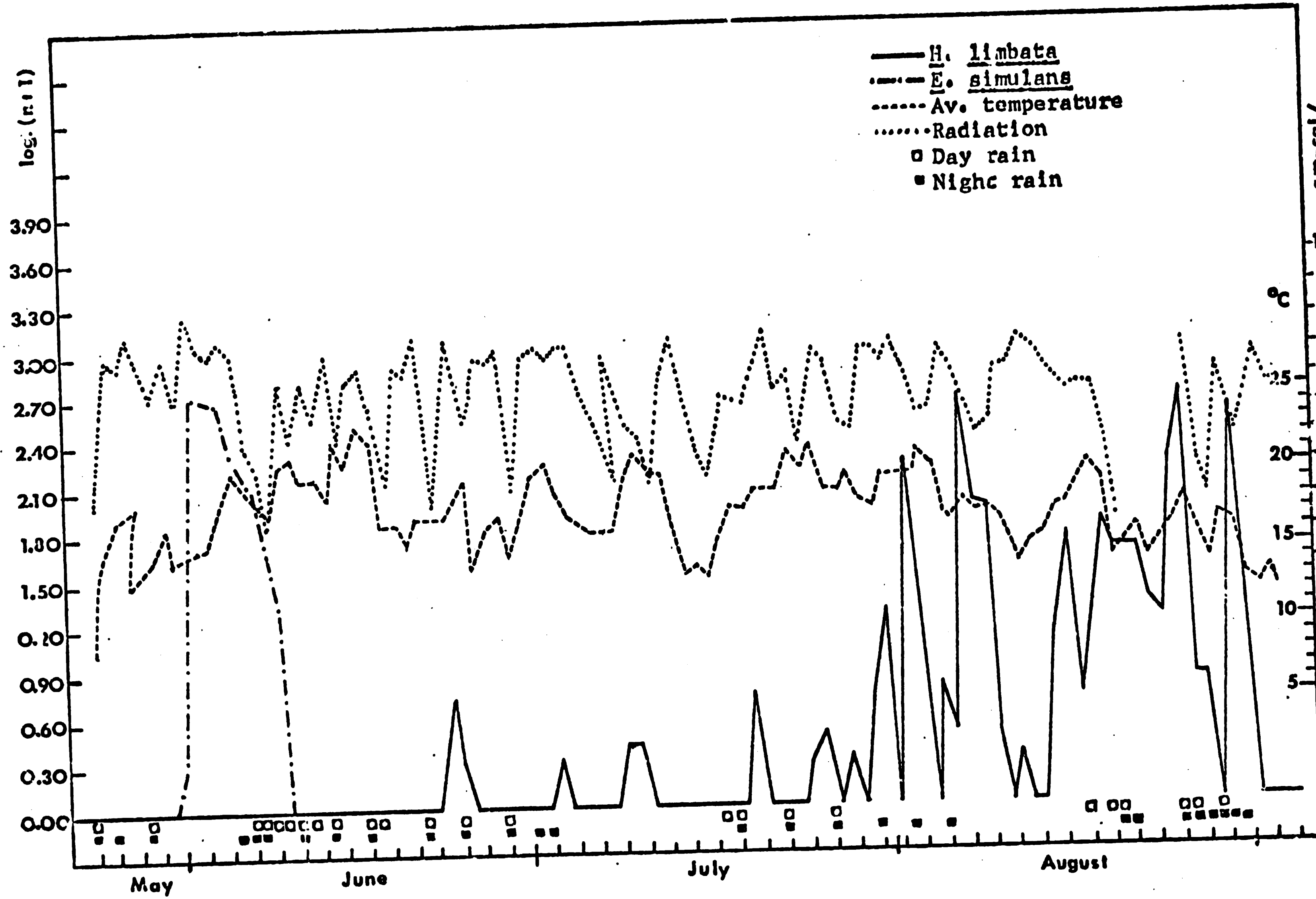

Figure 5.-- The relationship of log. catch to average air temperature, incident radiation, day rain, and night rain.

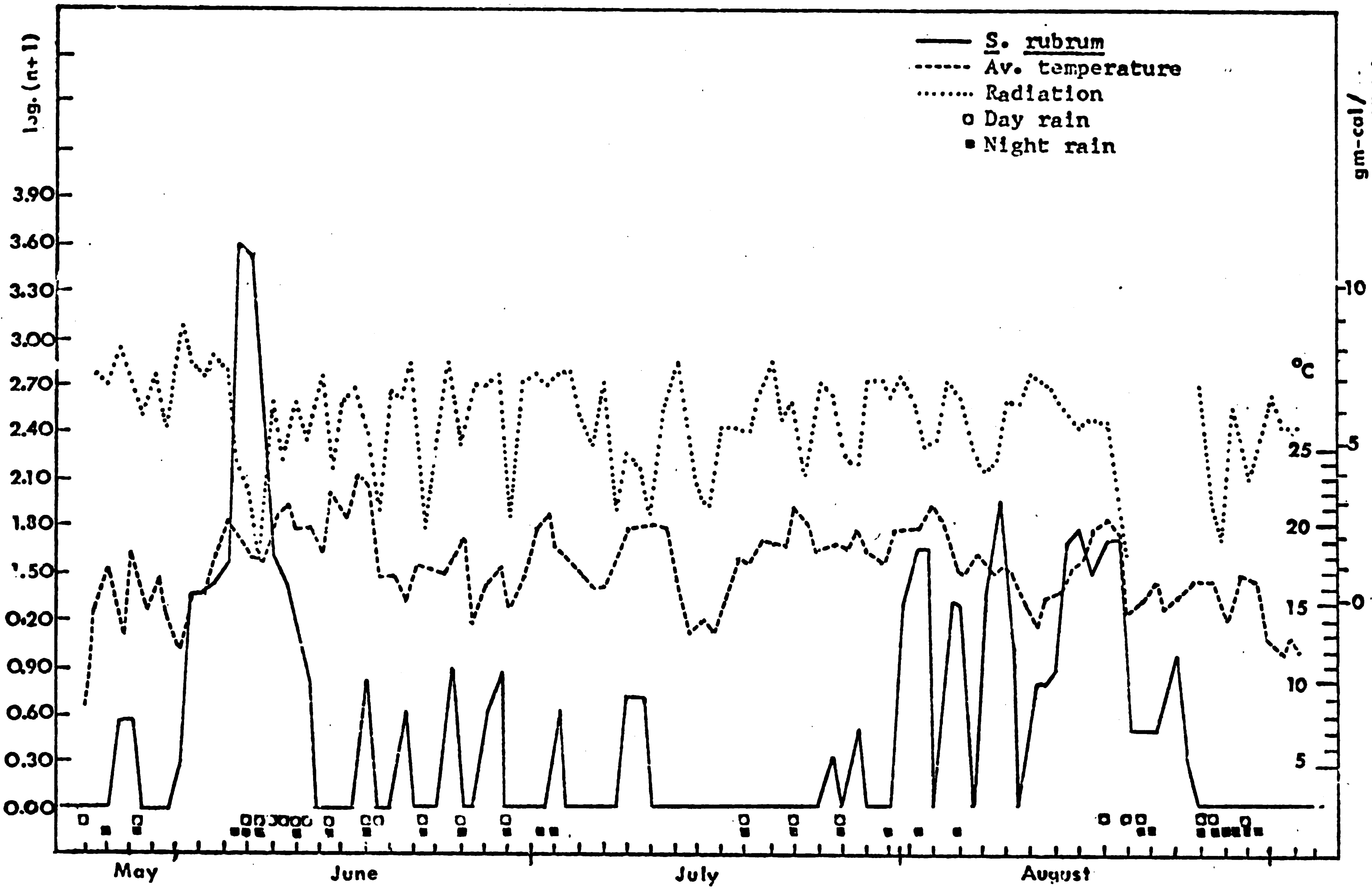

Figure 6.-- The relationship of log. catch to average air temperature, incident radiation, day rain, and night rain.

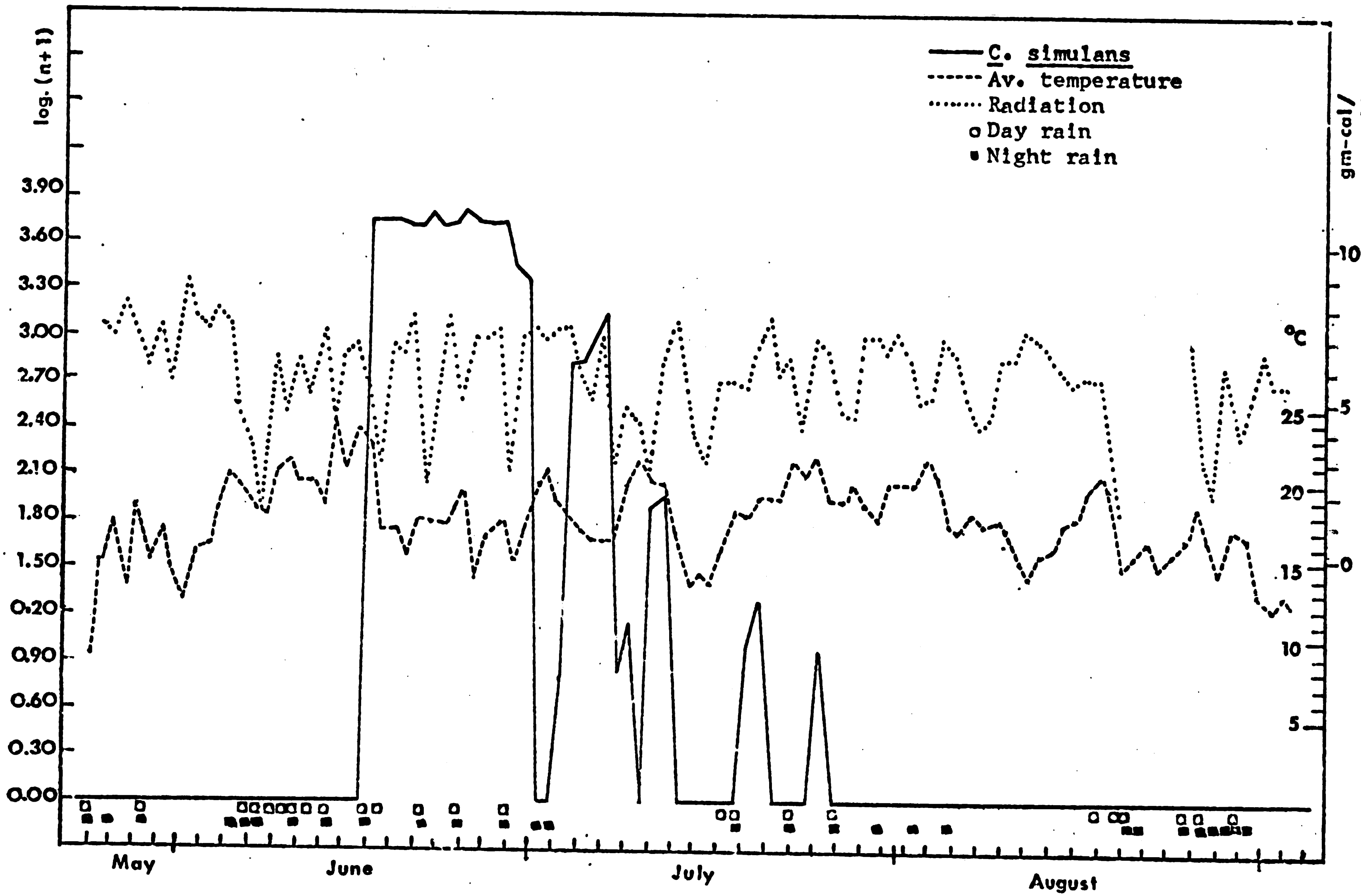

Figure 7.-- Scatter diagram showing the absence of any correlation between log. catch and maximum temperature for May through August. 1967.

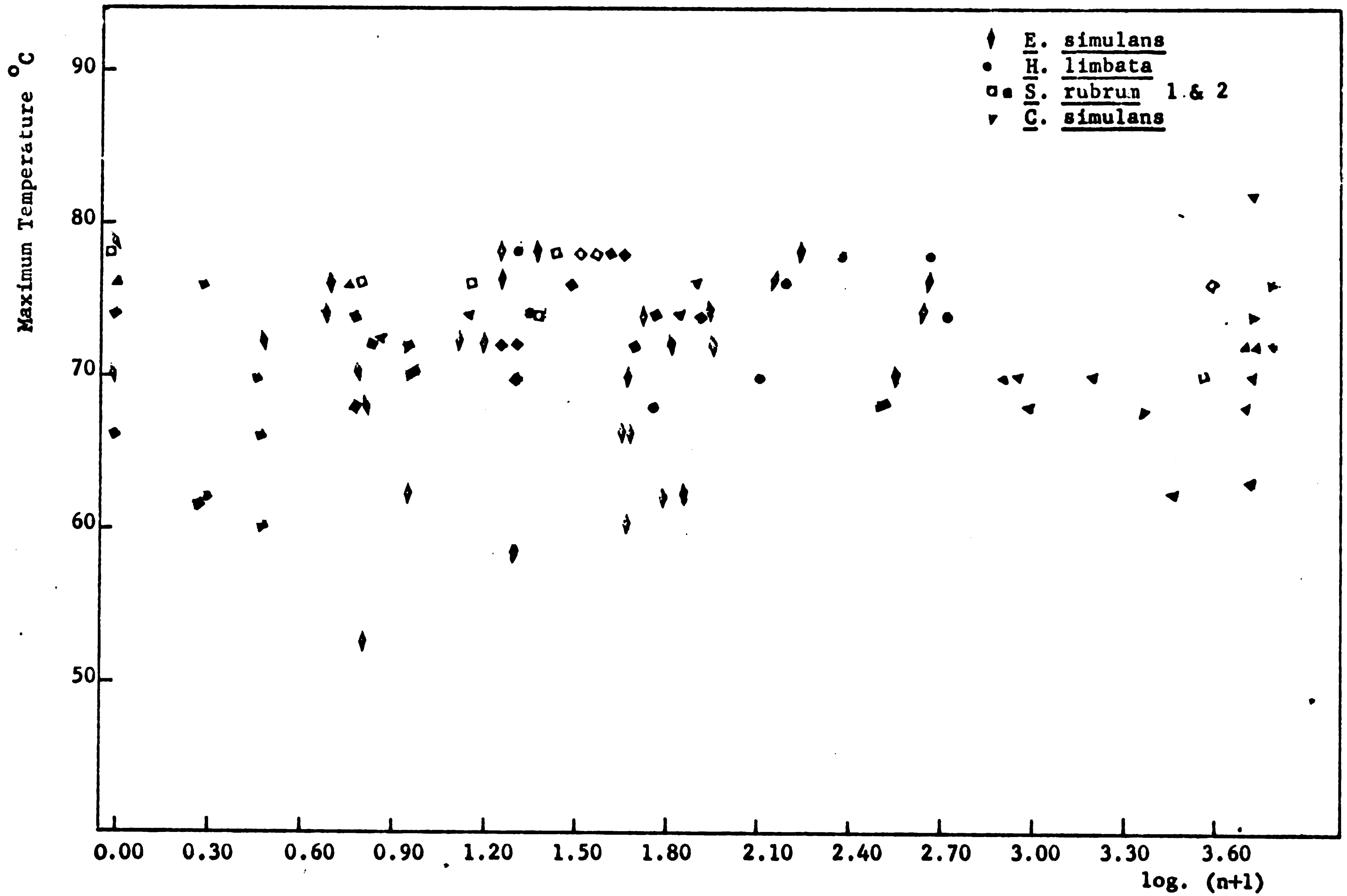

Figure 8.-- Scatter diagram showing the absence of any correlation between log. catch and daily range of temperature for May through August, 1967.

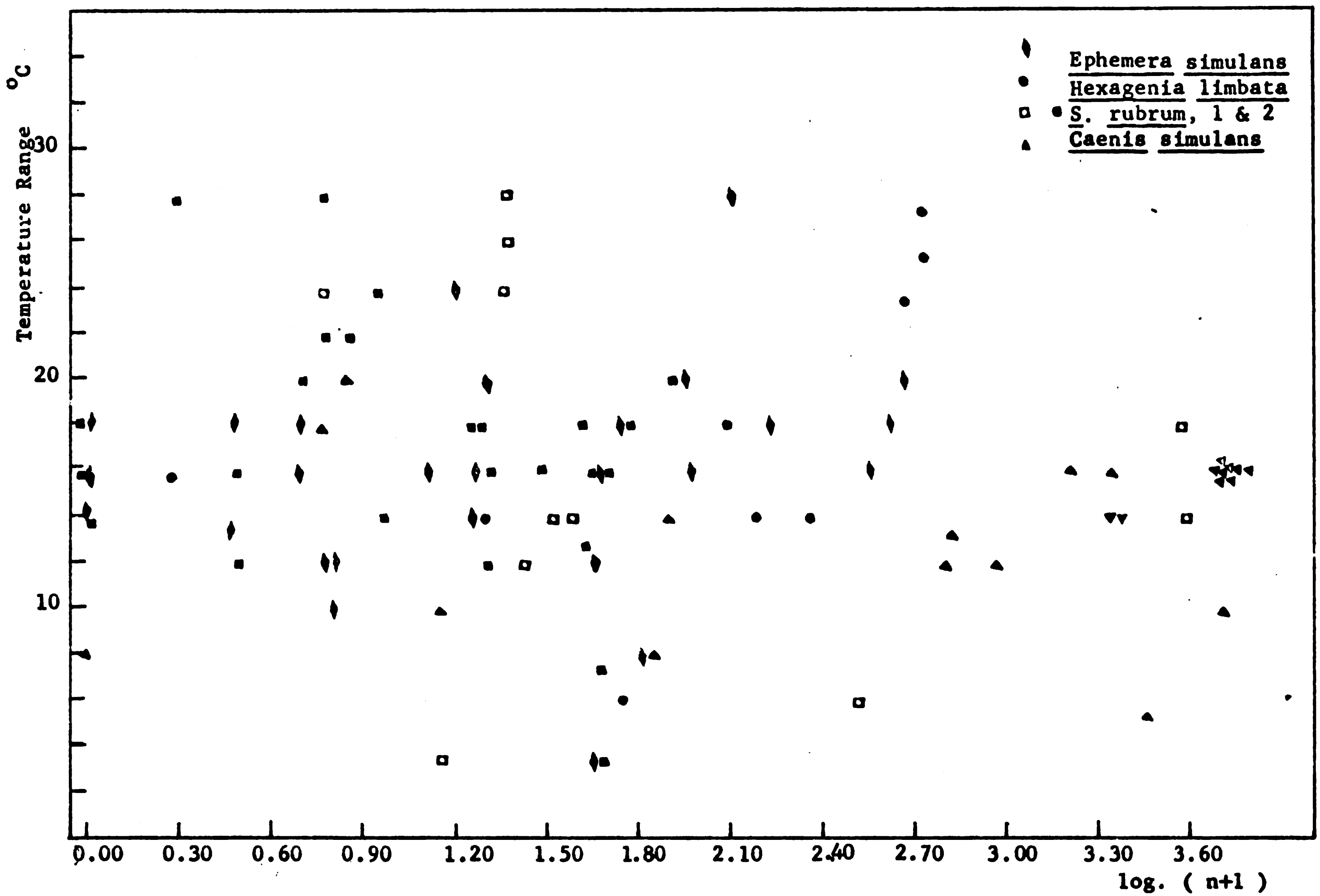

Figure 9.-- Scatter diagram showing the absence of any relation between log. catch and maximum humidity for May through August, 1967.

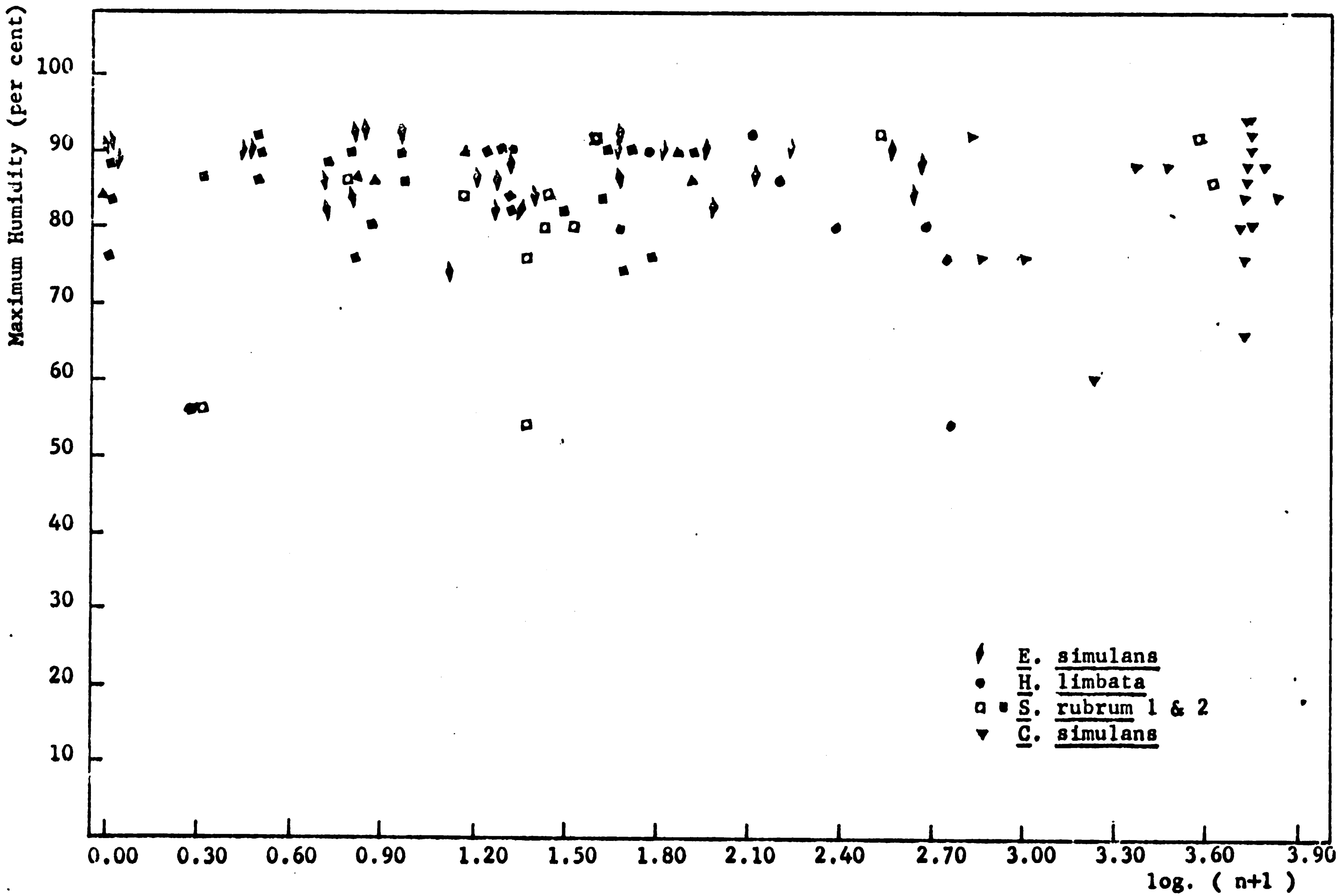

Figure 10.-- Scatter diagram showing the absence of any correlation between log. catch and minimum humidity for May through August, 1967.

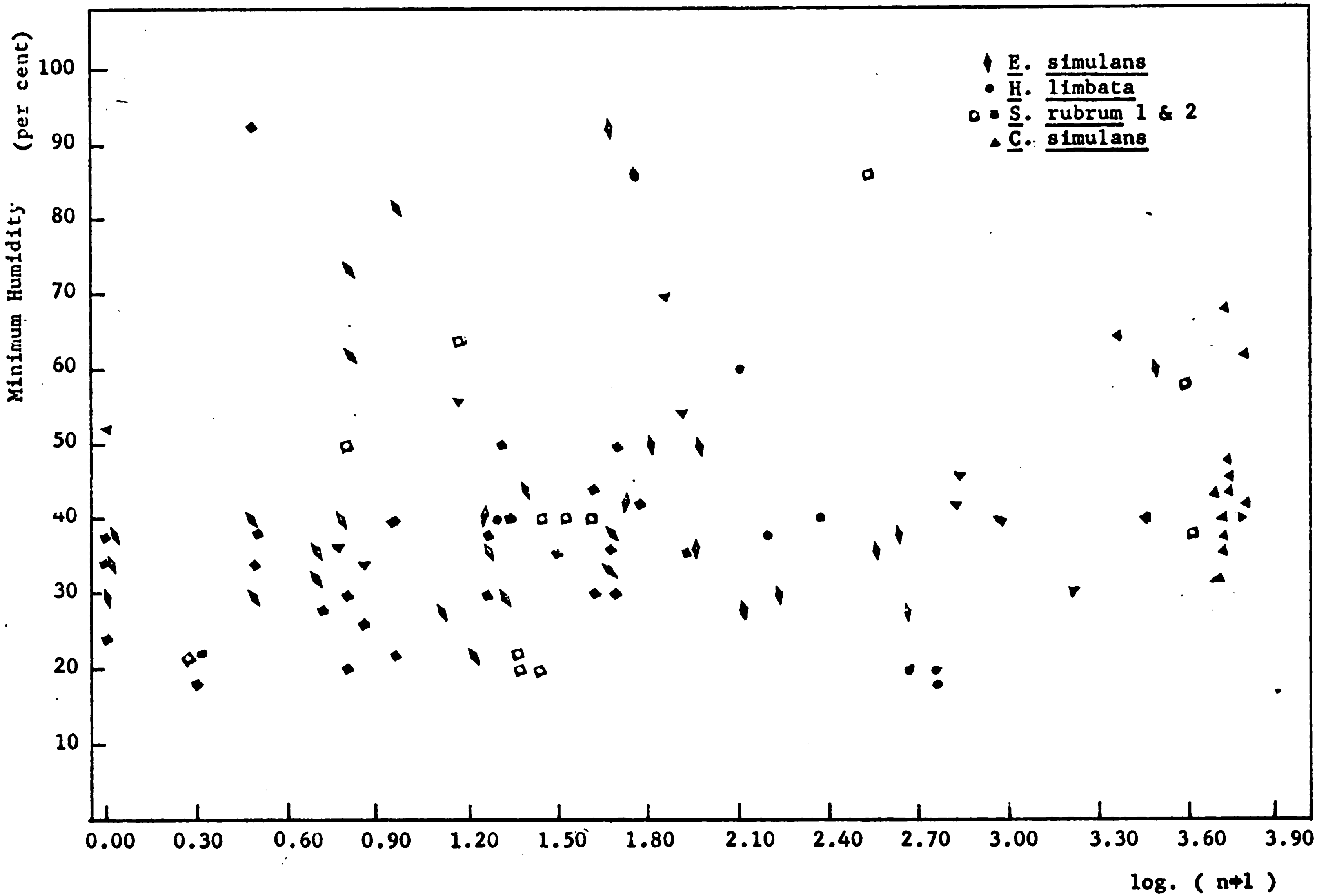

Figure 11.-- Scatter diagram showing the absence of any correlation between log. catch and average humidity for May through August, 1967.