# DISTRIBUTION AND BIOMASS STUDIES OF THE AQUATIC INVERTEBRATES OF A WARM-WATER STREAM

Thesis for the Degree of M. S.

MICHIGAN STATE UNIVERSITY

Darrell Lee King

1962

ABSTRACT

DISTRIBUTION AND BIOMASS STUDIES
OF THE AQUATIC INVERTEBRATES OF A
WARM-WATER STREAM

by Darrell Lee King

The Red Cedar River, a warm-water stream in south-central Michigan, was investigated during 1958 and 1959 to determine production, standing crop, and distribution of the aquatic invertebrate fauna. The study section, 30 river miles long, falls into five natural zones from each of which dredge samples were taken at randomly selected locations.

Thirty-five families of aquatic insects were collected during the study period, there being about the same number of families of insects in each zone but with the number of individuals per family differing from zone to zone.

The standing crop of invertebrates, exclusive of molluscs, was estimated to be 50.40 pounds per acre with 95% confidence limits about 45% of the mean. The addition of the molluscs increased the 95% confidence limits of the total standing crop to about 115% of the mean. The shell weight of the molluscs was included and this coupled with the variation of mollusc distribution caused the increase in variability.

The ratio of total insect weight to tubificid worm weight is suggested as a possible means of delineating stream pollution.

The insect populations of the various sampling stations

are compared on the basis of relative importance, which is the product of the percent composition by numbers of a given family and the corresponding percent of total composition by weight.

The "coefficient of similarity" method was used unsuccessfully to compare the insect fauna of five sampling areas.

The abundance of unionid clams below the outfall of a sewage treatment plant suggests that the domestic wastes may fertilize this area, but it was shown that the aquatic insects were reduced in this area. Tubificid worms were shown to be most abundant below a metal plating plant.

DISTRIBUTION AND BIOMASS STUDIES
OF THE AQUATIC INVERTEBRATES OF A
WARM-WATER STREAM

by

Darrell Lee King

A THESIS

Submitted to
Michigan State University
in partial fulfillment of the reqûirements
for the degree of

MASTER OF SCIENCE

Department of Fisheries and Wildlife

1962

Robert C. Ball
10-18-62

# ACKNOWLEDGEMENTS

The writer wishes to express his sincere appreciation to Dr. Robert C. Ball for the direction of this project and for his many helpful suggestions concerning the organization and presentation of this thesis.

Thanks are also extended to Mr. Robin L. Vannote and Mr. John C. Carr for assistance in the field work, to Mr. Kenneth J. Linton for aid in the statistical analysis of the data, to Dr. Don W. Hayne for planning the sampling schedule, and to Miss Sharon Hammond for aid in preparation of the final manuscript.

This study was financed by a grant from the National Institute of Health (Project K-24 [C2] ).

TABLE OF CONTENTS

## LIST OF TABLES

| TABLE | | PAGE |
|---|---|---|

## LIST OF FIGURES

## LIST OF APPENDICES

## INTRODUCTION

In February of 1958 an investigation of the energy exchange in a warm-water stream was initiated. In this study a special attempt was made to correlate changes in primary and secondary production with variation in stream ecology.

The first phase of this project was a study of the sources of the nutrient content of the stream (Vannote, 1961). This was followed by a study of the organic production of aufwuchs in the several zones of the stream. The next phase of the project undertaken was a study of the predator and consumer levels in the five study zones of the river. This thesis, representing a portion of the overall project, considers the bottom invertebrates of the river, with special attention to the aquatic insects.

The invertebrate populations in each of the study zones were sampled at intervals of one week in 1958 and of two weeks in 1959 to measure production and standing crop and to determine the distribution of the invertebrate fauna.

The information presented here will be correlated with the other physical, chemical, and biological factors as these phases of the project are completed.

## DESCRIPTION OF THE STUDY AREA

The Red Cedar River, a tributary of the Grand River drainage system, is a slow-flowing, warm-water stream located in the south-central portion of the lower peninsula of Michigan. It arises from Cedar Lake, which is located in Marion township, Livingston County, Township 1 north Range 3 east of the Michigan meridian. From its point of origin, the Red Cedar flows northwestward through Livingston County for about 19 miles, then westward through Ingham County for about 29 miles, ending at its confluence with the Grand River in Lansing, Michigan. The main channel of the river is approximately 49 miles in length.

The river and its tributaries drain an area of about 472 square miles, with the Sycamore Creek drainage making up about one-fourth of the total (Figure I).

The elevation at the outflow of Cedar Lake is 934 feet above sea level, while at the confluence of the Red Cedar River with the Grand River the elevation is 817 feet above sea level. Approximately one-half of the fall is in the upper one-third of the river, but the average gradient of the river from Cedar Lake to the Grand River is 2.4 feet per mile (Figure II).

Although the Red Cedar drainage has a stable vegetation cover, floods often occur in the spring when rain and snow-

Figure I. Map of the watershed of the Red Cedar River showing the five zones of the study section

Figure I

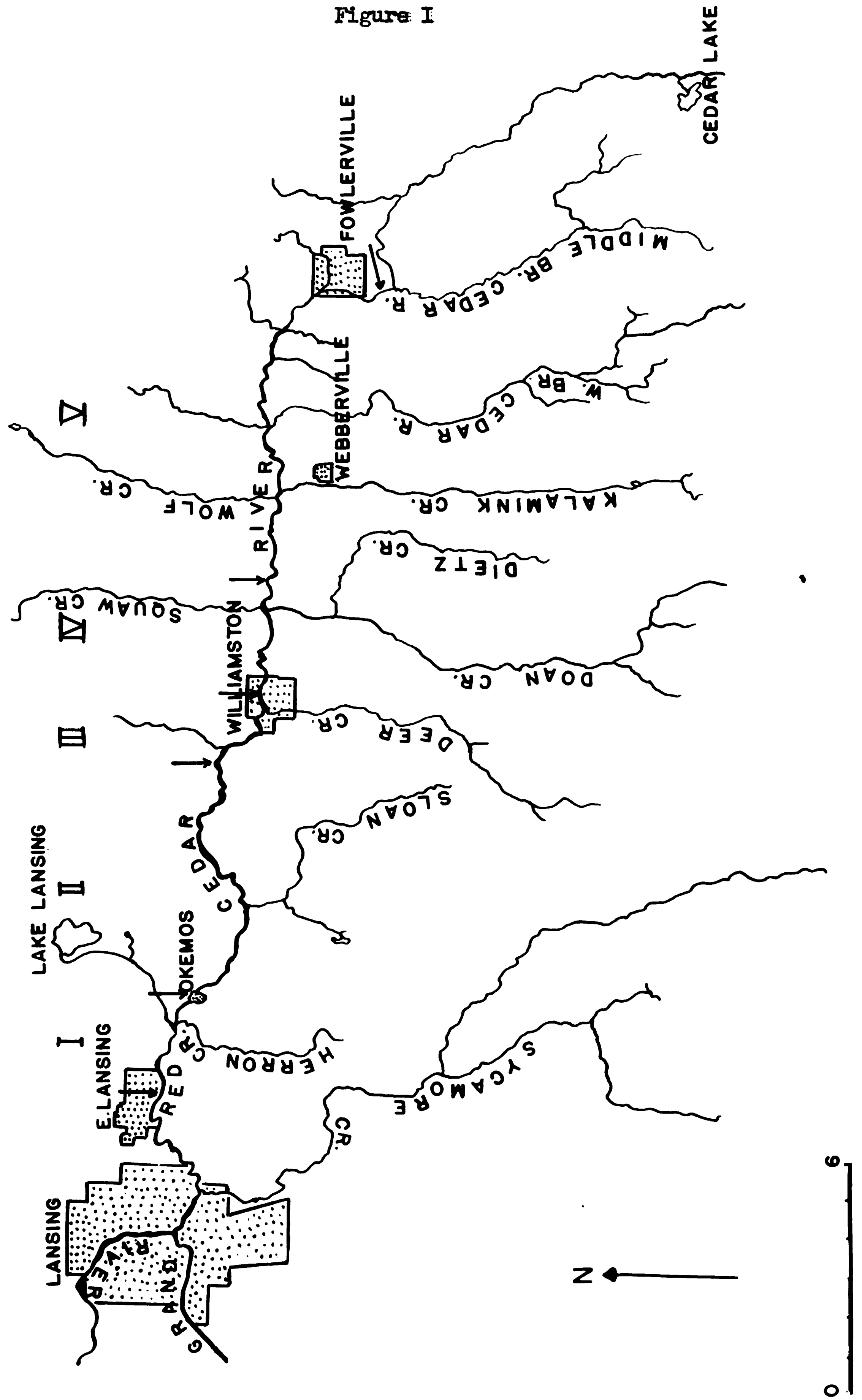

LANSING
GRAND RIVER
E. LANSING
RED CR.
HERRON CR.
OKEMOS
LAKE LANSING
CEDAR RIVER
SLOAN CR.
DEER CR.
WILLIAMSTON
DOAN CR.
SQUAW CR.
DIETZ CR.
KALAMINK CR.
WEBBERVILLE
WOLF CR.
W. BR. CEDAR R.
FOWLERVILLE
MIDDLE BR. CEDAR R.
CEDAR LAKE
SYCAMORE CR.
I
II
III
IV
V
N
0
6
MILES

Figure II. Profile of the Red Cedar River. (Data from U. S. G. S. Topographic maps)

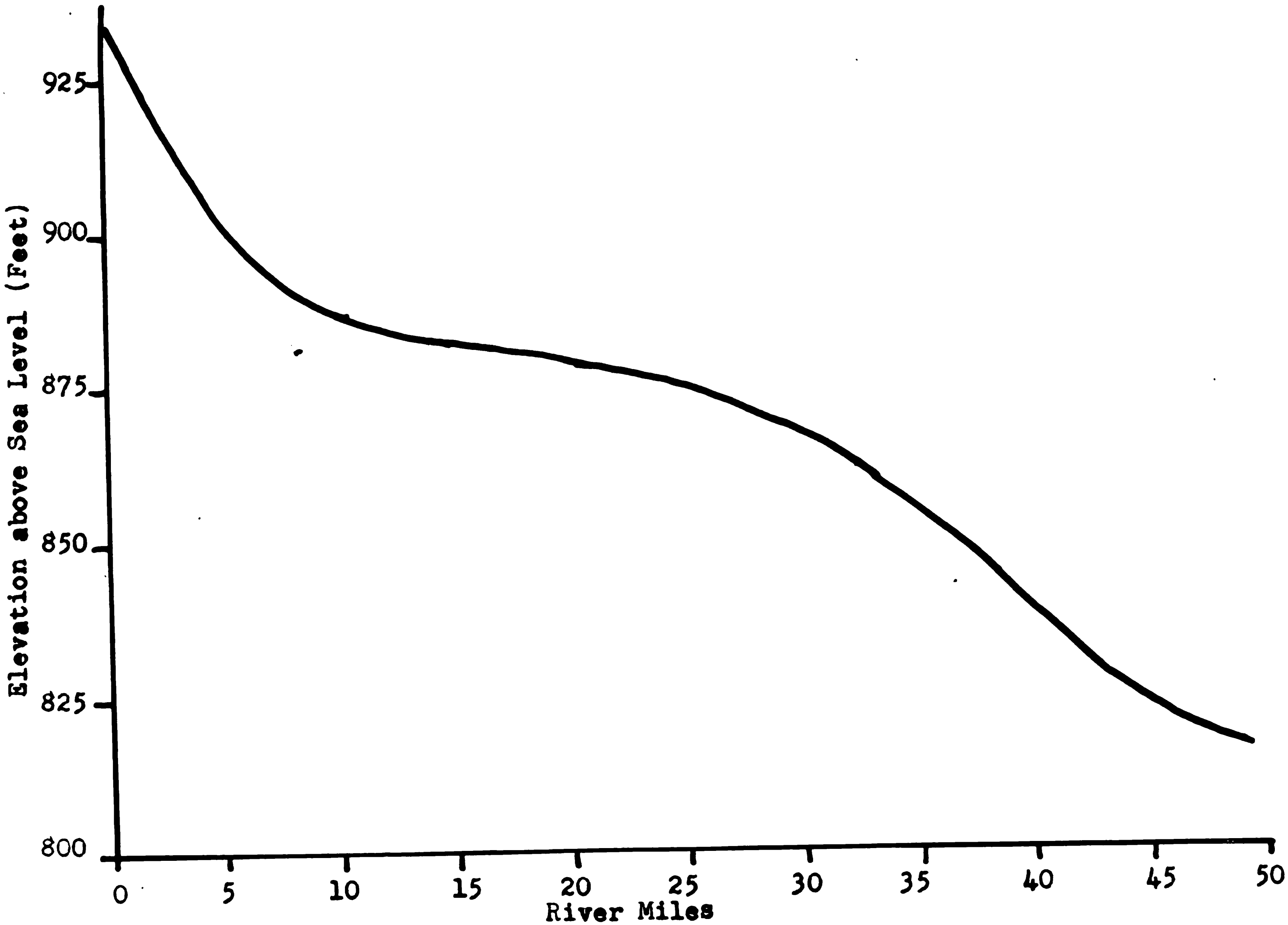

Elevation above Sea Level (Feet)
925
900
875
850
825
800
0
5
10
15
20
25
30
35
40
45
50
River Miles

Figure II

melt swell the river while the ground is still frozen. The period of maximum discharge generally occurs in March or April, while the minimum discharge is recorded in the early autumn before the winter rains begin. During the fall of 1959, unusually prolonged periods of heavy rain caused an above average discharge. The mean discharge for 1958-1959 was 198 cubic feet per second, with a maximum of 2,210 cfs and a minimum of 11 cfs. The total discharge for 1958 was below a 10-year average, while the total discharge for 1959 was slightly above the 10 year average (Figure III). These discharge values were recorded at a U. S. G. S. gauging station at Farm Lane bridge, seven miles above the mouth of the river, and excluded the discharge from the Sycamore Creek watershed. These discharge measurements apply to the 355 square mile portion of the Red Cedar watershed above Farm Lane bridge.

The Red Cedar arises in an area made up primarily of marsh and wet lands, and much of the upper end of the river has been dredged to facilitate drainage of the marshes and swamps for agricultural purposes.

There are three impoundments on the Red Cedar River, the largest of which is near Williamston. The original dam at Williamston was constructed in 1840 to power a saw mill, but was replaced with a concrete structure at a later date. At present, a constant flow generator utilizes a thirteen foot head of water to power a private refrigeration and frozen food plant (Brehmer, 1956). Approximately three

Figure III. Graph of the mean discharge per month in cubic feet per second for the Red Cedar River for the years 1958 and 1959, and a ten year average (1946-1956)

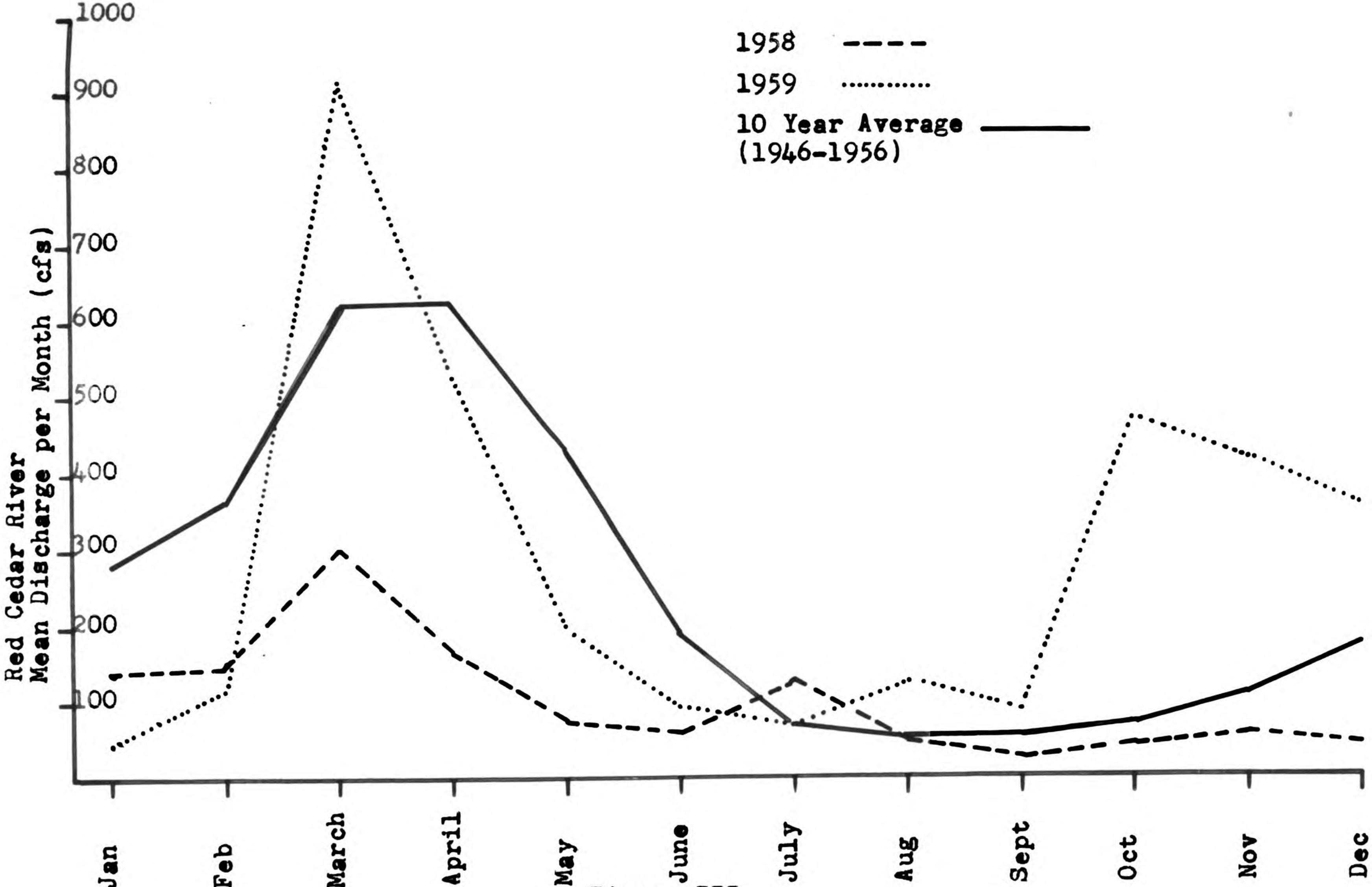

1958
1959
10 Year Average
(1946-1956)
Red Cedar River
Mean Discharge per Month (cfs)
1000
900
800
700
600
500
400
300
200
100
Jan
Feb
March
April
May
June
July
Aug
Sept
Oct
Nov
Dec

Figure III

miles of the river are under the influence of this dam and the impoundment averages about 200 feet in width, but is nowhere greater than one-quarter of a mile wide; the width being limited by the high banks along this section of the river. The maximum depth of this impoundment is about ten feet, but there are large mud flats which are exposed when the reservoir is drawn down during periods of low flow. The shallower areas of this impoundment support a heavy growth of aquatic plants, chiefly Ceratophyllum demersum, Elodea canadensis, and an undetermined species of Nuphar.

The second impoundment is at a picnic area in Okemos. The original dam, constructed here to furnish power for a grist mill, has been replaced with a stone ballast type to create a small pool for recreational purposes.

The third impoundment is on the Michigan State University campus and was constructed primarily for recreational purposes, although it also supplies water to a power plant (Meehan, 1958).

Both the dam at Okemos and the one on the Michigan State University campus serve to decrease the velocity of the river, but neither of these dams has as much effect on the river as the dam at Williamston. The impoundment at Williamston is truly pond-like while the other two impoundments are better described as very slow-moving river areas.

With the exception of the impounded areas and the dredged area on the upper portion of the stream, the Red Cedar River is a slow-flowing meandering stream with well stabilized banks and a well stabilized channel.

The river flows through rolling farm and suburban land and touches upon four urban communities before entering the East Lansing-Lansing metropolitan area. The area immediately adjacent to the river is predominately woodland, while most of the watershed is utilized for dairy and small grain farming.

Above Fowlerville the river is quite clean, although the water has a reddish-brown stain which is characteristic of the entire river. At Fowlerville the river receives effluent from a metal plating plant and domestic pollution from septic tank drains. From Webberville it receives very small amounts of pollution via Kalamink Creek, one of its tributaries. Williamston contributes domestic pollution from septic tank drains and a sewage treatment plant. Gross pollution occurs below Williamston with the recovery zone extending two to three miles, depending on the season and the flow of the river (Brehmer, 1958).

From three miles below Williamston to Okemos, the Red Cedar is a relatively clean stream. However, from Okemos to the confluence with the Grand River, the Red Cedar receives domestic wastes from a series of storm drains, septic tanks, and a sewage treatment plant.

Bottom type varies from mud and detritus to coarse gravel in the Red Cedar River while vegetation varies from sparse to abundant. The Red Cedar is a slow-flowing river averaging about 0.5 feet per second with a range of from

0 to 3 feet per second.

## The Study Section

The section of the river chosen as the study area consists of 30 miles of the main river, extending from the Farm Lane bridge on the campus of Michigan State University to the Van Buren road bridge, a little over a mile above Fowlerville. This section of the river drains 355 square miles.

The study section is divided naturally into five zones, (Figure I) the first of which begins at the Farm Lane bridge and ends at the Okemos Road bridge in Okemos. The arrows in Figure I correspond to the roads used as limits of the five river zones. Zone I is about three and one-half miles long and includes the impounded water on the campus which receives domestic pollutants from a series of storm and septic tank overflow drains. Zone I is entirely within an urban area. The bottom type in this zone grades from silt in the impounded area to sand flats in the upper end of the zone. There is one rocky riffle about 500 feet below the Okemos Road bridge. The average depth in the impounded area is six feet, while an average of 15 inches of water covers the sand flats.

The second zone is eight and one-half miles long, beginning at Okemos Road and extending upstream to Zimmer Road, which is about three miles downstream from Williamston. Zimmer Road is near the end of the recovery area below the Williamston sewage treatment plant, and zone II is no doubt enriched by the effluent from this plant. Woodlands adjoin the river for nearly the full length of this zone. The bottom type in zone II ranges from silt and detritus in the pools to sand flats and rubble in the riffles. In this zone there are many large beds of Vallisneria americana and Saururus cernuus.

Zone III includes the polluted and recovery areas of the stream below the Williamston sewage treatment plant and is two and one-half miles long. This zone begins at Zimmer Road and ends at the dam in Williamston. The river flows through an urban area for one mile, then through woodlands for the remainder of zone III. There are extensive beds of Vallisnenia americana and Saururus cernuus on the silt and detritus bottom common to this zone.

Zone IV includes the section of the river under the influence of the dam at Williamston and is four miles in length. This zone begins at the dam and extends upstream to Dietz Road. The upper portion of this zone is bordered by woodlands, while the lower mile is in the city of Williamston. The bottom material is predominantly silt and detritus, although there are occasional small areas of hardpan clay or sand. The shallower areas are covered with dense beds of Ceratophyllum demersum and Elodea canadensis while large beds of an undetermined species of Nuphar are common in the deeper water. Aquatic vegetation borders the channel for the full length of zone IV.

The fifth zone is twelve miles long and includes the remainder of the study section. This zone is bordered by woodlands and pastures. Sand and gravel make up the bottom material in the lower portion of this zone, while in the upper dredged portion silt covers the bottom to a depth of 18 inches. Vast beds of *Vallisneria americana* are common in this zone, especially in the silted, dredged portion.

## METHODOLOGY

All of the bottom samples, with the exception of those taken from zone IV, were taken with a Petersen dredge. The deeper water of the impoundment necessitated the use of a boat. An Ekman dredge was used to take the bottom samples in zone IV. The Petersen dredge sampled an area of 0.83 square feet while the Ekman dredge sampled a 0.22 square foot area.

The dredges were chosen as samplers because the current in most areas of the Red Cedar River is not strong enough to sweep the material into the bag on a Surber sampler while the deeper holes preclude the use of a Hess-type sampler.

All sampling sites were randomly selected. The zone to be sampled was first divided into mile units, one of which was selected from a table of random numbers. The chosen mile was then sub-divided into portions 1/10 of a mile in length, with one 1/10 of a mile portion being selected from the table of random numbers. The selected 1/10 of a mile portion was then further sub-divided into tenths, one-tenth of which was selected from the table of random numbers. Thus, the area selected for sampling was 0.01 mile, or 52.9 feet long. This is as small an area as it is practical to use for this type of survey, since it is difficult to pin-point a location on the stream smaller than 0.01 mile.

After the sampling site had been chosen, the sampling points along the transect were chosen by selecting several random numbers from the table of random numbers. Sixteen to twenty numbers were chosen in 1958 and ten numbers were selected for all samples in 1959. These numbers were divided into two categories designated even and odd. Every other number was designated even with the intervening numbers being designated odd. A cable, graduated in feet, was then stretched across the river at the randomly chosen location. One dredge sample was taken at each of the randomly selected points along this transect, with each point corresponding to one of the randomly selected numbers. The sample was thus divided into two sub-samples, designated even and odd. The even and odd sub-samples were kept separate through all subsequent handling.

After the dredge hauls were taken, the bottom material was screened with a 30-mesh sieve to remove silt and the finer sand. The residue was then placed in buckets and removed to the laboratory. The organisms were picked alive from the samples the same day they were collected, or where this was impossible the organisms were refrigerated and picked the next day. In the laboratory, the sample was screened again with a 30-mesh sieve and picked by the flotation method, utilizing a concentrated sugar solution. The sugar solution was made for each sample and then discarded. Two parts water to one part sugar made the solution which was then poured over a portion of the sample contained in a white enamel pan. The sugar solution floated most of the organisms out of the bottom material. However, the bottom material was carefully checked to make sure that no molluscs or case-forming caddis larvae were overlooked. All final sorting was done by hand.

After the organisms had been separated from the bottom material, they were preserved in a 70% alcohol solution containing 5% glycerine.

The samples were analyzed during the winter following their collection. The 1958 collections were measured for total volume, classified to family, and counted. The organisms collected in 1959 were classified to family and counted. Wet weight was then taken for all organisms except the molluscs. In order to determine the wet weight, the organisms were removed from the preservative and soaked in tap water for thirty minutes. Following this soaking period, the organisms were placed in small 30-mesh screens and spun in a centrifuge for 30 seconds at 1800 r.p.m. to remove the excess moisture. The organisms were then weighed on an H4 Mettler balance accurate to 0.001 gram.

Since it was not deemed valid to include the weight of the mollusc shells in the wet weight values, the molluscs were analyzed for total volume rather than for wet weight.

## DESCRIPTION OF SAMPLING SITES

### 1958 Samples

The samples from zone I were taken July 21 and July 28, 1958, one-quarter of a mile below the confluence of Lake Lansing drain with the Red Cedar. The river was 66 feet wide on July 21 and 64 feet wide on July 28. Sixteen samples were taken each day with a Petersen dredge. The bottom materials associated with these samples are listed in Table I. The depth of the water in this area averages about 2 feet, which is roughly the average depth over the entire study section with the exception of zone IV where the average depth is about seven feet.

Zone II was sampled on September 25 and October 2, 1958, approximately one mile downstream from the U. S. 16 bridge (Figure IV). Eighteen Petersen dredge samples were taken each day, and the width of the river was 60 feet on September 25 and 58 feet on October 2. The bottom materials included in these samples are listed in Table I.

Zone III was sampled one-quarter of a mile below the Williamston sewage treatment plant on September 4 and 11, 1958. Twenty Petersen dredge samples were taken each day and the river was 42 feet wide on both dates. The bottom materials associated with these samples are shown in Table I.

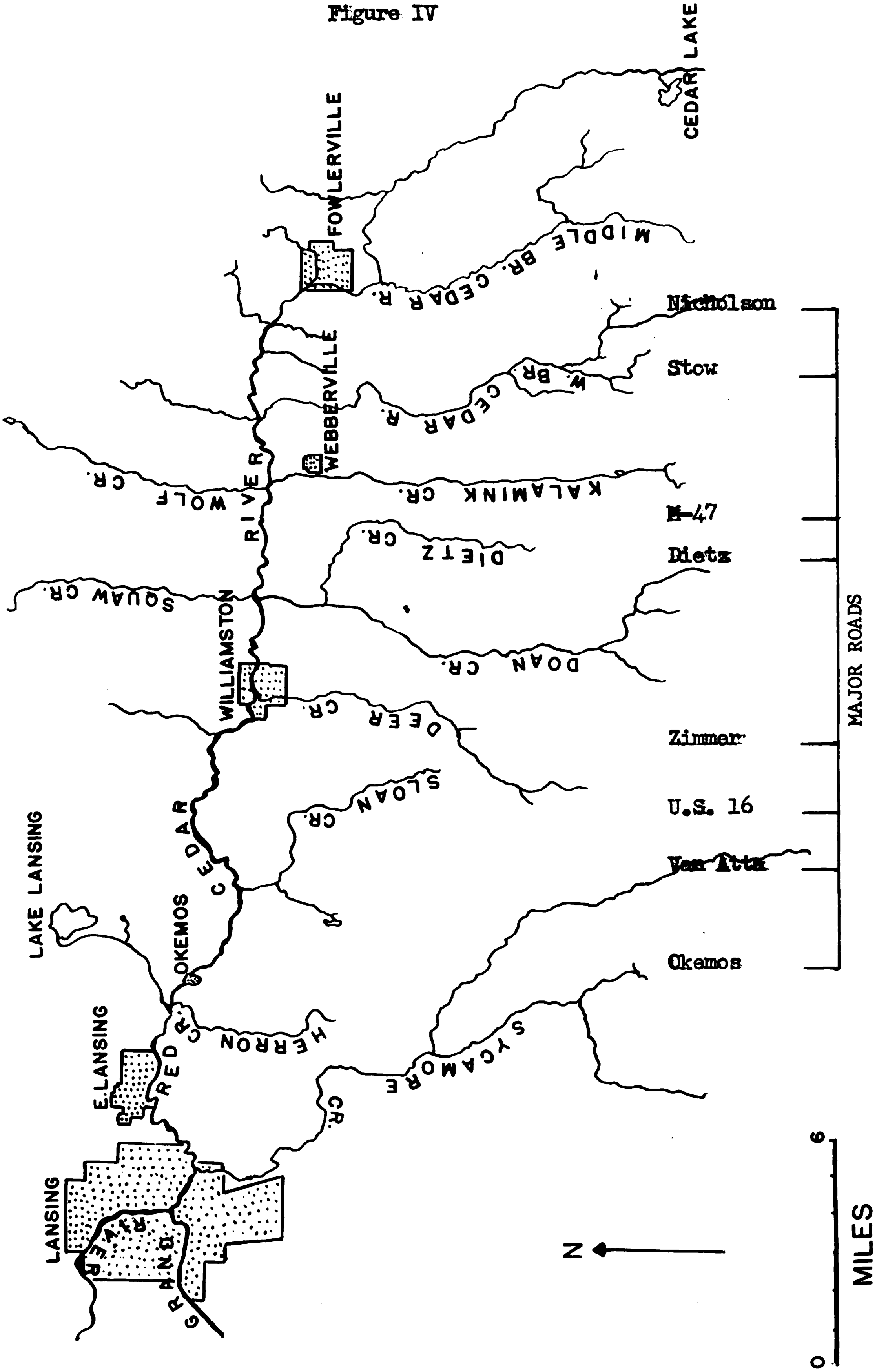
Zone IV was sampled on August 4 and 11, 1958, approx-

Table I. Bottom materials associated with dredge samples taken from the Red Cedar River in 1958, showing the number of dredge hauls containing each material

| Bottom Material / Sampling Station and date | Detritus | Detritus and Silt | Silt | Silt and Sand | Sand | Sand and Gravel | Gravel | Gravel and Detritus | Sand and Shells | Gelatinous Silt and Detritus |
|---|---|---|---|---|---|---|---|---|---|---|
| Station I | | | | | | | | | | |
| July 21 | 1 | | 2 | 1 | 2 | 6 | 4 | | | |
| July 28 | | 3 | | 2 | 4 | 4 | 3 | | | |
| Station II | | | | | | | | | | |
| September 24 | | 2 | | 3 | 4 | 2 | 3 | 2 | 2 | |
| October 2 | 2 | 2 | | 1 | 3 | 2 | 3 | 1 | 4 | |
| Station III | | | | | | | | | | |
| September 4 | | 2 | | 5 | 3 | 8 | 2 | | | |
| September 11 | 2 | 4 | | | | 13 | | 1 | | |
| Station IV | | | | | | | | | | |
| August 4 | | | | | | | | | | 20 |
| August 11 | | | | | | | | | | 20 |

Figure IV. Map of the watershed of the Red Cedar River showing the major roads that cross the river

Figure IV



CEDAR LAKE
FOWLERVILLE
MIDDLE BR. CEDAR R.
WEBBERVILLE
W. BR. CEDAR R.
WOLF CR.
KALAMINK CR.
RIVER
DIETZ CR.
SQUAW CR.
WILLIAMSTON
DOAN CR.
DEER CR.
SLOAN CR.
CEDAR
LAKE LANSING
OKEMOS
E. LANSING
RED CR.
HERRON CR.
SYCAMORE CR.
LANSING
GRAND RIVER
Nicholson
Stow
M-47
Dietz
Zimmer
U.S. 16
Van Atta
Okemos
MAJOR ROADS
N
0
6
MILES

imately 1.6 miles above the dam at Williamston. Twenty Ekman dredge samples were taken each day and the river was 60 feet wide on both dates. The bottom materials of all samples taken from this location were silt and detritus mixed with a jelly-like mud.

## 1959 Samples

Zone I was sampled September 21 and October 3, 1959, 300 feet below the entrance of Lake Lansing drain. Ten Petersen dredge samples were taken on each day and the river was 79 feet wide on both dates. The bottom materials included in the samples are listed in Table II.

Zone II was sampled approximately one-half mile below Van Atta Road on August 12 and 27, 1959. Ten Petersen dredge samples were taken each day. The river was 55 feet wide on August 12 and 57 feet wide on August 27. The bottom materials in this area are sand and gravel. The bottom of the area sampled was covered with a large bed of *Vallisneria americana* and all samples included this plant as well as sand and gravel.

Zone III was sampled on June 10 and 25, 1959, one-half mile below the Williamston sewage treatment plant and the river was 57 feet wide on both dates. Ten Petersen dredge samples were taken each day and the bottom materials collected are listed in Table II.

Zone IV was sampled two miles above the dam in Williamston on June 29 and July 14, 1959. Ten Ekman dredge samples

Table II. Bottom materials associated with dredge samples taken from the Red Cedar River in 1959, showing the number of dredge hauls containing each material

| Sampling Station and date \ Bottom Material | Detritus | Detritus and Silt | Silt | Silt and Sand | Sand | Sand and Gravel | Gravel | Gravel and Detritus | Gravel and Stones | Stones | Sand, Gravel, and Vegetation | Gelatinous Silt and Detritus | Sand, Gravel, and Stones | Sand, Silt, and Detritus |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Station I | | | | | | | | | | | | | | |
| September 21 | 1 | 1 | | | | 6 | | | | | | | | 2 |
| October 3 | | 5 | | | | 5 | | | | | | | | |
| Station II | | | | | | | | | | | | | | |
| August 12 | | | | | | | | | | | 10 | | | |
| August 27 | | | | | | | | | | | 10 | | | |
| Station III | | | | | | | | | | | | | | |
| June 10 | | | | | | 4 | 2 | | 4 | | | | | |
| June 25 | | 1 | | | | 3 | | | 5 | 1 | | | | |
| Station IV | | | | | | | | | | | | | | |
| June 29 | | | | | | | | | | | | | | 10 |
| July 14 | | | | | | | | | | | | | | 10 |
| Station V-1 | | | | | | | | | | | | | | |
| July 19 | | | | | | | | | | | | | 10 | |
| August 3 | | | | | | | | | | | | | 10 | |
| Station V-2 | | | | | | | | | | | | | | |
| October 27 | | | | | | | | | | | | | | 10 |
| November 12 | | | | | | | | | | | | | | 10 |
| Station V-3 | | | | | | | | | | | | | | |
| February 6 | | | | | | | | | | | | 14 | | |
| February 13 | | | | | | | | | | | | 10 | | |

were taken each day. The width of the river was 110 feet on June 29 and 100 feet on July 14. The bottom materials for all samples taken from this area were a mixture of sand, silt, and detritus.

Zone V was sampled 100 feet above Nicholson Road on February 6 and 13, 1959. The river was 18 feet wide on February 6 and 21 feet wide on February 13. Fourteen Petersen dredge samples were taken on February 6 and ten on February 13. The bottom type found in all samples was a black gelatinous ooze containing much detritus. This sampling station was designated V-3.

Zone V was sampled about 800 feet above the M-47 bridge on July 19 and August 3, 1959. Ten Petersen dredge samples were taken each day. The river was 37 feet wide on July 19 and 38 feet wide on August 3. This area is a riffle and the bottom material is composed of sand, gravel, and stones. This sampling station was designated V-1.

On October 27 and November 12, 1959, zone V was sampled one-quarter of a mile above the Stow Road Bridge. The river in this dredged area was 40 feet wide on both days. The bottom material in this area is quite uniform and is composed of sand, silt, and detritus. This sampling station was designated V-2.

## DISTRIBUTION OF AQUATIC INSECTS IN THE RED CEDAR RIVER

### 1958 Samples

The Red Cedar River was sampled two times in each of four locations in 1958. Each sample consisted of an even and an odd sub-sample containing an equal number of dredge samples from randomly selected areas along a transect across the river. The data indicate, when subjected to a matched pairs test that there was no significant difference at the 95% level in the number of insects found in the even and odd sub-samples of the randomly selected samples taken from the Red Cedar River in 1958. It was further indicated that there was no significant difference in the number of insects in the two samples taken at each of the four sampling locations.

Twenty-seven families of insects were included in the collections taken from the Red Cedar River in 1958 (Table III). The ubiquitous Tendipedidae are by far the most abundant family of insects in the river, ranging from a high of 66% of the total number collected below a sewage treatment plant to a low of 32% of the total number in the pond-like reservoir above Williamston.

The Elmidae, the small beetles which spend their entire life in water, were the next most common family in the 1958

Table III. Percent Composition by Numbers of the Aquatic Insects in the Red Cedar River in 1958

| Organism | Sampling Zone IV | III | II | I |
|---|---|---|---|---|
| Poduridae | | | .0- | .1 |
| Heptageniidae | | .6 | .1 | 1.3 |
| Baetidae | 6.8 | 1.8 | 3.8 | 1.0 |
| Ephemeridae | 2.0 | .4 | .6 | 2.1 |
| Hydropsychidae | .3 | .4 | .2 | |
| Psychomyiidae | .3 | .1 | .7 | 1.9 |
| Limnephilidae | | .0- | .2 | 10.5 |
| Leptoceridae | .7 | .2 | .1 | .3 |
| Molannidae | | | .1 | |
| Rhyacophilidae | | | .3 | .2 |
| Phryganeidae | | | | .1 |
| Helicopsychidae | | | | .1 |
| Sialidae | 4.6 | .1 | .4 | 1.9 |
| Gomphidae | | .0- | .1 | .2 |
| Coenagrionidae | .4 | .3 | .3 | .1 |
| Pyralidae | | .1 | .0- | |
| Elmidae | 40.8 | 22.5 | 18.1 | 23.3 |
| Psephenidae | | | .0- | .6 |
| Dryopidae | | | .1 | 3.8 |
| Haliplidae | | | .0- | .1 |
| Helodidae | | | .0- | |
| Corixidae | 4.1 | 3.5 | 2.8 | |
| Tipulidae | | | .1 | .1 |
| Tendipedidae | 32.0 | 66.5 | 65.1 | 52.2 |
| Heleidae | 8.0 | 3.2 | 6.6 | .3 |
| Tabanidae | | .4 | .4 | |
| Rhagionidae | | | .0- | |

collections. The Elmidae and Tendipedidae combined made up 73% of the total number of insects at station IV, 89% at station III, 83% at station II, and 75% of the total number of insects taken at station I.

Of the mayflies, the Ephemeridae, entirely *Hexagenia*, were the most common at station I, while the Baetidae were more numerous at the other three stations.

Sialidae were present at all four stations, being most abundant at station IV. These insects, while present in small numbers, undoubtedly made up a large percent of the total weight of the collection.

The damselflies of the family Coenagrionidae were present at all stations but were never more abundant than .41% of the total number of insects present.

Other families of insects were present at each of the four stations, and the percent composition by number of all insects collected in 1958 is shown in Table III. The estimated number per acre and number per square meter for the 1958 collections from the Red Cedar River are tabulated in Appendix A.

## 1959 Samples

Most of the studies of the distribution of aquatic insects in streams include little quantification of results. Jones (1943, 1948, and 1951) in his studies of English rivers makes little attempt to quantify his results, being more interested in the presence or absence of the various organisms. Richardson (1921) in his studies on the Illinois

River, estimated the abundance of bottom fauna in numbers per acre and pounds per acre but the aquatic insects were all considered in one group. Moffett (1936) estimated number and volume of insects per square foot in small trout streams in Utah. Gaufin and Tarzwell (1952) in their studies on Lytle Creek, used the criteria of present, absent, and abundant to record the occurance of the aquatic insects.

Pennak and Van Gerpen (1947) point out the necessity of considering both number and weight of aquatic invertebrates when studying an invertebrate community. This is to equalize the effect of small numbers of large insects and large numbers of small insects. A large Ephemeridae nymph will weigh 50 times more than a Tendipedidae larvae and when numbers alone are considered, these two insects are treated as being of equal importance.

In this study, an attempt was made to equalize the weight and numbers of the families of insects making up the sample. It is felt that the smaller insects with the shorter life histories exhibit a higher turnover rate than do the larger insects with longer life histories. Tendipedidae with a life cycle of six weeks can produce 8 or 10 generations in the two years necessary for the Ephemeridae, Hexagenia to produce one. Based on standing crop estimates, a consideration of numbers alone gives undue importance to the more numerous smaller insects while a consideration of weight alone favors the less common larger insects. In the discussion of distribution in this study an attempt was made to correct for this undesirable aspect of standing crop estimates. In order to make this correction it was necessary to assume that the large numbers of the potentially more productive smaller insects are equal in importance to the greater weight of the longer lived insects.

The relative importance of the various families of insects in the Red Cedar River was calculated by multiplying the percent of total composition by numbers of a given family times the corresponding percent of total composition by weight.

Table IV shows the percent composition by number and weight of the thirty-five families of aquatic insects collected in all samples taken from the Red Cedar River in 1959. Table V shows the result of multiplying the percent of total number times the percent of total weight, this is referred to as relative importance. The second column of Table V shows the rank of the 35 families of insects collected based on their relative importance. The rank by relative importance is compared with rank by percent of total number and by percent of total weight in Table VI. Relative importance and rank by relative importance will be used in all comparisons of distribution of aquatic insects taken from the Red Cedar River in 1959.

When the even and odd numbered sub-samples are compared by a matched pairs test, the data indicate that there was no significant difference at the 95% level in the number of insects found in the even and odd numbered sub-samples

Table IV. Percent composition by numbers and weight of all insects collected from the Red Cedar River in 1959

| Organism | Percent by Number | Percent by Weight |
|---|---|---|
| Poduridae | .009 | .000- |
| Perlidae | .074 | .169 |
| Heptageniidae | .166 | .196 |
| Baetidae | .841 | .234 |
| Ephemeridae | 4.500 | 11.096 |
| Hydropsychidae | 1.534 | 1.810 |
| Psychomyiidae | .656 | .352 |
| Brachycentridae | .388 | .156 |
| Limnephilidae | .111 | 6.794 |
| Hydroptilidae | .046 | .013 |
| Leptoceridae | .037 | .048 |
| Sialidae | 1.969 | 8.439 |
| Sisyridae | .009 | .009 |
| Gomphidae | .203 | 11.048 |
| Coenagrionidae | 2.727 | 6.252 |
| Agrionidae | .055 | .100 |
| Libellulidae | .092 | 7.410 |
| Pyralidae | .721 | 2.388 |
| Elmidae | 14.584 | 3.959 |
| Gyrinidae | .046 | .043 |
| Hydrophilidae | 2.809 | 6.790 |
| Psephenidae | .055 | .482 |
| Dryopidae | .009 | .009 |
| Corixidae | .120 | .065 |
| Belastomatidae | .009 | .820 |
| Saldidae | .046 | .495 |
| Mesoveliidae | .018 | .043 |
| Tipulidae | 3.503 | 9.759 |
| Culicidae | .083 | .030 |
| Simuliidae | 5.222 | .968 |
| Tendipedidae | 49.627 | 9.429 |
| Heleidae | 7.301 | 1.038 |
| Tabanidae | 1.423 | 9.342 |
| Empididae | .961 | .174 |
| Ephydridae | .046 | .039 |

Table V. Relative importance of all families of insects collected, based on all collections of bottom fauna from the Red Cedar River in 1959

| Organism | Relative importance x $10^{-8}$ | Rank |
|---|---|---|
| Poduridae | .0- | 35 |
| Perlidae | 125.06 | 23 |
| Heptageniidae | 325.36 | 20 |
| Baetidae | 1,967.94 | 17 |
| Ephemeridae | 499,320.00 | 3 |
| Hydropsychidae | 27,765.40 | 11 |
| Psychomyiidae | 2,309.12 | 16 |
| Brachycentridae | 605.28 | 19 |
| Limnephilidae | 7,541.34 | 14 |
| Hydroptilidae | 5.98 | 32 |
| Leptoceridae | 17.76 | 30 |
| Sialidae | 166,163.91 | 7 |
| Sisyridae | .81 | 34 |
| Gomphidae | 22,427.44 | 12 |
| Coenagrionidae | 170,492.04 | 6 |
| Agrionidae | 55.00 | 26 |
| Libellulidae | 6,817.20 | 15 |
| Pyralidae | 17,217.48 | 13 |
| Elmidae | 577,380.56 | 2 |
| Gyrinidae | 19.78 | 28 |
| Hydrophilidae | 190,731.10 | 5 |
| Psephenidae | 265.10 | 21 |
| Dryopidae | .81 | 33 |
| Corixidae | 78.00 | 24 |
| Belastomatidae | 73.80 | 25 |
| Saldidae | 227.70 | 22 |
| Mesoveliidae | 7.74 | 31 |
| Tipulidae | 341,857.77 | 4 |
| Culicidae | 24.90 | 27 |
| Simuliidae | 50,548.96 | 10 |
| Tendipedidae | 4,679,329.83 | 1 |
| Heleidae | 75,784.38 | 9 |
| Tabanidae | 132,936.66 | 8 |
| Empididae | 1,672.14 | 18 |
| Ephydridae | 17.94 | 29 |

Relative importance is the product of the percent of total number times the percent of total weight.

Table VI. Three methods of ranking the various families of aquatic insects collected from the Red Cedar River in 1959, based on all insects collected in 1959

| Organism | Rank by percent number | Rank by percent weight | *Rank by relative importance |
|---|---|---|---|
| Poduridae | 35 | 35 | 35 |
| Perlidae | 23 | 23 | 23 |
| Heptageniidae | 18 | 21 | 20 |
| Baetidae | 13 | 20 | 17 |
| Ephemeridae | 5 | 1 | 3 |
| Hydropsychidae | 10 | 13 | 11 |
| Psychomyiidae | 15 | 19 | 16 |
| Brachycentridae | 16 | 24 | 19 |
| Limnephilidae | 20 | 8 | 14 |
| Hydroptilidae | 26 | 32 | 32 |
| Leptoceridae | 29 | 27 | 30 |
| Sialidae | 9 | 6 | 7 |
| Sisyridae | 33 | 33 | 34 |
| Gomphidae | 17 | 2 | 12 |
| Coenagrionidae | 8 | 10 | 6 |
| Agrionidae | 24 | 25 | 26 |
| Libellulidae | 21 | 7 | 15 |
| Pyralidae | 14 | 12 | 13 |
| Elmidae | 2 | 11 | 2 |
| Gyrinidae | 27 | 28 | 28 |
| Hydrophilidae | 7 | 9 | 5 |
| Psephenidae | 25 | 18 | 21 |
| Dryopidae | 34 | 34 | 33 |
| Corixidae | 19 | 26 | 24 |
| Belastomatidae | 32 | 16 | 25 |
| Saldidae | 28 | 17 | 22 |
| Mesoveliidae | 30 | 29 | 31 |
| Tipulidae | 6 | 3 | 4 |
| Culicidae | 22 | 31 | 27 |
| Simuliidae | 4 | 15 | 10 |
| Tendipedidae | 1 | 4 | 1 |
| Heleidae | 3 | 14 | 9 |
| Tabanidae | 11 | 5 | 8 |
| Empididae | 12 | 22 | 18 |
| Ephydridae | 28 | 30 | 29 |

*Relative importance ranked by percent weight x percent numbers. 1 signifies most abundant, 2 next most abundant, etc.

of the randomly selected samples taken from the Red Cedar River in 1959. It was also indicated, again with a matched pairs test, that there was no significant difference at the 95% level between the total weight of the insects found in the even and odd sub-samples of the random samples taken from the Red Cedar River in 1959. Since no significant difference could be demonstrated between the even and odd sub-samples, the data from the sub-samples were combined and all calculations were based on the total sample.

The Cochran Q test was used to compare the degree of heterogeneity in family composition of the insect fauna in four zones of the Red Cedar River for the summer of 1959. The data from zone IV were omitted from this analysis because this atypical reservoir zone was sampled with an Ekman dredge rather than the Petersen dredge which was used for all other zones. It is felt that this reduction in area sampled warranted the exclusion of the sampling results from zone IV. Using the Cochran Q test, a significant difference at the 1% level was demonstrated in the degree of heterogeneity in family composition of the insect fauna in four zones of the Red Cedar for the summer of 1959. Since the Cochran Q test does not allow individual comparisons, these data were submitted to a one way analysis of variance. This analysis demonstrated a significant difference at the 95% level in the degree of heterogeneity in family composition of the insect fauna of the four river zones. The four individual river zones were compared by a Tukey multiple range test and the difference was found to be between zones II and III. No other significant difference was demonstrated.

The results of these analyses indicate that there is no significant difference in the degree of heterogeneity in family composition of insect fauna between zones I, II, and V, thus indicating that the family composition of these zones is somewhat uniform. The difference found between zones II and III may be attributed to the effect of the effluent of the Williamston sewage treatment plant on the aquatic insects of zone III. This tends to bear out the statement by Gaufin and Tarzwell (op. cit.) that there is a greater variety of insect types in unpolluted than in polluted water.

After adjusting all figures to common units, number per square meter and pounds per acre, the sample means for all 1959 samples were compared. No significant difference was demonstrated at the 95% level in number per square meter or pounds per acre in the samples taken from the Red Cedar River in 1959. Since no significant difference was demonstrated between these samples, the two samples taken at each sampling station were combined and all calculations were based on the combined samples.

The percent composition by numbers of the aquatic insects taken from the Red Cedar River in 1959 at the seven sampling stations is shown in Table VII and the percent composition by weight of the aquatic insects for these same collections is tabulated in Table VIII. The rank by rel-

Table VII. Percent Composition by Numbers of the Aquatic Insects in the Five Study Zones of the Red Cedar River in 1959

| Organism \ Sampling Station | *V-3 | *V-2 | *V-1 | IV | III | II | I |
|---|---|---|---|---|---|---|---|
| Poduridae | | | .1 | | | | |
| Perlidae | | | .5 | | | .1 | |
| Heptageniidae | | | .3 | | .1 | .3 | .2 |
| Baetidae | .1 | .1 | .3 | .2 | .1 | 1.8 | 1.8 |
| Ephemeridae | | | | 12.3 | | 1.5 | 26.5 |
| Hydropsychidae | .6 | | 1.2 | | | 4.5 | |
| Psychomyiidae | | .6 | 1.6 | | 2.1 | .2 | .6 |
| Brachycentridae | 2.2 | | .2 | | | | .4 |
| Limnephilidae | | .1 | .1 | | .5 | .1 | |
| Hydroptilidae | .1 | | .2 | | | | |
| Leptoceridae | | | | | | .1 | .1 |
| Sialidae | .9 | .9 | 4.9 | 3.1 | 1.3 | 1.6 | 2.5 |
| Sisyridae | | | | | | .0- | |
| Gomphidae | .3 | .5 | .1 | | .1 | .1 | .4 |
| Coenagrionidae | 14.9 | 4.0 | | .2 | | .0- | .1 |
| Agrionidae | | | | | | .2 | |
| Libellulidae | .1 | .6 | | | | | |
| Pyralidae | 1.6 | .4 | | | | 1.5 | |
| Elmidae | 17.8 | 6.9 | 22.4 | 15.9 | 3.6 | 18.1 | 13.9 |
| Gyrinidae | | | | | | .2 | |
| Hydrophilidae | 16.3 | 3.2 | | | | .0- | |
| Psephenidae | | | .1 | | | .1 | .1 |
| Dryopidae | | | | | | | .1 |
| Corixidae | | | | 2.1 | | | |
| Belastomatidae | | .1 | | | | | |
| Saldidae | | .7 | | | | | |
| Mesoveliidae | | .1 | .1 | | | | |
| Tipulidae | .3 | 4.5 | 18.8 | | .3 | 2.0 | .1 |
| Culicidae | | | .1 | 1.0 | .1 | | |
| Simuliidae | | | | | | 18.0 | |
| Tendipedidae | 24.2 | 60.7 | 37.0 | 54.6 | 90.6 | 46.4 | 43.0 |
| Heleidae | 13.7 | 10.6 | 9.0 | 10.5 | .7 | 2.8 | 10.2 |
| Tabanidae | 3.0 | 6.2 | .5 | .2 | .1 | .3 | .1 |
| Empididae | 3.9 | | 2.8 | | .4 | .0- | |
| Ephydridae | | | | | | .2 | |

*V-3 is the sampling station at Nicholson road.
*V-2 is the sampling station at Stow road.
*V-1 is the sampling station at Highway M-47.

Table VIII. Percent Composition by Weight of the Aquatic Insects in the Five Study Zones in the Red Cedar River in 1959

| Organism \ Sampling Station | V-3 | V-2 | V-1 | IV | III | II | I |
|---|---|---|---|---|---|---|---|
| Poduridae | | | .0- | | | | |
| Perlidae | | | 1.2 | | | .3 | |
| Heptageniidae | | | 1.0 | | .1 | .4 | .1 |
| Baetidae | .0- | .0- | .1 | .2 | .5 | 1.0 | .4 |
| Ephemeridae | | | | 52.5 | | 19.4 | 67.2 |
| Hydropsychidae | 3.2 | 2.5 | | | | 2.8 | |
| Psychomyiidae | | .2 | 1.1 | | 1.9 | .4 | .2 |
| Brachycentridae | .3 | | .1 | | | | .4 |
| Limnephilidae | | .6 | 9.7 | | 56.2 | 13.0 | |
| Hydroptilidae | .0- | | .1 | | | | |
| Leptoceridae | | | | | | .3 | .0- |
| Sialidae | 6.6 | 5.1 | 20.8 | 2.5 | .2 | 5.1 | 18.9 |
| Sisyridae | | | | | | .1 | |
| Gomphidae | 23.9 | 9.5 | 5.0 | | 2.1 | .3 | 1.3 |
| Coenagrionidae | 15.0 | 4.5 | | 4.7 | | .0- | .2 |
| Agrionidae | | | | | | .7 | |
| Libellulidae | .4 | 36.9 | | | | | |
| Pyralidae | 3.7 | 1.4 | | | | 5.7 | |
| Elmidae | 2.6 | 1.0 | 8.7 | 11.6 | 1.6 | 7.6 | 3.3 |
| Gyrinidae | | | | | | .3 | |
| Hydrophilidae | 16.5 | 3.6 | | | | 2.4 | |
| Psephenidae | | | .1 | | | 2.9 | .4 |
| Dryopidae | | | | | | | .1 |
| Corixidae | | | | 2.4 | | | |
| Belastomatidae | | 4.2 | | | | | |
| Saldidae | | 2.6 | | | | | |
| Mesoveliidae | | .2 | .0- | | | | |
| Tipulidae | .4 | 9.3 | 42.2 | | 4.4 | 17.9 | 1.1 |
| Culicidae | | | .0- | .8 | .1 | | |
| Simuliidae | | | | | | 6.4 | |
| Tendipedidae | 7.7 | 5.8 | 6.1 | 21.9 | 32.3 | 11.0 | 5.8 |
| Heleidae | 1.3 | 1.3 | .9 | 3.3 | .5 | .3 | .6 |
| Tabanidae | 18.1 | 14.0 | .2 | .2 | .1 | 1.6 | .2 |
| Empididae | .3 | | .3 | | .1 | .1 | |
| Ephydridae | | | | | | .3 | |

ative importance of the insect fauna at the seven sampling stations in 1959 is shown in Table IX.

The order of importance of the various families of aquatic insects was determined from their rank by relative importance. Relative importance is calculated by multiplying the percent of total composition by numbers of a given family times the corresponding percent of total composition by weight. It is felt that this method tends to equalize the weight and numbers of smaller insects with short life histories and of larger insects with longer life cycles.

The most important family of insects in the entire study area was the Tendipedidae. It was the principal family at all sampling stations with the exception of the M-47 and Nicholson Road stations in zone V and the sampling station in zone I. This large family with its many species is represented on all bottom types in the Red Cedar River and is very common on the large sand flats. At the M-47 station and station I, Tendipedidae ranked second, and at Nicholson Road it was the third most prominent family.

The Hydrophilidae were the most prevalent insects at the Nicholson Road station. These aquatic beetles are primarily herbivorous (Usinger, 1956) and were found in abundance in the dense aquatic vegetation at this sampling site. These insects were only found at three sampling stations but were the fifth most prominent group of insects in the entire study area (Tables VI and IX). This family is limited to areas of dense vegetation in the Red Cedar River.

Table IX. Rank by Relative Importance of the Aquatic Insects at Seven Stations in the Red Cedar River in 1959

| Organism \ Sampling Station | V-3 | V-2 | V-1 | IV | III | II | I |
|---|---|---|---|---|---|---|---|
| Poduridae | | | 20 | | | | |
| Perlidae | | | 10 | | | 22 | |
| Heptageniidae | | | 12 | | 11 | 15 | 11 |
| Baetidae | 15 | 17 | 14 | 9 | 9 | 9 | 6 |
| Ephemeridae | | | | 2 | | 5 | 1 |
| Hydropsychidae | 10 | | 6 | | | 6 | |
| Psychomyiidae | | 14 | 7 | | 4 | 17 | 8 |
| Brachycentridae | 12 | | 16 | | | | 9 |
| Limnephilidae | | 15 | 9 | | 2 | 10 | |
| Hydroptilidae | 16 | | 15 | | | | |
| Leptoceridae | | | | | | 21 | 16 |
| Sialidae | 7 | 10 | 4 | 5 | 7 | 8 | 3 |
| Sisyridae | | | | | | 24 | |
| Gomphidae | 9 | 9 | 11 | | 8 | 20 | 7 |
| Coenagrionidae | 2 | 5 | | 8 | | 25 | 14 |
| Agrionidae | | | | | | 14 | |
| Libellulidae | 14 | 4 | | | | | |
| Pyralidae | 8 | 13 | | | | 7 | |
| Elmidae | 5 | 8 | 3 | 3 | 3 | 2 | 4 |
| Gyrinidae | | | | | | 18 | |
| Hydrophilidae | 1 | 7 | | | | 16 | |
| Psephenidae | | | 17 | | | 13 | 12 |
| Dryopidae | | | | | | | 15 |
| Corixidae | | | | 6 | | | |
| Belastomatidae | | 12 | | | | | |
| Saldidae | | 11 | | | | | |
| Mesoveliidae | | 16 | 19 | | | | |
| Tipulidae | 13 | 3 | 1 | | 5 | 4 | 10 |
| Culicidae | | | 18 | 7 | 12 | | |
| Simuliidae | | | | | | 3 | |
| Tendipedidae | 3 | 1 | 2 | 1 | 1 | 1 | 2 |
| Heleidae | 6 | 6 | 5 | 4 | 6 | 11 | 5 |
| Tabanidae | 4 | 2 | 13 | 10 | 13 | 12 | 13 |
| Empididae | 11 | | 8 | | 10 | 23 | |
| Ephydridae | | | | | | 19 | |

The foremost family of insects at the M-47 station in 1959 was Tipulidae. These insects, found at all sampling stations except station IV, were fourth in importance for the entire study area, based on all insects collected in 1959. The larvae of this family are reported to be primarily herbivorous and were found in all bottom types in the Red Cedar River.

The second most common group of insects in the river as a whole in 1959 belong to the family Elmidae. Usinger (ibid.) states that these beetles are rare in streams with mud or sand bottoms, low gradient, or with a heavy sediment load. The Red Cedar River has a low gradient, carries a heavy sediment load during spring floods, and the bottom material is primarily mud and sand. Elmidae larvae and adults were common at all sampling stations and in bottom material ranging from silt and detritus to coarse gravel. These insects were second in importance in both the 1958 and 1959 collections. Burlington (1962) found Elmidae in all areas sampled in the Wabash River.

The insects third in prominence over the entire study area belonged to the family Ephemeridae. The only representative of this family collected from the Red Cedar River in 1959 was Hexagenia. Burks (1953) states that the burrowing mayflies, including Hexagenia, are scavengers and feed primarily on detritus. They are found only in silt and detritus areas of zones I, II, and IV, but, based on the rank by relative importance, this family was the most common group of insects at station I (Table IX). These insects, spending their larval life buried in the mud, appear to be unavailable to fish except at emergence. Their absence from station III is attributed to the sewage effluent from the Williamston sewage treatment plant. The absence of Hexagenia in an area subjected to domestic pollution (zone III) and in an area receiving effluent from a metal plating plant (zone V) and its presence in the remainder of the stream points out that this organism is intolerant to pollution and that its distribution may be used to delineate polluted areas in the Red Cedar River.

Coenagrionidae was the family ranking sixth in the total study area based on the rank by relative importance. Representatives of this family of damselflies were found climbing about in areas with an abundance of aquatic vegetation, being especially abundant at the upper zone V sampling stations (Table IX).

The family Sialidae was common at all sampling sites and was seventh in importance in the entire study area. These insects were collected from all bottom types in the Red Cedar River, in areas ranging from riffles to the pond-like reservoir (Table IX).

The predaceous Tabanidae was the eighth most prominent group collected from the river in 1959. Representatives of this family were found at all areas sampled and on all types of bottom material (Table IX).

The Heleidae (Ceratopogonidae) were found in large numbers at all stations sampled, and were the second most numerous insect collected from the study area. Based on the rank by relative importance, this group ranked ninth in the total study area in 1959 (Table VI).

The relative importance of the other families of aquatic insects collected is tabulated for the seven sampling stations in Table IX and for the entire study area in Table VI. These less commonly encountered families will not be considered in detail.

The major factor determining the distribution of the various families of aquatic insects in the Red Cedar River is believed to be tolerance of the individual families of different environmental conditions.

Some families, such as Tendipedidae, Heleidae, Tabanidae, Sialidae, Elmidae and Baetidae, were represented on all types of bottom material sampled. Others, such as Coenagrionidae and Hydrophilidae, were found only where there was abundant aquatic vegetation. Psephenidae were found only at three sampling stations and all of these stations were in the faster flowing areas of the Red Cedar River. Corixidae were recorded only at the reservoir station, station IV.

In sand flats the Ephemeridae and Sialidae were rare while in the areas characterized by mud and detritus they were common. Station II, with fast flowing water and dense vegetation, was the only place where Simuliidae were found.

Type of bottom material, presence or absence of vegetation, velocity of water, and temperature are all important factors in determining the type of insect community present in a given area of a stream. Bottom type varies from mud and detritus to coarse gravel in the Red Cedar River; while vegetation varies from sparse to abundant. The Red Cedar River is a slow-flowing stream averaging about 0.5 feet per second with a range of from 0 to 3 feet per second. The water temperature does not vary more than one or two degrees Fahrenheit over the entire study area on a given day, so there is little effect on the composition of the invertebrate populations of the various zones due to temperature differences.

A significant difference was demonstrated in the degree of heterogeneity in family composition of the insect fauna between stations II and III. This difference is attributed to the effect of the effluent from the Williamston sewage treatment plant in zone III. No other significant difference was demonstrated in the degree of heterogeneity of family composition of the insect fauna of the Red Cedar River in 1959. The reservoir zone was not included in this analysis for reasons stated previously.

## Coefficient of Similarity

Burlington (op.cit.), using data from his study of the distribution of aquatic invertebrates below outfalls of organic pollution in the Wabash River in Indiana, advances a method for comparing the invertebrate fauna in various areas of the same stream. This method considers frequency and mean density of all families collected, in that "prominence values" are calculated by multiplying the density of a family times the square root of the frequency. The coefficient of similarity is calculated by the following formula: $C = \frac{2W}{a + b}$ ; where a is the sum of the "prominence values" of all families at one station, b is the sum of the "prominence values" at a second station, and W is the sum of the "prominence values" the two stations have in common for each family. A matrix allows the comparison of a given station with all others. A coefficient of similarity of 1.000 is complete similarity.

The aquatic insect data from all 1959 bottom fauna collections from the Red Cedar River consisting of ten Petersen dredge samples were analysed by this method. The results of this analysis are shown in Figure V.

Figure V

The coefficient of similarity between sampling stations on the Red Cedar River with regard to aquatic insects collected during the summer of 1959

Sampling Stations

| | I | II | III | V-1 | V-2 |
|---|---|---|---|---|---|
| I | - | | | | |
| II | .505 | - | | | |
| III | .549 | .678 | - | | |
| V-1 | .442 | .383 | .282 | - | |
| V-2 | .680 | .567 | .679 | .394 | - |

This method did not work well with the data from the insect collections from the Red Cedar River. Station III was 0.5 miles below the outfall of a sewage treatment plant while station II, by all indications a fairly clean area, was 7.5 miles below the sewage treatment plant. The coefficient of similarity for these two stations was the second highest of all comparisons made, yet the results of a one way analysis of variance and a Tukey multiple range test demonstrated a significant difference in the degree of heterogeneity in family composition between these two stations.

The reason for this high coefficient of similarity between stations II and III is that there were inordinately large numbers of Tendipedidae found at both stations. These insects were not identified to species, but it can be assumed that there was a difference in the species composition of the Tendipedidae between these two stations.

Few families of insects were collected at station III while many families, including Simuliidae and other pollution intolerant forms, were collected at station II. It is not uncommon to have large numbers of Tendipedidae in clean water areas, but as Gaufin and Tarzwell (op. cit.) found, the species composition of a given family will differ greatly between polluted and clean water areas.

It is felt that a great deal of consideration must be given to bottom type, water current, and other factors before this method will yield satisfactory results.

## COMPARISON OF THE INSECT FAUNA OF THE RED CEDAR RIVER WITH THAT OF OTHER STREAMS

The aquatic insect fauna of the Red Cedar River, based on collections from the entire study area, is compared with the insect fauna of eight other streams in Table X.

Mud Creek is a small trout stream located in Algonquin Park, Ontario. This stream is characterized by many long shallow gravel riffles which terminate in deep, slow-flowing silted pools (Sprules, 1941). The Wenatchee River is a trout and salmon stream located in Western Washington (Ruggles, 1959). Mill Creek is a small trout stream, located near Salt Lake City, Utah, with a gradient of 150 feet per mile and a bottom predominently of gravel (Moffett, op. cit.).

The Calumet River, the Kankakee River, the St. Joseph River, and the White River are all warm water streams located in Indiana (Murray, 1938, and Denham, 1938). Trail Creek is a smaller Indiana stream which is spring fed and is several degrees cooler than the larger streams mentioned above (Murray, op. cit.).

It is shown in Table X that the streams classified as trout streams are richer in Ephemeroptera, Trichoptera, and Plecoptera than any of the warm water streams, including the Red Cedar River. In the warm-water streams, the aquatic Diptera make up a large percent of the total number of aquatic insects, ranging from 68% in the Red Cedar River to 95% in

Table X. Comparison of family composition of aquatic insect populations in the Red Cedar River with those of other streams (Units are percent of total number)

| Organism | Red Cedar River | Mud[1] Creek | Wanatchee[2] River | Streams Mill[3] Creek | Calumet[4] River | Trail[4] Creek | Kankakee[4] River | St. Joseph[4] River | White[5] River |
|---|---|---|---|---|---|---|---|---|---|
| Collembola | .0- | | | | | | | | |
| Plecoptera | .1 | 2.1 | 9.5 | 2.3 | | | | | |
| Ephemeroptera | 5.1 | 55.8 | 68.0 | 12.7 | 1.7 | 7.1 | 4.7 | 3.0 | 15.2 |
| Trichoptera | 2.8 | 8.3 | 13.0 | 72.7 | 2.2 | 17.0 | 7.7 | 11.6 | 3.9 |
| Odonata | 3.1 | | | | | | | | |
| Hemiptera | .2 | | | | | | | | |
| Megaloptera | 2.0 | | | | | | | | |
| Neuroptera | .0- | | | | | | | | |
| Lepidoptera | .7 | | | | | | | | |
| Coleoptera | 17.5 | | | .5 | 1.2 | .3 | 1.8 | 2.4 | .3 |
| Diptera | 68.2 | 31.3 | 7.4 | 11.8 | 94.9 | 75.6 | 85.8 | 83.0 | 79.8 |
| Miscellaneous | | 2.5 | 2.1 | | | | | | .2 |

1/Sprules, 1941; 2/Ruggles, 1959; 3/Moffett, 1936; 4/Murray, 1938; 5/Denham, 1938 the Calumet River.

The Red Cedar River is more similar to Trail Creek than any of the other streams considered. The other four Indiana rivers are all polluted and have a higher percentage of Diptera than does either the Red Cedar River or Trail Creek. Gaufin and Tarzwell (op. cit.) found that as a stream becomes polluted there is an increase in the number of Diptera and a corresponding decrease in the numbers of the other insects in the stream.

Another very important factor in determining the distribution of aquatic insects is the temperature of the water. In clear cold trout streams there are usually many insects such as the Pteronarcidae and Limnephilidae which require two or more years for their larval development. In the warm-water streams of the midwest the most common insects are those with a larval period of one year or less, insects such as many of the aquatic Diptera.

Ide (1935) found that the lower and warmer reaches of streams have a richer ephemerid fauna than the upper reaches of the same streams where the temperatures are much lower. He postulates that the low temperatures may render it impossible for certain species to grow sufficiently quickly to complete their life cycles at an optimum time of year. He feels that larval development may be delayed so that emergence takes place when conditions are unsuitable for reproduction. Ide made but little attempt to quantify his results, so this does not mean that there were greater numbers of ephemerids in the lower reaches of these streams, but simply that there were more species present in this area.

If what Ide found for the ephemerids can be extrapolated to include all of the aquatic insects, it can be theorized that the absence of large numbers of the aquatic Diptera in cold-water streams is due, in part, to their inability to complete their larval development. Conversely, the competition from the Diptera and other organisms with short life cycles in warm-water streams may be sufficient to reduce the numbers of the insects with the longer life histories.

## BOTTOM FAUNA OTHER THAN AQUATIC INSECTS

The distributions of bottom fauna, other than aquatic insects, taken in the collections from the Red Cedar River in 1958 and 1959 are presented in Tables XI and XII.

The Pelecypoda and Gastropoda in the 1958 collections were analyzed only for total volume, while in 1959 these organisms were counted and then analyzed for total volume. The Tubificidae in the 1958 collections were analyzed for total volume, and in 1959 these organisms were analyzed for wet weight by the same procedure outlined for the insects. Since handling causes the tubificid worms to break into several pieces, no attempt was made to count these organisms. All other organisms included in Tables XI and XII were handled in the same manner as the aquatic insects.

The most obvious point that these tables bring out is the complete lack of bottom invertebrates, other than tubificid worms and aquatic insects, in the upper portion of zone V (Tables XI and XII). The greatest densities of tubificid worms were recorded for the areas which contained no invertebrates other than insects. The high densities of tubificid worms and the complete lack of other invertebrates in these areas is attributed to the effect of the effluent from the metal plating plant.

The Gastropoda were progressively more numerous from

Table XI. Molluscs and tubificid worms collected from the Red Cedar River (units are grams per square meter)

| Organism | Sampling Station | | | | | | |
|---|---|---|---|---|---|---|---|
| | V-3 | V-2 | V-1 | IV | III | II | I |
| Tubificidae | | | | | | | |
| 1958 | | | | 1.48 | .49 | .38 | .93 |
| 1959 | 14.80 | 8.37 | .08 | .86 | .24 | .01 | .10 |
| Pelecypoda | | | | | | | |
| 1958 | | | | | 35.03 | 51.10 | 32.82 |
| 1959 | | | | .50 | 605.18 | 84.70 | 15.22 |
| Gastropoda | | | | | | | |
| 1958 | | | | | 2.43 | 4.50 | 14.59 |
| 1959 | | | .65 | 4.20 | 2.60 | 10.88 | 103.67 |

Table XII. Bottom fauna other than aquatic insects collected from the Red Cedar River (units are number per square meter)

| Organism* | V-3 | V-2 | Sampling Station V-1 | IV | III | II | I |
|---|---|---|---|---|---|---|---|
| Amphipoda | | | | | | | |
| 1958 | | | | 41.95 | 13.62 | 349.78 | 15.40 |
| 1959 | | | | | | 2.59 | |
| Hirudinea | | | | | | | |
| 1958 | | | | 97.46 | 3.56 | .72 | 1.22 |
| 1959 | | | .65 | | 7.78 | 3.89 | .65 |
| Hydracarina | | | | | | | |
| 1958 | | | | 13.58 | 12.64 | 13.68 | 4.86 |
| 1959 | | | 4.54 | | 1.30 | 3.24 | 1.30 |
| Copepoda | | | | | | | |
| 1958 | | | | 1.24 | | | 1.22 |
| Planariidae | | | | | | | |
| 1958 | | | | | | 7.92 | 16.20 |
| Annelida | | | | | | | |
| 1959 | | | | | | | .65 |
| Decapoda | | | | | | | |
| 1959 | | | | | 1.94 | 5.84 | |

* These organisms were not represented in the collections from stations V-2 and V-3

the upper to the lower zones of the study section. The Pelecypoda are most common in zone III (Table XI). Based on the collections, the Decapoda are shown to be present only in zones II and III, but since the crayfish actively avoid the dredge, the population estimates of these organisms are without doubt much too low.

Hirudinea and Hydracarina are common in all areas of the study section except the upper portion of zone V. The other organisms listed in Table XII are more habitat specific and are found only where the bottom type is suitable for their development.

## BIOMASS ESTIMATES OF THE BOTTOM FAUNA OF THE RED CEDAR RIVER

A biomass estimate of the invertebrate fauna of a stream gives an indication of the productivity of the stream. Estimates of invertebrate biomass have been used to calculate the food grade of trout streams (Needham, 1934), but relatively little work has been done on warm-water streams. Richardson (op. cit.) found the average invertebrate biomass of the Illinois River to be 98 pounds per acre, but this figure includes large numbers of molluscs with the aquatic insects comprising only 8.1 pounds per acre of the total.

Moffett (op. cit.), in his survey of some small trout streams in Utah, found the standing crop of the bottom fauna to range between 110 and 330 pounds per acre. Since molluscs were encountered very rarely in his collections, these figures consist almost entirely of invertebrates other than molluscs.

The Wenatchee River in western Washington is another cold-water stream which at one time had a very large standing crop of bottom fauna (Ruggles, op. cit.). This stream had a standing crop of 249 pounds of bottom fauna per acre in 1940 but in 1955, after the establishment of a salmon run, this figure was reduced to 29 pounds per acre.

The invertebrate biomass for the Sturgeon River, a Michigan trout stream, was estimated to be 53 pounds per acre in 1958 (Bryant, 1960), 36.6 pounds per acre in 1959 (Knight, 1961), and 66 pounds per acre in 1960 (Zettelmaier, 1961). The bottom fauna of the Sturgeon River is composed primarily of insects (Bryant, op. cit.).

Standing crop estimates for the various families of insects are shown in Table XIII. Standing crop estimates in pounds per acre for all bottom invertebrates, except molluscs, from the Red Cedar River are shown in Table XIV. The biomass estimates for the molluscs are tabulated in Table XV. Table XVI shows the estimates of total standing crop of invertebrates in the Red Cedar River in 1958 and 1959.

Estimates of the standing crop of bottom invertebrates, exclusive of molluscs, for the various 1959 sampling sites are shown in Figure VI. As can be seen from this figure, the insects compose but a small portion of the invertebrate biomass in the upper area of zone V. The abundance of tubificid worms, up to 132 pounds per acre, is attributed to the effect of the metal plating plant.

## Ratio of Insects to Tubificid Worms

The ratio of total insect weight to tubificid worm weight for the two collections taken at the Nicholson Road station is .350:1. The ratios of insect weight to tubificid worm weight for all seven sampling stations in 1959 are shown in Figure VII. This ratio is very low for the upper two stations and increases greatly at the M-47 station, which is a small riffle with a bottom of gravel and larger stones, a bottom type not productive of tubificid worms.

Table XIII. Standing crop estimates for the aquatic insects taken from the Red Cedar River in 1959, based on all insects collected in 1959

| Organism | No./$M^2$ | gm./$M^2$ |
|---|---|---|
| Poduridae | .1 | .000- |
| Perlidae | .2 | .001 |
| Heptageniidae | 1.7 | .004 |
| Baetidae | 9.3 | .005 |
| Ephemeridae | 64.9 | .324 |
| Hydropshchidae | 15.4 | .038 |
| Psychomyiidae | 6.6 | .016 |
| Brachycentridae | 3.8 | .002 |
| Limnephilidae | 1.2 | .145 |
| Hydroptilidae | .5 | .000- |
| Leptoceridae | .4 | .001 |
| Sialidae | 25.1 | .184 |
| Sisyridae | .1 | .000- |
| Gomphidae | 2.0 | .236 |
| Coenagrionidae | 27.6 | .141 |
| Agrionidae | .6 | .002 |
| Libellulidae | .9 | .134 |
| Pyralidae | 7.2 | .051 |
| Elmidae | 164.6 | .104 |
| Gyrinidae | .5 | .001 |
| Hydrophilidae | 28.2 | .145 |
| Psephenidae | .6 | .010 |
| Dryopidae | .1 | .000- |
| Corixidae | 4.6 | .005 |
| Belastomatidae | .1 | .017 |
| Saldidae | .5 | .010 |
| Mesoveliidae | .2 | .001 |
| Tipulidae | 29.6 | .181 |
| Culicidae | 2.4 | .002 |
| Simuliidae | 52.3 | .020 |
| Tendipedidae | 585.0 | .237 |
| Heleidae | 90.1 | .031 |
| Tabanidae | 14.5 | .199 |
| Empididae | 9.6 | .025 |
| Ephydridae | .5 | .001 |
| Total | 1,151.0 | 2.273 |

Table XIV. Standing crop estimates of bottom fauna from the Red Cedar River in pounds per acre

| Sampling station | Insects lbs/acre | Tubificid worms lbs/acre | *Other invertebrates exclusive of molluscs lbs/acre |
|---|---|---|---|
| 1958 | | | |
| IV | 26.42 | 13.21 | |
| III | 16.18 | 4.34 | |
| II | 22.63 | 3.37 | |
| I | 18.42 | 8.32 | |
| 1959 | | | |
| V-3 | 46.24 | 132.04 | |
| V-2 | 26.26 | 74.66 | |
| V-1 | 14.83 | .69 | .04 |
| IV | 14.00 | 7.64 | |
| III | 8.74 | 2.16 | 2.88 |
| II | 20.02 | .13 | 47.28 |
| I | 13.57 | .90 | .47 |

* In 1958 all invertebrates except tubificid worms and molluscs were combined for total volume determinations. In 1959 the insects were separated from all other invertebrates for total weight determinations.

Table XV. Standing crop estimates of molluscs from the Red Cedar River in pounds per acre (shell weight included)

| Sampling station | Pelecypoda | Gastropoda |
|---|---|---|
| 1958 | | |
| IV | | |
| III | 401.71 | 21.68 |
| II | 455.82 | 40.12 |
| I | 292.82 | 130.14 |
| 1959 | | |
| V-3 | | |
| V-2 | | |
| V-1 | | 5.78 |
| IV | 4.40 | 37.44 |
| III | 5,398.52 | 23.12 |
| II | 756.02 | 98.10 |
| I | 135.83 | 924.80 |

Table XVI. Standing crop estimates of invertebrates from the Red Cedar River in pounds per acre

| Sampling station | Total | Total less molluscs |
|---|---|---|
| 1958 | | |
| IV | 39.63 | 39.63 |
| III | 443.91 | 20.52 |
| II | 521.94 | 26.00 |
| I | 449.70 | 26.74 |
| 1959 | | |
| V-3 | 178.28 | 178.28 |
| V-2 | 100.92 | 100.92 |
| V-1 | 21.34 | 15.56 |
| IV | 63.48 | 21.64 |
| III | 5,435.42 | 13.78 |
| II | 921.55 | 67.43 |
| I | 1,075.57 | 14.94 |

Figure VI. Estimates of standing crop of bottom fauna at the various sampling stations on the Red Cedar River, based on the 1959 collections

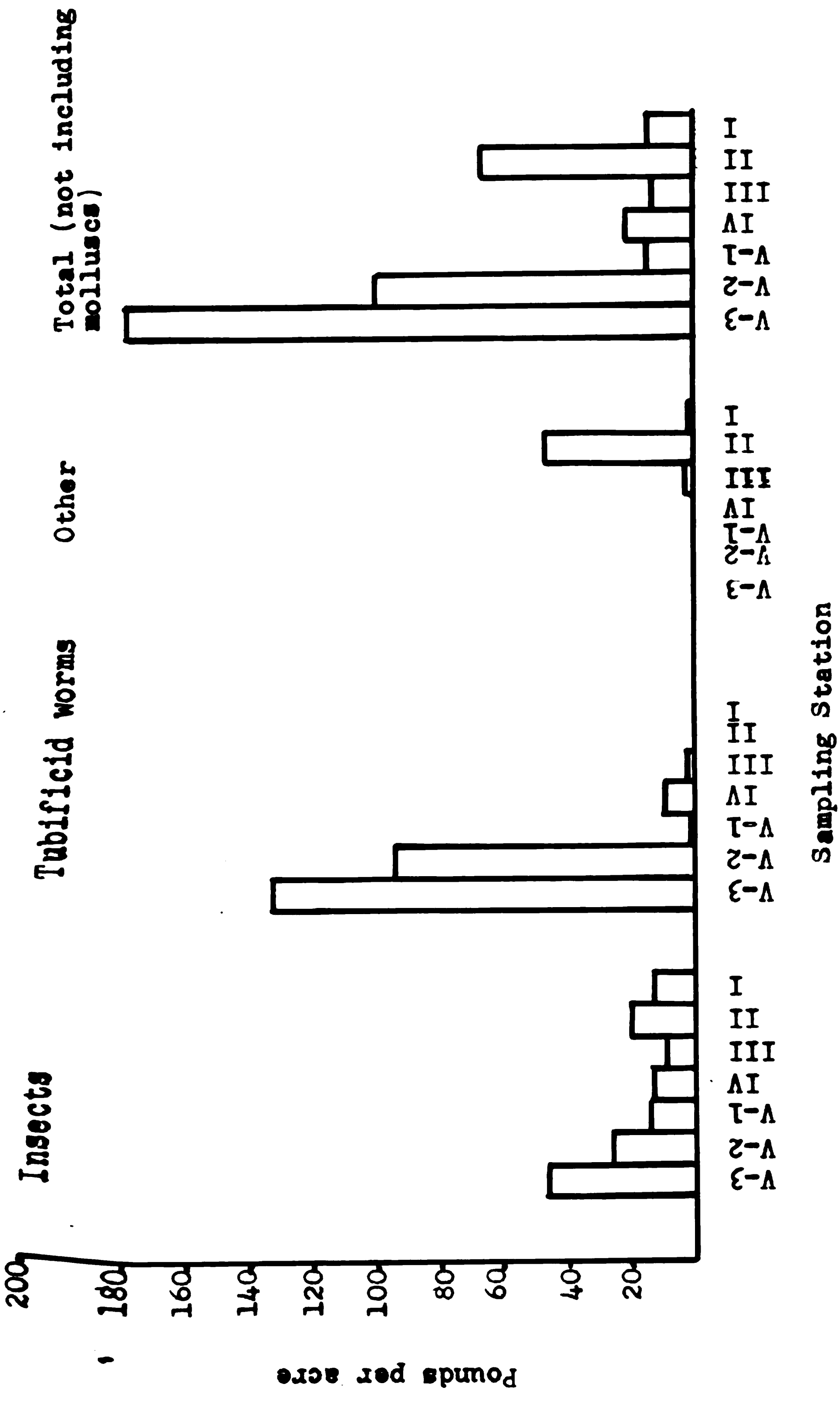
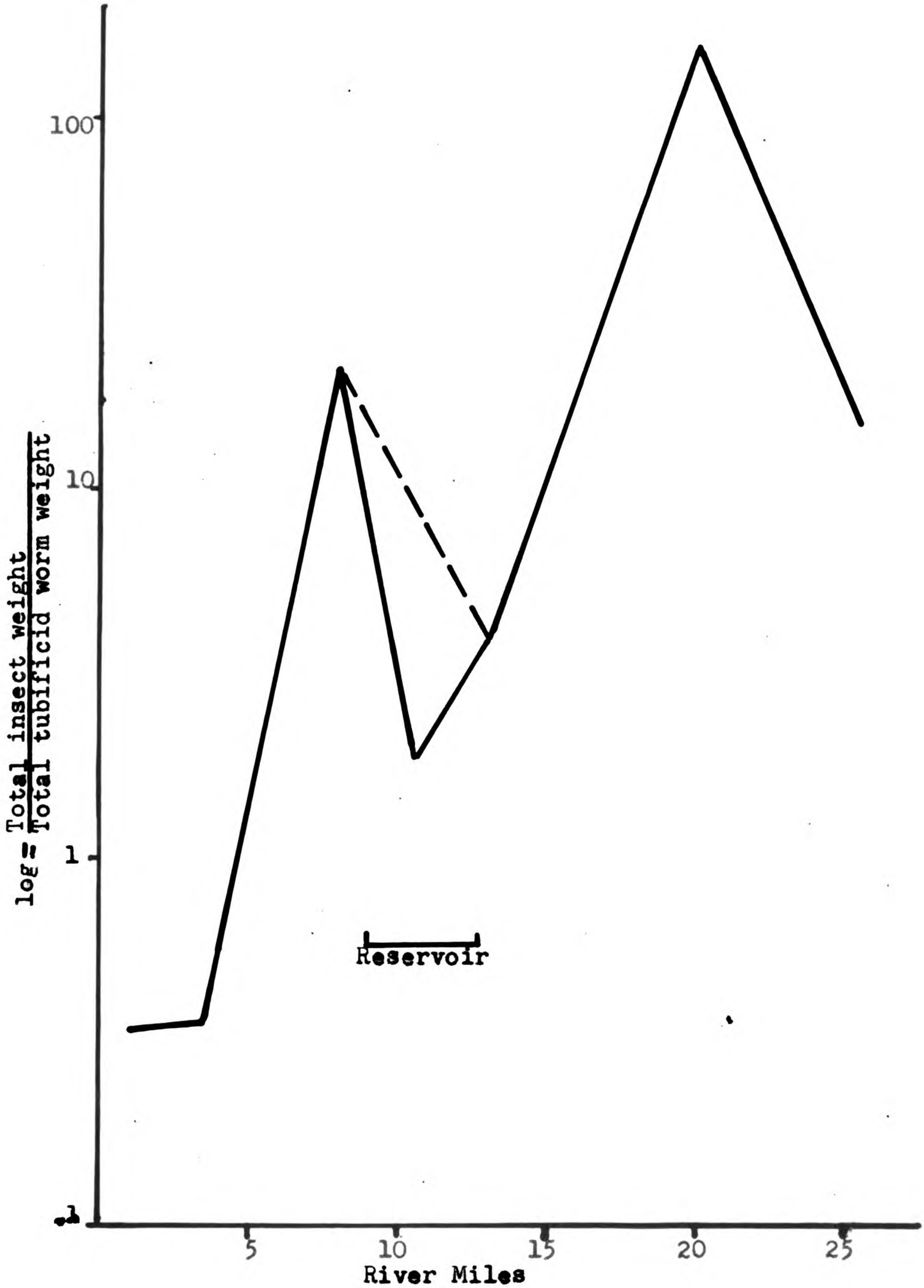

Insects
Tubificid worms
Other
Total (not including molluscs)
I
II
III
IV
V-1
V-2
V-3
200
180
160
140
120
100
80
60
40
20
Pounds per acre
Sampling Station

Figure VI

Figure VII. A logarithm plot of the ratio of total insect weight to total tubificid worm weight against river miles, based on the 1959 collections.



100
10
1
.1
log = Total insect weight / Total tubificid worm weight
Reservoir
5
10
15
20
25
River Miles
Downstream


Figure VII

This ratio is reduced in the reservoir area, as would be expected with the change in the composition of the insect population in this pond-like habitat. The broken line in Figure VII represents an extrapolation through this atypical zone. The first sampling station below the dam was also below the Williamston sewage treatment plant. The insect to tubificid worm weight ratio in this area was lower than the ratio at the M-47 station. This ratio reaches its peak, of 154:1, at station II in the clean water zone and declines again in the urban area of zone I. It is felt that this ratio may have a possible use in delineating stream pollution.

## Standing Crop of Insects

The average standing crop of insects in the Red Cedar River in 1959 was 20.52 pounds per acre. The insect standing crop was not estimated for 1958 because the insects were combined with all other invertebrates except molluscs and tubificid worms. Mean standing crop estimates and various measures of variability are listed in Table XVII.

The standing crop estimates for aquatic insects in the Red Cedar River are lower than the insect biomass estimates for the previously mentioned trout streams. The collections from the trout streams included a much higher percentage of the larger insect larvae with longer life histories than did the collections from the Red Cedar River.

The Red Cedar has many large sand flats which are in a constant state of flux and which contain little but tendipedid midge larvae. The Tendipedidae are the most common insect in

Table XVII. Variability and confidence limits of the bottom fauna collected from the Red Cedar River in 1958 and 1959 (units are pounds per acre)

| | Sample size | Mean | Standard deviation | 95% confidence limits of the mean |
|---|---|---|---|---|
| Invertebrates exclusive of molluscs and tubificid worms | | | | |
| 1958 | 8 | 28.22 | 8.60 | 21.02-35.42 |
| 1959 | 14 | 27.75 | 27.31 | 11.98-43.52 |
| Both years combined | 22 | 27.93 | 22.05 | 10.87-44.99 |
| Aquatic Insects | | | | |
| 1959 | 14 | 20.52 | 14.89 | 11.92-29.12 |
| Tubificid Worms | | | | |
| 1958 | 8 | 7.31 | 5.60 | 2.62-12.00 |
| 1959 | 14 | 31.17 | 48.93 | 2.92-59.42 |
| Both years combined | 22 | 22.50 | 41.88 | 3.93-41.07 |
| Total Invertebrates exclusive of molluscs | | | | |
| 1958 | 8 | 35.53 | 13.72 | 24.05-47.01 |
| 1959 | 14 | 58.89 | 63.47 | 22.23-95.55 |
| Both years combined | 22 | 50.40 | 51.85 | 27.40-73.40 |
| Total molluscs (including shells) | | | | |
| 1958 | 8 | 381.72 | 271.22 | 154.89-608.55 |
| 1959 | 14 | 1054.72 | 2849.14 | -590.77-2700.21 |
| Both years combined | 22 | 809.99 | 2271.46 | -197.39-1817.37 |
| Total Invertebrates including molluscs and tubificid worms | | | | |
| 1958 | 8 | 417.25 | 258.26 | 201.24-633.26 |
| 1959 | 14 | 1113.61 | 2836.46 | -524.55-2751.77 |
| Both years combined | 22 | 860.39 | 2262.86 | -143.19-1863.97 |

the Red Cedar and because of their small size show a lower standing crop than communities of insects which reach a larger size but have a longer period of larval development; such as the hellgrammites and larger stoneflies common to the trout streams. Although the smaller insects with the shorter life histories do not exhibit as large a standing crop, the turn-over rate is much higher than in the longer lived individuals, since some of these smaller insects have several generations per year. Thus, the communities composed primarily of insects with short life histories may have a much greater potential for production than a community of insects with life histories of from 2 to 5 years.

## Standing Crop of Molluscs

There are three main groups of molluscs in the Red Cedar River, the large unionid clams, the small fingernail clams belonging to the family Sphaeridae, and snails, chiefly Viviparidae. The Unionidae and Viviparidae are common below the sewage treatment plant and the Sphaeridae are more common in the sand flats of other areas.

The standing crop estimates of the molluscs are based on the volume of the entire organism, including the shell, and the assumption that a displacement of a milliliter of water is equal to one gram. This method is subject to some error so the total standing crop estimates of bottom invertebrates are given with and without the molluscs in Table XVI and various measures of variability are given in Table XVII.

## Total Standing Crop

The average standing crop of invertebrates, excluding the molluscs, in the Red Cedar River for 1958 and 1959 was estimated at 50.40 pounds per acre with 95% confidence limits of the mean of 27.40 - 73.40 pounds per acre. When the molluscs were included, the average standing crop was estimated to be 860.39 pounds per acre with 95% confidence limits of the mean of -143.19 - 1,863.97 pounds per acre (Table XVII).

## DISCUSSION

The invertebrate fauna of the Red Cedar River, a warm-water stream in south-central Michigan, was sampled during 1958 and 1959 to determine distribution and to estimate the standing crop.

Thirty-five families of aquatic insects were collected during the study period. There are about the same number of families of insects in each of the five river zones, but the number of individuals per family differs from zone to zone. There is some difference in composition within each of the zones; that is, the family composition may vary in different areas of a zone. However, with the exception of zone III, this variation within each zone is quite small. The main modifying factor in zone III is the effluent from a sewage treatment plant.

Statistical analyses of the data suggest that there is a good deal of uniformity in the family composition of zones I, II, and V. Zone III was shown to have fewer families than zone II. The data from zone IV, the impounded area, were not included in these analyses because a different collecting device was used.

The average standing crop of invertebrates, exclusive of molluscs, in the Red Cedar River in 1958 and 1959 was estimated to be 50.40 pounds per acre with 95% confidence limits of the mean of 27.40 - 73.40 pounds per acre, about 45% of the mean. However, when the standing crop estimate of molluscs is added to that of the other invertebrates, the confidence limits are about 115% of the mean. The shell weight of the molluscs was included in this estimate and this coupled with the difference of mollusc distribution caused the increase in variability.

## Pollutional Aspects

Various groups of aquatic invertebrates are generally represented in any bottom collection taken from a stream. Under clean-water conditions more species of organisms are present but generally with fewer individuals per species than in polluted water. The adverse effect of pollutants on certain organisms has led to the use of these organisms as pollution indicators, and it is universally agreed that Plecoptera, Ephemeroptera, and Trichoptera are intolerant to pollution. These three orders of aquatic insects are largely cold-water organisms and, with the exception of the burrowing mayfly *Hexagenia*, were not common in the collections from the Red Cedar River. *Hexagenia* was common in zones I, II, and IV but was absent from the area subjected to domestic pollution (zone III) and the area receiving effluent from a metal plating plant (zone V). The presence of *Hexagenia* in all zones except those known to be affected by pollution suggests that this organism may be used to delineate pollution in the Red Cedar River.

Zone V of the study section of the Red Cedar River is subjected to the effluent of a metal plating plant. This area of the river was found to have a much higher standing crop of tubificid worms than the lower reaches of the river, indicating that these organisms are very tolerant of metal plating plant wastes. No live molluscs were found for a distance of 9 miles below the plating plant, although empty mollusc shells were abundant. Molluscs were not found in appreciable numbers until the river had reached the upper end of zone III, about 15 miles below the entrance of the plating wastes.

Fish kills occur below the plating plant at infrequent intervals, usually during periods of high water. This suggests that the settling ponds may be flooded, thus releasing large quantities of plating wastes into the stream. The sudden release of these toxic wastes would depopulate the invertebrates from a portion of the stream below the plating plant.

Judging from the size of the tubificid worm population in zone V, these organisms apparently are not severely affected by metal plating wastes. In event of a complete depopulation of the molluscs and the aquatic insects, the aquatic insects, with their flying adult stage, could rapidly repopulate this area. The molluscs, with their much slower method of dispersion, could not repopulate the area nearly as fast as the insects. This may account for the complete lack of living molluscs and the presence of numerous empty shells, which, judging by their eroded condition, have been empty for many years.

A second source of pollution in the study section of the Red Cedar River is the effluent entering zone III from the sewage treatment plant of the city of Williamston. Gross pollution occurs below Williamston for a distance of two to three miles, depending on the season and the flow of the river (Brehmer, op. cit.). This area supports large numbers of unionid clams and the larger viviparid snails. The abundance of unionid clams, 5,398 pounds per acre, in zone III and their near absence in the remainder of the study section suggests that the domestic wastes entering from the sewage treatment plant may fertilize zone III.

The results of a one way analysis of variance and a Tukey multiple range test demonstrated a significant difference in the degree of heterogeneity in family composition of aquatic insects between zones II and III, with zone III having fewer families than zone II immediately downstream from it. This reduction in the number of families of aquatic insects is attributed to the effect of the domestic wastes entering from the Williamston sewage treatment plant.

## SUMMARY

1. The invertebrate fauna of the Red Cedar River, a warm-water stream in south-central Michigan, was sampled during 1958 and 1959 to determine the distribution of the organisms and to estimate the standing crop.

2. Thirty-five families of insects were collected from the Red Cedar River during the study period, with the most common one being Tendipedidae.

3. In the discussion of distribution an attempt was made to equalize the importance of weight and numbers of the insects making up the sample. A consideration of numbers alone gives undue importance to the more numerous, smaller insects while a consideration of weight alone favors the less common, larger insects. The insects collected are compared on the basis of their relative importance. The relative importance of the various families of insects collected from the Red Cedar River is calculated by multiplying the percent of total composition by numbers of a given family times the corresponding percent of total composition by weight.

4. An attempt was made to use the "coefficient of similarity" method to compare the insect fauna from five sampling areas on the Red Cedar River. This method did not give good results for the Red Cedar River data, primarily because of the large numbers of Tendipedidae in both clean

and polluted areas.

5. The aquatic insect fauna of the Red Cedar River is compared with the aquatic insect fauna of eight other streams and is found to be intermediate between that of trout streams and that of the larger rivers of Indiana.

6. The ratio of the total insect weight to the tubificid worm weight is suggested as a possible means of delineating stream pollution.

7. The average standing crop of the invertebrates, excluding the molluscs, for the Red Cedar River for 1958 and 1959 was estimated to be 50.40 pounds per acre with 95% confidence limits of the mean of 27.40 - 73.40 pounds per acre. When the molluscs were included, the average standing crop was estimated to be 860.39 pounds per acre with 95% confidence limits of the mean of -143.19 - 1,863.97 pounds per acre.

## LITERATURE CITED


Brehmer, M. L. 1956. A biological and chemical survey of the Red Cedar River in the vicinity of Williamston, Michigan. M.S. thesis, Michigan State University.

Brehmer, M. L. 1958. A study of nutrient accural, uptake, and regeneration as related to primary production in a warm-water stream. Ph.D. thesis, Michigan State University.

Bryant, W. C. 1960. Movement of radiophosphorus through the invertebrate community of a trout stream. M. S. thesis, Michigan State University.

Burks, B. D. 1953. The mayflies, or Ephemeroptera, of Illinois. Bull. Illinois Lab. Nat. Hist., pp 1-216.

Burlington, R. F. 1962. Quantitative biological assessment of pollution. Jour. Water and Pollution Control Federation, Vol. 34, No. 2, pp 179-183.

Denham, S. C. 1938. A limnological investigation of the west fork and the common branch of the White River. Invest. Indiana Lakes and streams, No. 5, pp 17-71.

Gaufin, A. R. and C. M. Tarzwell. 1952. Aquatic invertebrates as indicators of stream pollution. Pub. Health Rep., Vol. 67, No. 1, pp 57-64.

Ide, F. P. 1935. The effect of temperature on the distribution of the mayfly fauna of a stream. Univ. Toronto Stud. Biol. Ser., No. 39, pp 3-76.

Jones, J. R. E. 1943. The fauna of the river Teifi, West Wales. Jour. Anim. Ecol., Vol. 12, pp 115-123.

Jones, J. R. E. 1948. The fauna of four streams in the Black Mountain district of South Wales. Jour. Anim. Ecol., Vol. 17, pp 51-65.

Jones, J. R. E. 1951. An ecological study of the river Towy. Jour. Anim. Ecol., Vol. 20, pp 68-86.

Knight, A. W. 1961. The translocation of radiophosphorus through an aquatic ecosystem. M. S. thesis, Michigan State University.

Meehan, W. R. 1958. The distribution and growth of fish in the Red Cedar River drainage in relation to habitat and volume of flow. Ph. D. thesis, Michigan State University.

Moffett, J.W. 1936. A quantitative study of the bottom fauna in some Utah streams variously effected by erosion. Bull. Univ. Utah Biol. Ser., Vol. 3, No. 3, pp 1-32.

Murray, M. J. 1938. Survey of some northern Indiana streams with special reference to trout production. Invest. Indiana Lakes and Streams, No. 7, pp 79-99.

Murray, M. J. 1938. An ecological study of the invertebrate fauna of some northern Indiana streams. Invest. Indiana Lakes and Streams, No. 8, pp 101-110.

Needham, P. R. 1935. Quantitative studies of stream bottom foods. Trans. Am. Fish. Soc., Vol. 64, pp 238-247.

Pennak, R. W. and E. D. Van Gerpen. 1947. Bottom fauna production and physical nature of substrates in a northern Colorado trout stream. Ecology, Vol. 28, No. 1, pp 42-48.

Richardson, R. E. 1921. The small bottom and shore fauna of the middle and lower Illinois River and its connecting lakes, Chillicothe to Grafton; its valuation; its sources of food supply; and its relation to the fishery. Ill. Nat. Hist. Surv. Bull., Vol. 13, Article 15, pp 363-522.

Ruggles, C. R. 1959. Salmon populations and bottom fauna in the Wenatchee River, Washington. Trans. Am. Fish. Soc., Vol. 88, No. 3, pp 186-190.

Sprules, W. M. 1941. The effect of a beaver dam on the insect fauna of a trout stream. Trans. Am. Fish. Soc., Vol. 70, pp 236-248.

Usinger, R. L. 1956. Aquatic insects of California. Univ. of Calif. Press, 508 pp.

Vannote, R. L. 1961. Chemical and hydrological investigations of the Red Cedar River watershed. M. S. thesis, Michigan State University.

Zettelmaier, J. L. 1961. The translocation of radiophosphorus through a lotic ecosystem. M. S. thesis, Michigan State University.

# APPENDIX A

Aquatic invertebrate data collected from the Red Cedar River in 1958

Zone I

Sample taken .25 mile below Lake Lansing drain, July 21,1958 (16 Petersen dredge hauls)

| Organism | No. | No./acre | No./$M^2$ |
|---|---|---|---|
| Poduridae | 1 | 3,280 | .81 |
| Heptageniidae | 5 | 16,400 | 4.05 |
| Baetidae | 6 | 19,680 | 4.86 |
| Ephemeridae | 26 | 85,280 | 21.07 |
| Psychomyiidae | 13 | 42,640 | 10.54 |
| Limnephilidae | 69 | 226,320 | 55.92 |
| Leptoceridae | 6 | 19,680 | 4.86 |
| Rhyacophilidae | 3 | 9,840 | 2.43 |
| Phryganeidae | 1 | 3,280 | .81 |
| Sialidae | 11 | 36,080 | 8.92 |
| Gomphidae | 1 | 3,280 | .81 |
| Elmidae | 227 | 744,560 | 183.98 |
| Psephenidae | 4 | 13,120 | 3.24 |
| Dryopidae | 38 | 124,640 | 30.80 |
| Tendipedidae | 376 | 1,233,280 | 304.74 |
| Heleidae | 3 | 9,840 | 2.43 |
| Total | 790 | 2,591,200 | 640.27 |
| Tubificidae | *.2 ml. | | |
| Pelecypoda | *47.0 ml. | | |
| Gastropoda | *27.0 ml. | | |
| Hirudinea | 3 | 9,840 | 2.43 |
| Hydracarina | 1 | 3,280 | .81 |
| Amphipoda | 22 | 72,160 | 17.83 |
| Copepoda | 3 | 9,840 | 2.43 |
| Planariidae | 30 | 98,400 | 24.31 |

*These organisms were not counted.

Zone I

Sample taken .25 mile below Lake
Lansing drain, July 28, 1958
(16 Petersen dredge hauls)

| Organism | No. | No./acre | No./$M^2$ |
|---|---|---|---|
| Heptageniidae | 18 | 59,040 | 14.59 |
| Baetidae | 12 | 39,360 | 9.72 |
| Ephemeridae | 13 | 42,640 | 10.54 |
| Psychomyiidae | 21 | 68,880 | 17.02 |
| Limnephilidae | 122 | 400,160 | 98.88 |
| Rhyacophilidae | 1 | 3,280 | .81 |
| Helicopsychidae | 2 | 6,560 | 1.62 |
| Sialidae | 23 | 75,440 | 18.64 |
| Gomphidae | 3 | 9,840 | 2.43 |
| Coenagrionidae | 1 | 3,290 | .81 |
| Elmidae | 198 | 649,440 | 160.48 |
| Psephenidae | 6 | 19,680 | 4.86 |
| Dryopidae | 32 | 104,960 | 25.94 |
| Haliplidae | 1 | 3,280 | .81 |
| Tipulidae | 1 | 3,280 | .81 |
| Tendipedidae | 576 | 1,889,280 | 466.84 |
| Heleidae | 3 | 9,840 | 2.43 |
| Total | 1,033 | 3,378,400 | 837.23 |
| Tubificidae | *2.1 ml. | | |
| Pelecypoda | *34.0 ml. | | |
| Gastropoda | *9.0 ml. | | |
| Hydracarina | 11 | 36,080 | 8.92 |
| Amphipoda | 16 | 52,480 | 12.97 |
| Planariidae | 10 | 32,800 | 8.10 |

*These organisms were not counted.

Zone II

Sample taken .5 mile below U.S. 16
bridge, September 25, 1958
(18 Petersen dredge hauls)

| Organism | No. | No./acre | No./$M^2$ |
|---|---|---|---|
| Poduridae | 1 | 2,916 | .72 |
| Heptageniidae | 3 | 8,747 | 2.16 |
| Baetidae | 88 | 256,582 | 63.40 |
| Ephemeridae | 16 | 46,651 | 11.53 |
| Hydropsychidae | 10 | 29,157 | 7.20 |
| Psychomyiidae | 18 | 52,483 | 12.97 |
| Limnephilidae | 12 | 34,988 | 8.64 |
| Rhyacophilidae | 6 | 17,494 | 4.32 |
| Molannidae | 3 | 8,747 | 2.16 |
| Sialidae | 12 | 34,988 | 6.17 |
| Gomphidae | 2 | 5,831 | 1.44 |
| Coenagrionidae | 5 | 14,578 | 3.60 |
| Elmidae | 509 | 1,484,091 | 366.72 |
| Dryopidae | 2 | 5,831 | 1.44 |
| Haliplidae | 1 | 2,916 | .72 |
| Corixidae | 34 | 99,134 | 24.50 |
| Tipulidae | 2 | 5,831 | 1.44 |
| Tendipedidae | 1,326 | 3,866,218 | 955.34 |
| Heleidae | 150 | 437,355 | 108.07 |
| Rhagionidae | 2 | 5,831 | 1.44 |
| Total | 2,202 | 6,420,369 | 1,583.98 |
| Tubificidae | *0.45 ml. | | |
| Pelecypoda | *86.0 ml. | | |
| Gastropoda | *11.0 ml. | | |
| Hirudinea | 1 | 2,916 | .72 |
| Hydracarina | 7 | 20,410 | 5.04 |
| Amphipoda | 414 | 1,207,100 | 298.27 |

*These organisms were not counted.

Zone II

Sample taken .5 mile below U.S. 16
bridge, October 2, 1958
(18 Petersen dredge hauls)

| Organism | No. | No./acre | No./$M^2$ |
|---|---|---|---|
| Heptageniidae | 4 | 11,663 | 2.88 |
| Baetidae | 132 | 384,872 | 95.10 |
| Ephemeridae | 19 | 55,398 | 13.69 |
| Hydropsychidae | 1 | 2,916 | .72 |
| Psychomyiidae | 25 | 72,892 | 18.01 |
| Limnephilidae | 2 | 5,831 | 1.44 |
| Leptoceridae | 3 | 8,747 | 2.16 |
| Rhyacophilidae | 13 | 37,904 | 9.37 |
| Sialidae | 9 | 26,241 | 6.48 |
| Gomphidae | 2 | 5,831 | 1.44 |
| Coenagrionidae | 14 | 40,820 | 10.09 |
| Pyralidae | 1 | 2,916 | .72 |
| Elmidae | 550 | 1,603,635 | 396.26 |
| Psephenidae | 2 | 5,831 | 1.44 |
| Dryopidae | 1 | 2,916 | .72 |
| Haliplidae | 1 | 2,916 | .72 |
| Helodidae | 1 | 2,916 | .72 |
| Corixidae | 129 | 376,125 | 92.94 |
| Tipulidae | 1 | 2,916 | .72 |
| Tendipedidae | 2,492 | 7,265,924 | 1,795.41 |
| Heleidae | 234 | 682,273 | 168.59 |
| Tabanidae | 25 | 72,892 | 18.01 |
| Total | 3,661 | 10,665,628 | 2,637.63 |
| Tubificidae | *0.60 ml. | | |
| Pelecypoda | *56.0 ml. | | |
| Gastropoda | *1.5 ml. | | |
| Hirudinea | 1 | 2,916 | .72 |
| Hydracarina | 31 | 90,387 | 22.33 |
| Amphipoda | 557 | 1,624,045 | 401.30 |
| Planariidae | 22 | 64,145 | 15.85 |

*These organisms were not counted.

Zone III

Sample taken .25 mile below the Williamston sewage disposal plant, September 4, 1958 (20 Petersen dredge hauls)

| Organism | No. | No./acre | No./$M^2$ |
|---|---|---|---|
| Heptageniidae | 25 | 65,602 | 16.21 |
| Baetidae | 50 | 131,205 | 32.42 |
| Ephemeridae | 11 | 28,865 | 7.13 |
| Hydropsychidae | 8 | 20,993 | 5.19 |
| Limnephilidae | 1 | 2,624 | .65 |
| Leptoceridae | 7 | 18,369 | 4.54 |
| Sialidae | 1 | 2,624 | .65 |
| Coenagrionidae | 2 | 5,248 | 1.30 |
| Pyralidae | 1 | 2,624 | .65 |
| Elmidae | 622 | 1,632,190 | 403.31 |
| Corixidae | 73 | 191,559 | 47.33 |
| Tendipedidae | 1,231 | 3,230,267 | 798.20 |
| Heleidae | 69 | 181,063 | 44.74 |
| Tabanidae | 8 | 20,993 | 5.19 |
| Total | 2,109 | 5,534,226 | 1,367.51 |
| Tubificidae | *0.5 ml. | | |
| Pelecypoda | *57.0 ml. | | |
| Gastropoda | *7.0 ml. | | |
| Hirudinea | 4 | 10,496 | 2.59 |
| Hydracarina | 8 | 20,993 | 5.19 |
| Amphipoda | 10 | 26,240 | 6.48 |

*These organisms were not counted.

Zone III

Sample taken .25 mile below the Williamston
sewage disposal plant, September 11, 1958
(20 Petersen dredge hauls)

| Organism | No. | No./acre | No./$M^2$ |
|---|---|---|---|
| Heptageniidae | 2 | 5,248 | 1.30 |
| Baetidae | 33 | 86,595 | 21.40 |
| Ephemeridae | 6 | 15.745 | 3.89 |
| Hydropsychidae | 10 | 26.241 | 6.48 |
| Psychomyiidae | 3 | 7,872 | 1.94 |
| Leptoceridae | 2 | 5,248 | 1.30 |
| Sialidae | 2 | 5,248 | 1.30 |
| Gomphidae | 1 | 2,624 | .65 |
| Coenagrionidae | 11 | 28,865 | 7.13 |
| Pyralidae | 3 | 7,872 | 1.94 |
| Elmidae | 426 | 1,117,867 | 276.22 |
| Corixidae | 90 | 236,169 | 58.36 |
| Tendipedidae | 1,864 | 4,891,322 | 1,208.64 |
| Heleidae | 80 | 209,928 | 51.87 |
| Tabanidae | 11 | 28,865 | 7.13 |
| Total | 2,544 | 6,675,709 | 1,649.55 |
| Tubificidae | *1.0 ml. | | |
| Pelecypoda | *82.0 ml. | | |
| Gastropoda | *0.5 ml. | | |
| Hirudinea | 4 | 18,368 | 4.54 |
| Hydracarina | 31 | 81,344 | 20.10 |
| Amphipoda | 32 | 83,968 | 20.75 |

*These organisms were not counted.

Zone IV

Sample taken from the reservoir 1.6 miles above the dam in Williamston, August 4, 1958
(20 Ekman dredge hauls)

| Organism | No. | No./acre | No./$M^2$ |
|---|---|---|---|
| Baetidae | 16 | 159,779 | 39.48 |
| Ephemeridae | 8 | 79,890 | 19.74 |
| Leptoceridae | 3 | 29,959 | 7.40 |
| Sialidae | 15 | 149,793 | 37.01 |
| Elmidae | 164 | 1,637,737 | 404.68 |
| Corixidae | 21 | 209,710 | 51.82 |
| Tendipedidae | 87 | 868,799 | 214.68 |
| Heleidae | 41 | 409,434 | 101.17 |
| Total | 355 | 3,545,101 | 875.98 |
| Tubificidae | *0.6 ml. | | |
| Hirudinea | 52 | 519,282 | 128.31 |
| Hydracarina | 6 | 59,917 | 14.81 |
| Amphipoda | 13 | 129,821 | 32.08 |
| Copepoda | 1 | 9,986 | 2.47 |

*These organisms were not counted.

Zone IV

Sample taken from the reservoir 1.6 miles above the dam in Williamston, August 11, 1958 (20 Ekman dredge hauls)

| Organism | No. | No./acre | No./$M^2$ |
|---|---|---|---|
| Baetidae | 34 | 339,531 | 83.90 |
| Ephemeridae | 7 | 69,903 | 17.27 |
| Hydropsychidae | 2 | 19,972 | 4.94 |
| Psychomyiidae | 2 | 19,972 | 4.94 |
| Leptoceridae | 2 | 19,972 | 4.94 |
| Sialidae | 19 | 189,738 | 46.88 |
| Coenagrionidae | 3 | 29,959 | 7.40 |
| Elmidae | 137 | 1,368,109 | 338.06 |
| Corixidae | 9 | 89,876 | 22.21 |
| Tendipedidae | 149 | 1,487,944 | 367.67 |
| Heleidae | 18 | 179,752 | 44.42 |
| Total | 382 | 3,814,728 | 942.63 |
| Tubificidae | *0.6 ml. | | |
| Hirudinea | 27 | 269,627 | 66.62 |
| Hydracarina | 5 | 49,931 | 12.34 |
| Amphipoda | 21 | 209,710 | 51.82 |

*These organisms were not counted.

# APPENDIX B

Aquatic invertebrate data collected from the Red Cedar River in 1959

Zone I

Sample taken 300 feet below Lake
Lansing drain, September 21, 1959
(10 Petersen dredge hauls)

| Organism | No. | No./acre | No./$M^2$ | Wt. (gm). | lbs/acre | gm/$M^2$ |
|---|---|---|---|---|---|---|
| Heptageniidae | 1 | 5,248 | 1.30 | .001 | .01 | .001 |
| Baetidae | 14 | 73,475 | 18.16 | .003 | .03 | .003 |
| Ephemeridae | 206 | 1,081,129 | 267.15 | .751 | 8.68 | .973 |
| Psychomyiidae | 3 | 15,745 | 3.89 | .003 | .03 | .003 |
| Brachycentridae | 1 | 5,248 | 1.30 | .001 | .01 | .001 |
| Leptoceridae | 1 | 5,248 | 1.30 | .001 | .01 | .001 |
| Sialidae | 10 | 52,482 | 12.97 | .096 | 1.11 | .124 |
| Gomphidae | 3 | 15,745 | 3.89 | .028 | .32 | .036 |
| Coenagrionidae | 1 | 5,248 | 1.30 | .004 | .05 | .006 |
| Elmidae | 151 | 792,478 | 195.82 | .059 | .68 | .076 |
| Psephenidae | 1 | 5,248 | 1.30 | .008 | .09 | .010 |
| Dryopidae | 1 | 5,248 | 1.30 | .002 | .02 | .002 |
| Tendipedidae | 394 | 2,067,791 | 510.95 | .076 | .88 | .099 |
| Heleidae | 100 | 524,820 | 129.68 | .005 | .05 | .006 |
| Total | 887 | 4,655,151 | 1,150.31 | 1.038 | 11.97 | 1.341 |
| Tubificidae | | | | .045 | .52 | .058 |
| Pelecypoda | 10 | 52,482 | 12.97 | 23.5 | 271.66 | 30.451 |
| Gastropoda | 3 | 15,745 | 3.89 | 1.0 | 11.56 | 1.295 |
| Annelida | 1 | 5,248 | 1.30 | .074 | .86 | .096 |
| Hirudinea | 1 | 5,248 | 1.30 | .004 | .05 | .006 |
| Hydracarina | 2 | 10,496 | 2.59 | .001 | .01 | .001 |

Zone I

Sample taken 300 feet below Lake
Lansing drain, October 3, 1959
(10 Petersen dredge hauls)

| Organism | No. | No./acre | No./acre | Wt. (gm) | lbs/acre | gm/$M^2$ |
|---|---|---|---|---|---|---|
| Heptageniidae | 3 | 15,745 | 3.89 | .002 | .02 | .002 |
| Baetidae | 10 | 52,482 | 12.98 | .005 | .06 | .007 |
| Ephemeridae | 159 | 834,464 | 206.20 | .799 | 9.24 | 1.036 |
| Psychomyiidae | 5 | 26,241 | 6.48 | .002 | .02 | .002 |
| Brachycentridae | 4 | 20,993 | 5.19 | .007 | .08 | .009 |
| Sialidae | 25 | 131,205 | 32.42 | .340 | 3.93 | .440 |
| Gomphidae | 3 | 15,745 | 3.89 | .002 | .02 | .002 |
| Elmidae | 40 | 209,928 | 51.87 | .016 | .18 | .020 |
| Tipulidae | 1 | 5,248 | 1.30 | .026 | .30 | .034 |
| Tendipedidae | 198 | 1,039,144 | 256.77 | .058 | .67 | .075 |
| Heleidae | 41 | 215,176 | 53.17 | .009 | .10 | .011 |
| Tabanicae | 2 | 10,496 | 2.59 | .004 | .05 | .006 |
| Total | 491 | 2,576,867 | 636.75 | 1.270 | 14.67 | 1.644 |
| Tubificidae | | | | .111 | 1.28 | .143 |
| Gastropoda | 60 | 314,892 | 77.81 | 159.0 | 1,838.04 | 206.042 |

Appendix B-2

Zone II

Sample taken .5 mile below Van Atta Road, August 12, 1959 (10 Petersen dredge hauls)

| Organism | No. | No./acre | No./$M^2$ | Wt. (gm) | lbs/acre | gm/$M^2$ |
|---|---|---|---|---|---|---|
| Baetidae | 18 | 94,468 | 23.34 | .012 | .14 | .016 |
| Ephemeridae | 25 | 131,205 | 32.42 | .231 | 2.67 | .299 |
| Hydropsychidae | 4 | 20,993 | 5.19 | .002 | .02 | .002 |
| Limnephilidae | 1 | 5,248 | 1.30 | .004 | .05 | .006 |
| Sialidae | 30 | 157,446 | 38.90 | .113 | 1.31 | .147 |
| Sisyridae | 1 | 5,248 | 1.30 | .002 | .02 | .002 |
| Gomphidae | 2 | 10,496 | 2.59 | .006 | .07 | .008 |
| Pyralidae | 5 | 26,241 | 6.48 | .035 | .40 | .045 |
| Elmidae | 265 | 1,390,773 | 343.66 | .130 | 1.50 | .168 |
| Hydrophilidae | 1 | 5,248 | 1.30 | .083 | .96 | .108 |
| Tipulidae | 29 | 152,198 | 37.61 | .379 | 4.38 | .491 |
| Simuliidae | 35 | 183,687 | 45.39 | .021 | .24 | .027 |
| Tendipedidae | 172 | 902,690 | 223.05 | .151 | 1.74 | .195 |
| Heleidae | 22 | 115,460 | 28.53 | .005 | .06 | .007 |
| Tabanidae | 1 | 5,248 | 1.30 | .001 | .01 | .001 |
| Ephydridae | 5 | 26,241 | 6.48 | .009 | .10 | .011 |
| Total | 616 | 3,232,890 | 798.84 | 1.184 | 13.67 | 1.533 |
| Tubificidae | | | | .016 | .18 | .020 |
| Pelecypoda | 320 | 1,679,424 | 414.98 | 88.8 | 1,026.53 | 115.074 |
| Gastropoda | 15 | 78,723 | 19.45 | 4.3 | 49.71 | 5.572 |
| Hirudinea | 5 | 26,241 | 6.48 | .523 | 6.04 | .677 |
| Hydracarina | 2 | 10,496 | 2.59 | .002 | .02 | .002 |
| Amphipoda | 2 | 10,496 | 2.59 | .005 | .06 | .007 |
| Decapoda | 1 | 5,248 | 1.30 | .581 | 6.72 | .753 |

Appendix B-3

Zone II

Sample taken .5 mile below Van
Atta Road, August 27, 1959
(10 Petersen dredge hauls)

| Organism | No. | No./acre | No./$M^2$ | Wt. (gm) | lbs/acre | gm/$M^2$ |
|---|---|---|---|---|---|---|
| Perlidae | 2 | 10,496 | 2.59 | .009 | .10 | .011 |
| Heptageniidae | 8 | 41,986 | 10.37 | .015 | .17 | .019 |
| Baetidae | 38 | 199,432 | 49.30 | .022 | .25 | .028 |
| Ephemeridae | 21 | 110,212 | 27.23 | .441 | 5.10 | .572 |
| Hydropsychidae | 138 | 724,252 | 178.96 | .096 | 1.11 | .124 |
| Psychomyiidae | 5 | 26,241 | 6.48 | .012 | .14 | .016 |
| Limnephilidae | 2 | 10,496 | 2.59 | .447 | 5.17 | .580 |
| Leptoceridae | 3 | 15,745 | 3.89 | .010 | .12 | .013 |
| Sialidae | 20 | 104,964 | 25.94 | .062 | .72 | .081 |
| Gomphidae | 1 | 5,248 | 1.30 | .004 | .05 | .006 |
| Coenagrionidae | 1 | 5,248 | 1.30 | .001 | .01 | .001 |
| Agrionidae | 6 | 31,489 | 7.78 | .023 | .26 | .029 |
| Pyralidae | 42 | 220,424 | 54.47 | .158 | 1.83 | .205 |
| Elmidae | 302 | 1,584,956 | 391.64 | .134 | 1.55 | .174 |
| Gyrinidae | 5 | 26,241 | 6.48 | .010 | .12 | .013 |
| Psephenidae | 4 | 20,993 | 5.19 | .101 | 1.17 | .131 |
| Tipulidae | 33 | 173,191 | 42.80 | .240 | 2.77 | .310 |
| Simuliidae | 530 | 2,781,546 | 687.32 | .202 | 2.34 | .262 |
| Tendipedidae | 1,280 | 6,717,696 | 1,659.94 | .232 | 2.68 | .300 |
| Heleidae | 67 | 351,629 | 86.89 | .004 | .05 | .006 |
| Tabanidae | 8 | 41,986 | 10.37 | .054 | .62 | .070 |
| Empididae | 1 | 5,248 | 1.30 | .004 | .05 | .006 |
| Total | 2,517 | 13,209,719 | 3,264.13 | 2.281 | 26.38 | 2.957 |
| Tubificidae | | | | .007 | .08 | .009 |
| Pelecypoda | 620 | 3,253,884 | 804.03 | 42.0 | 485.52 | 54.315 |
| Gastropoda | 27 | 141,701 | 35.01 | 12.5 | 144.50 | 16.198 |
| Hirudinea | 1 | 5,248 | 1.30 | .001 | .01 | .001 |
| Hydracarina | 3 | 15,745 | 3.89 | .001 | .01 | .001 |
| Amphipoda | 2 | 10,496 | 2.59 | .004 | .05 | .006 |
| Decapoda | 8 | 41,986 | 10.37 | 7.059 | 81.60 | 9.152 |

Zone III

Sample taken .5 mile below the Williamston
sewage disposal plant, June 10, 1959
(10 Petersen dredge hauls)

| Organism | No. | No./acre | No./$M^2$ | Wt. (gm) | lbs/acre | gm/$M^2$ |
|---|---|---|---|---|---|---|
| Baetidae | 1 | 5,248 | 1.30 | .004 | .05 | .006 |
| Psychomyiidae | 8 | 41,986 | 10.37 | .015 | .17 | .019 |
| Limnephilidae | 1 | 5,248 | 1.30 | .140 | 1.62 | .182 |
| Sialidae | 2 | 10,496 | 2.59 | .001 | .01 | .001 |
| Elmidae | 14 | 73,475 | 18.16 | .007 | .08 | .009 |
| Tendipedidae | 243 | 1,275,313 | 315.13 | .084 | .97 | .109 |
| Total | 269 | 1,411,766 | 348.85 | .251 | 2.90 | .326 |
| Tubificidae | | | | .131 | 1.51 | .169 |
| Pelecypoda | 3 | 15,745 | 3.89 | 3.0 | 34.68 | 3.888 |
| Gastropoda | 8 | 41,986 | 10.37 | 3.0 | 34.68 | 3.888 |
| Hirudinea | 10 | 52,482 | 12.97 | .053 | .61 | .069 |

Zone III

Sample taken .5 mile below the Williamston
sewage disposal plant, June 25, 1959
(10 Petersen dredge hauls)

| Organism | No. | No./acre | No./$M^2$ | Wt. (gm) | lbs/acre | gm/$M^2$ |
|---|---|---|---|---|---|---|
| Heptageniidae | 2 | 10,496 | 2.59 | .001 | .01 | .001 |
| Baetidae | 8 | 41,986 | 10.37 | .003 | .03 | .003 |
| Psychomyiidae | 21 | 110,212 | 27.23 | .014 | .16 | .018 |
| Limnephilidae | 6 | 31,489 | 7.78 | .699 | 8.08 | .906 |
| Sialidae | 16 | 83,971 | 20.75 | .021 | .24 | .027 |
| Gomphidae | 1 | 5,248 | 1.30 | .031 | .36 | .040 |
| Elmidae | 37 | 194,183 | 47.98 | .017 | .20 | .022 |
| Tipulidae | 4 | 20,993 | 5.19 | .066 | .76 | .085 |
| Culicidae | 2 | 10,496 | 2.59 | .001 | .01 | .001 |
| Tendipedidae | 1,025 | 5,379,405 | 1,329.25 | .399 | 4.61 | .517 |
| Heleidae | 10 | 52,482 | 12.97 | .008 | .09 | .010 |
| Tabanidae | 1 | 5,248 | 1.30 | .001 | .01 | .001 |
| Empididae | 5 | 26,241 | 6.48 | .002 | .02 | .002 |
| Total | 1,138 | 5,972,450 | 1,475.78 | 1.263 | 14.58 | 1.633 |
| Tubificidae | | | | .242 | 2.80 | .313 |
| Pelecypoda | 21 | 110,212 | 27.23 | 931.0 | 10,762.36 | 1,206.460 |
| Gastropoda | 2 | 10,496 | 2.59 | 1.0 | 11.56 | 1.295 |
| Hirudinea | 2 | 10,496 | 2.59 | .019 | .22 | .025 |
| Hydracarina | 2 | 10,496 | 2.59 | .001 | .01 | .001 |
| Decapoda | 3 | 15,745 | 3.89 | .425 | 4.91 | .550 |

Appendix B-5

Zone IV

Sample taken from the reservoir 2.0 miles
above the dam, June 29, 1959
(10 Ekman dredge hauls)

| Organism | No. | No./acre | No./$M^2$ | Wt. (gm) | lbs/acre | gm/$M^2$ |
|---|---|---|---|---|---|---|
| Baetidae | 1 | 19,972 | 4.94 | .001 | .04 | .004 |
| Ephemeridae | 60 | 1,198,350 | 296.11 | .153 | 6.74 | .756 |
| Sialidae | 11 | 219,698 | 54.29 | .005 | .22 | .025 |
| Coenagrionidae | 1 | 19,972 | 4.94 | .030 | 1.32 | .148 |
| Elmidae | 34 | 679,065 | 167.80 | .022 | .97 | .109 |
| Corixidae | 13 | 259,642 | 64.16 | .015 | .66 | .074 |
| Culicidae | 5 | 99,862 | 24.68 | .004 | .18 | .020 |
| Tendipedidae | 159 | 3,175,628 | 784.70 | .071 | 3.13 | .351 |
| Heleidae | 36 | 719,010 | 177.67 | .012 | .53 | .059 |
| Tabanidae | 1 | 19,972 | 4.94 | .001 | .04 | .004 |
| Total | 321 | 6,411,171 | 1,584.23 | .314 | 13.83 | 1.550 |
| Tubificidae | | | | .254 | 11.19 | 1.254 |

Zone IV

Sample taken from the reservoir 2.0 miles
above the dam, June 29, 1959
(10 Ekman dredge hauls)

| Organism | No. | No./acre | No./$M^2$ | Wt. (gm) | lbs/acre | gm/$M^2$ |
|---|---|---|---|---|---|---|
| Ephemeridae | 16 | 319,560 | 78.96 | .181 | 7.97 | .893 |
| Sialidae | 8 | 159,780 | 39.48 | .011 | .48 | .054 |
| Elmidae | 64 | 1,278,240 | 315.85 | .052 | 2.29 | .257 |
| Culicidae | 1 | 19,972 | 4.94 | .001 | .04 | .004 |
| Tendipedidae | 178 | 3,555,105 | 878.47 | .068 | 2.99 | .335 |
| Heleidae | 29 | 579,202 | 143.12 | .009 | .40 | .045 |
| Total | 296 | 5,312,685 | 1,460.82 | .322 | 14.17 | 1.588 |
| Tubificidae | | | | .093 | 4.10 | .460 |
| Pelecypoda | 2 | 39,945 | 9.87 | .2 | 8.81 | .988 |
| Gastropoda | 9 | 179,752 | 44.42 | 1.7 | 74.87 | 8.393 |

Appendix B-6

Zone V

Sample taken 800 feet above the M-47 bridge,
July 19,1959
(10 Petersen dredge hauls)

| Organism | No. | No./acre | No./M$^2$ | Wt. (gm) | lbs/acre | gm/M$^2$ |
|---|---|---|---|---|---|---|
| Perlidae | 5 | 26,241 | 6.48 | .026 | .30 | .034 |
| Heptageniidae | 3 | 15.745 | 3.89 | .015 | .17 | .019 |
| Baetidae | 1 | 5,248 | 1.30 | .001 | .01 | .001 |
| Hydropsychidae | 4 | 20,993 | 5.19 | .010 | .11 | .012 |
| Psychomyiidae | 12 | 62,978 | 15.56 | .001 | .01 | .001 |
| Brachycentridae | 1 | 5,248 | 1.30 | .003 | .03 | .003 |
| Limnephilidae | 1 | 5,248 | 1.30 | .141 | 1.63 | .183 |
| Sialidae | 46 | 241,417 | 59.65 | .501 | 5.79 | .649 |
| Elmidae | 82 | 430,352 | 106.34 | .050 | .58 | .065 |
| Psephenidae | 1 | 5,248 | 1.30 | .002 | .02 | .002 |
| Tipulidae | 83 | 435,601 | 107.64 | .140 | 1.62 | .182 |
| Culicidae | 1 | 5,248 | 1.30 | .001 | .01 | .001 |
| Tendipedidae | 245 | 1,285,809 | 317.72 | .088 | 1.02 | .114 |
| Heleidae | 24 | 125,975 | 31.13 | .003 | .03 | .003 |
| Tabanidae | 3 | 15,745 | 3.89 | .001 | .01 | .001 |
| Empididae | 9 | 47,234 | 11.67 | .003 | .03 | .003 |
| Total | 521 | 2,734,312 | 675.66 | .986 | 11.37 | 1.291 |
| Tubificidae | | | | .060 | .69 | .077 |
| Gastropoda | 4 | 20,993 | 5.19 | 1.0 | 11.56 | 1.295 |
| Hydracarina | 3 | 15,745 | 3.89 | .001 | .01 | .001 |

Zone V

Sample taken 800 feet above the M-47 bridge,
August 3,1959
(10 Peterson dredge hauls)

| Organism | No. | No./acre | No./$M^2$ | Wt. (gm) | lbs/acre | gm/$M^2$ |
|---|---|---|---|---|---|---|
| Poduridae | 1 | 5,248 | 1.30 | .000+ | .00+ | .000+ |
| Perlidae | 1 | 5,248 | 1.30 | .004 | .05 | .006 |
| Heptageniidae | 1 | 5,248 | 1.30 | .011 | .13 | .014 |
| Baetidae | 3 | 15,739 | 3.89 | .001 | .01 | .001 |
| Hydropsychidae | 11 | 57,730 | 14.26 | .053 | .61 | .068 |
| Psychomyiidae | 9 | 47,234 | 11.67 | .027 | .31 | .035 |
| Limnephilidae | 1 | 5,248 | 1.30 | .107 | 1.24 | .139 |
| Hydroptilidae | 3 | 15,745 | 3.89 | .002 | .02 | .002 |
| Sialidae | 17 | 89,129 | 22.02 | .033 | .38 | .042 |
| Gomphidae | 1 | 5,248 | 1.30 | .129 | 1.49 | .167 |
| Elmidae | 209 | 1,096,874 | 271.01 | .172 | 2.00 | .224 |
| Mesoveliidae | 1 | 5,248 | 1.30 | .001 | .01 | .001 |
| Tipulidae | 161 | 844,960 | 208.79 | .943 | 10.90 | 1.222 |
| Tendipedidae | 235 | 1,233,327 | 304.76 | .068 | .79 | .088 |
| Heleidae | 93 | 488,083 | 120.60 | .021 | .24 | .027 |
| Tabanidae | 4 | 20,993 | 5.19 | .004 | .05 | .006 |
| Empididae | 27 | 141,701 | 35.01 | .005 | .06 | .007 |
| Total | 778 | 4,083,100 | 1,008.89 | 1.581 | 18.29 | 2.049 |
| Tubificidae | | | | .059 | .68 | .076 |
| Hirudinea | 1 | 5,248 | 1.30 | .004 | .05 | .006 |
| Hydracarina | 4 | 20,993 | 5.19 | .002 | .02 | .002 |

Appendix B-8

Zone V

Sample taken .25 mile above the Stow
Road bridge, October 27, 1959
(10 Petersen dredge hauls)

| Organism | No. | No./acre | No./$M^2$ | Wt. (gm) | lbs/acre | gm/$M^2$ |
|---|---|---|---|---|---|---|
| Baetidae | 2 | 10,496 | 2.59 | .001 | .01 | .001 |
| Psychomyiidae | 7 | 36,737 | 9.08 | .006 | .07 | .008 |
| Limnephilidae | 1 | 5,248 | 1.30 | .027 | .31 | .035 |
| Sialidae | 7 | 36,737 | 9.08 | .085 | .98 | .110 |
| Gomphidae | 3 | 15,745 | 3.89 | .041 | .47 | .053 |
| Libellulidae | 5 | 26,241 | 6.48 | 1.026 | 11.86 | 1.330 |
| Coenagrionidae | 41 | 215,176 | 53.17 | .147 | 1.70 | .190 |
| Elmidae | 89 | 467,089 | 115.42 | .040 | .46 | .052 |
| Hydrophilidae | 38 | 199,432 | 49.28 | .139 | 1.61 | .180 |
| Pyralidae | 5 | 26,241 | 6.48 | .062 | .72 | .081 |
| Saldidae | 5 | 26,241 | 6.48 | .114 | 1.32 | .148 |
| Mesoveliidae | 1 | 5,248 | 1.30 | .009 | .10 | .011 |
| Tipulidae | 59 | 309,644 | 76.51 | .294 | 3.40 | .381 |
| Tendipedidae | 780 | 4,093,596 | 1,011.53 | .201 | 2.32 | .260 |
| Heleidae | 108 | 566,806 | 140.06 | .051 | .59 | .066 |
| Tabanidae | 38 | 199,432 | 49.28 | .335 | 3.87 | .434 |
| Total | 1,189 | 6,240,109 | 1,541.93 | 2.578 | 29.79 | 3.340 |
| Tubificidae | | | | 8.529 | 98.60 | 11.053 |

Zone V

Sample taken .25 mile above the Stow Road bridge, November 12, 1959 (10 Petersen dredge hauls)

| Organism | No. | No./acre | No./$M^2$ | Wt. (gm) | lbs/acre | gm/$M^2$ |
|---|---|---|---|---|---|---|
| Psychomyiidae | 1 | 5,248 | 1.30 | .001 | .01 | .001 |
| Sialidae | 6 | 31,489 | 7.78 | .148 | 1.71 | .192 |
| Gomphidae | 4 | 20,993 | 5.19 | .389 | 4.50 | .504 |
| Libellulidae | 3 | 15,745 | 3.89 | .651 | 7.53 | .844 |
| Coenagrionidae | 15 | 78,723 | 19.45 | .059 | .68 | .076 |
| Elmidae | 9 | 47,234 | 11.67 | .004 | .05 | .006 |
| Hydrophilidae | 7 | 36,737 | 9.08 | .024 | .28 | .031 |
| Belastomatidae | 1 | 5,248 | 1.30 | .189 | 2.18 | .244 |
| Tipulidae | 4 | 20,993 | 5.19 | .129 | 1.49 | .167 |
| Tendipedidae | 77 | 404,111 | 99.86 | .062 | .72 | .081 |
| Heleidae | 42 | 220,424 | 54.47 | .009 | .10 | .011 |
| Tabanidae | 49 | 257,162 | 63.54 | .302 | 3.49 | .391 |
| Total | 218 | 1,144,107 | 272.72 | 1.967 | 22.73 | 2.548 |
| Tubificidae | | | | 4.388 | 50.72 | 5.686 |

Appendix B-10

Zone V

Sample taken 100 feet above Nicholson
Road, February 6, 1959
(14 Petersen dredge hauls)

| Organism | No. | No./acre | No./$M^2$ | Wt. (gm) | lbs/acre | gm/$M^2$ |
|---|---|---|---|---|---|---|
| Baetidae | 2 | 7,497 | 1.85 | .001 | .01 | .001 |
| Hydropsychidae | 4 | 14,995 | 3.71 | .116 | .96 | .107 |
| Brachycentridae | 23 | 86,221 | 21.31 | .016 | .13 | .014 |
| Hydroptilidae | 2 | 7,497 | 1.85 | .001 | .01 | .001 |
| Sialidae | 7 | 26,241 | 6.48 | .207 | 1.71 | .191 |
| Gomphidae | 4 | 14,995 | 3.71 | 1.915 | 15.81 | 1.773 |
| Libellulidae | 1 | 3,748 | .93 | .024 | .20 | .022 |
| Coenagrionidae | 187 | 701,009 | 173.22 | .889 | 7.34 | .823 |
| Pyralidae | 15 | 56,231 | 13.89 | .179 | 1.48 | .166 |
| Elmidae | 200 | 749,743 | 185.26 | .136 | 1.12 | .126 |
| Hydrophilidae | 145 | 543,564 | 134.31 | .728 | 6.01 | .674 |
| Tipulidae | 3 | 11,246 | 2.78 | .021 | .17 | .019 |
| Tendipedidae | 327 | 1,225,829 | 302.90 | .500 | 4.13 | .463 |
| Helidae | 193 | 723,502 | 178.78 | .089 | .74 | .082 |
| Tabanidae | 28 | 104,964 | 25.94 | .863 | 7.13 | .799 |
| Empididae | 37 | 138,702 | 34.27 | .012 | .10 | .010 |
| Total | 1,178 | 4,415,984 | 1,091.19 | 5.697 | 47.05 | 5.271 |
| Tubificidae | | | | 11.273 | 93.08 | 10.438 |

Appendix B-11

Zone V

Sample taken 100 feet above Nicholson Road, February 13, 1959 (10 Petersen dredge hauls)

| Organism | No. | No./acre | No./$M^2$ | Wt. (gm) | lbs/acre | gm/$M^2$ |
|---|---|---|---|---|---|---|
| Hydropsychidae | 5 | 26,241 | 6.48 | .140 | 1.62 | .182 |
| Brachycentridae | 12 | 62,978 | 15.56 | .009 | .10 | .011 |
| Sialidae | 8 | 41,986 | 10.37 | .321 | 3.71 | .416 |
| Libellulidae | 1 | 5,248 | 1.30 | .006 | .07 | .008 |
| Coenagrionidae | 49 | 257,162 | 63.54 | .310 | 3.58 | .401 |
| Pyralidae | 11 | 57,730 | 14.26 | .116 | 1.34 | .150 |
| Elmidae | 82 | 430,352 | 106.34 | .073 | .84 | .094 |
| Hydrophilidae | 113 | 593,047 | 146.54 | .590 | 6.82 | .764 |
| Tipulidae | 2 | 10,496 | 2.59 | .010 | .12 | .013 |
| Tendipedidae | 57 | 299,147 | 73.92 | .114 | 1.32 | .148 |
| Heleidae | 25 | 131,205 | 32.42 | .014 | .16 | .018 |
| Tabanidae | 19 | 99,716 | 24.64 | .586 | 6.77 | .759 |
| Empididae | 25 | 131,205 | 32.42 | .014 | .16 | .018 |
| Total | 409 | 2,146,513 | 530.38 | 2.303 | 26.61 | 2.982 |
| Tubificidae | | | | 11.572 | 133.77 | 14.996 |