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THE UNIVERSITY OF ALBERTA

# EFFECTS OF DIELDRIN ON DIVERSITY OF MACROINVERTEBRATES IN A SLOUGH IN CENTRAL ALBERTA



by

DAVID MICHAEL ROSENBERG

A THESIS

SUBMITTED TO THE FACULTY OF GRADUATE STUDIES AND RESEARCH

IN PARTIAL FULFILMENT OF THE REQUIREMENTS FOR THE DEGREE

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The undersigned certify that they have read, and recommend to the Faculty of Graduate Studies and Research, for acceptance, a thesis entitled Effects of dieldrin on diversity of macroinvertebrates in a slough in central Alberta

submitted by David Michael Rosenberg

in partial fulfilment of the requirements for the degree of Doctor of Philosophy

in Entomology

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Date March 20, 1973

## ABSTRACT

Sufficient dieldrin was applied in July, 1967, to a slough in central Alberta to give a concentration of approximately one part per billion in water. Dieldrin levels in mud, water, vegetation, and invertebrates were monitored by gas chromatography until fall, 1968. Residues were undetectable in mud, water, and vegetation by the spring of 1968 but persisted at very low levels in non-transient invertebrate populations throughout the remainder of the study. Results indicate that no food chain magnification of the pesticide occurred within any of the non-transient invertebrate groups.

The treatment slough as well as a control slough were intensively sampled for littoral macroinvertebrates for 18 months before and 18 months after pesticide application to determine whether or not the dieldrin affected macroinvertebrate diversity. Special attention was given to immature Chironomidae. A diversity index derived from information theory was used to monitor possible changes in diversity induced by pesticides. However, no changes in diversity could be detected.

DEDICATION

To my wife Trudy

and to the memory of Zaide Hanson

... for different reasons.

ACKNOWLEDGMENTS

I would like to thank W. G. Evans, my supervising professor, whose original concept formed the basis of this study; for suggesting the use of H'', for Te Vega; and for his advice, continual encouragement, and the many helpful discussions we have had. Thanks are also due to the other members of my advisory committee for their help: G. E. Ball, Department of Entomology, University of Alberta; H. F. Clifford and J. R. Nursall who replaced Dr. Clifford during his sabbatical leave, both of the Department of Zoology, University of Alberta; and W. F. Allen, Department of Chemistry, University of Alberta.

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P. S. Corbet (Odonata), Department of Biology, University of Waterloo, Waterloo, Ontario; D. Barr (water mites), Royal Ontario Museum, Toronto, Ontario; H. B. Leech (Coleoptera), California Academy of Sciences, San Francisco, California; B. S. Cheary (*Laccobius*), Department of Entomology, University of California, Riverside, California; R. Gunderson (*Enochrus*), St. Cloud State College, St.Cloud, Minnesota; and J. R. Zimmerman (*Laccophilus*), New Mexico State University, Las Cruces, New Mexico.

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## AUTOBIOGRAPHICAL SKETCH

I was born in Edmonton, Canada on August 24, 1943. My pre-university schooling was taken at Talmud Torah Hebrew School, Highlands and Westminster Junior High Schools, and Ross Sheppard Composite High School. I entered the University of Alberta as a pre-veterinary medicine student in 1961. The following year I changed to a pattern of studies in entomology and zoology to pursue a lifelong interest in invertebrates. I completed my B.Sc. (Hons.) in 1965 and entered a Ph.D. program in the Department of Entomology under Dr. W. G. Evans. In 1968, I accompanied him on Stanford Oceanographic Expedition #18 to the Eastern Tropical Pacific. I received University of Alberta Honour Prizes in 1963, 1964, and 1965; an NRC Bursary in 1965; NRC Scholarships in 1966, 1967, and 1968; and a University of Alberta Dissertation Fellowship in 1969.

In 1965, I married Trudy (née Kline).

I am presently employed by the Fisheries Research Board of Canada, Freshwater Institute, Winnipeg, Manitoba.

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# I. INTRODUCTION

"The community concept is one of the most important principles in ecological thought and in ecological practice" (Odum, 1959; p.246).

Community studies typically take either an energy or structure approach (Wilhm and Dorris, 1966). With regard to the latter, Hairston (1959, p. 404) states: "The prevalent conviction among ecologists that natural communities represent important and meaningful assemblages of organisms has prompted a diverse series of analyses [which] have been used to approach the subject from several more or less distinct points of view--function, location and biotic composition". Hairston continues to say that the last of these, biotic (= species) composition, has been used as an approach to the analysis of community structure for a number of years and that elements of this approach include "species frequency, species per unit area, the spatial distribution of species, and the numerical abundance of species". I have chosen the last of these as my approach to characterizing the effects of a single application of a low concentration of dieldrin[1] on part of a slough macroinvertebrate community. In this context, "The concept of diversity is particularly important because it is commonly considered an attribute of a natural or organized community..."

---

[1] Dieldrin is herein used to refer to a material containing not less than 85% 1,2,3,4,10,10-hexachloro-exo-6,7-epoxy-1,4,4a,5,6,7,8,8a-octahydro-1,4-endo, exo-5,8-dimethanonaphthalene (Martin, 1961).

(McIntosh, 1967; p. 392).

"Species diversity, applied to an ecosystem, can simply mean the number of species found there, or it can refer to a more complex measure which takes into account the respective numbers of individuals..." (Lloyd, Zar, and Karr, 1968b; p. 257). In deference to the valid criticism of Hurlbert (1971), I define diversity as: the number of species and the distribution of individuals among the species (McIntosh, 1967; p. 393) and use Odum's (1959, p. 281) term "diversity index" to refer to some measure that accounts for the ratio between the number of species and the number of individuals.

Many measures of species diversity have been proposed (see Hairston, 1959; Patten, 1962; Whittaker, 1965; Southwood, 1966; Wilhm and Dorris, 1966; Wilhm, 1967, 1972; Lloyd *et al.*, 1968b; Cancela da Fonseca, 1969; and Morris, 1971; for reviews). Among these, a count of the number of species present is simplest. However, species counts depend on sample size and tell us nothing about species abundance (Preston, 1962; MacArthur, 1965; Sheldon, 1968; Kohn, 1971; and Cameron, 1972). Hurlbert (1971) has probably overemphasized the confusion resulting from the use of the term "species diversity" as meaning just a list of species versus species and individuals. Some authors have tried to establish theoretical relations between species and individuals (Fisher, Corbet, and Williams, 1943; Preston, 1948; and Margalef, 1958). With reference to such indices, Margalef (1958, p. 50) states that they "have the drawback of attempting to adjust a natural distribution to a simple mathematical expression of a more or less arbitrary form, and this does not always work". Diversity indices derived from information theory solve this problem by dealing with the information content of a community

(Margalef, 1958). How this is achieved has been variously stated and re-stated in the literature. For example, see Margalef's original work, Margalef (1958), Hairston (1959), MacArthur and MacArthur (1961), Patten (1962), MacArthur (1965), Pielou (1966 a, b, c, d), Wilhm and Dorris (1966), Lloyd *et al.* (1968b), McCloskey (1970), Wilhm (1970b), Cairns and Dickson (1971), and Cameron (1972). One of the clearest statements is by Pielou (1966d, p. 463): "Diversity is thus equated with the amount of uncertainty that exists regarding the species of an individual selected at random from a population. The more species there are and the more nearly even their representation, the greater the uncertainty and hence the greater the diversity. Information content, which is a measure of uncertainty, is therefore a reasonable measure of diversity".

Diversity indices derived from information theory incorporate several parameters of community structure into one expression. Erman and Helm (1971, p. 241) state: "Objective analysis of large amounts of quantitative data is a primary requirement of invertebrate community studies". The advantages of being able to include vast amounts of data on species abundances and the numbers of individuals in each species into a single, quantitative expression are obvious. Equally obvious, however, are the drawbacks. Interpretation of a single expression which includes several parameters is difficult. If the relative influences of these parameters were known, interpretation would be easier (Sager and Hasler, 1969). To this end, some authors have added a comparison of the diversity of a sample with the diversity of some hypothetical sample (for example, Patten's, 1962, "redundancy"; and Lloyd and Gehlardi's, 1964, and Pielou's, 1966c, "equitability"). Examples of the

use of the concepts of redundancy and equitability can be found in Wilhm and Dorris (1966), Wilhm (1967), Tramer (1969), and Kricher (1972).

Several other theoretical and practical strengths and weaknesses characterize diversity indices derived from information theory. Among the weaknesses are:

1. The indices are insensitive to biological detail (Patten, 1962). One species can replace another and, providing it is there in the same proportion as the first, no change will result in the index. (For that matter, two entirely different faunas can theoretically give the same diversity value. This, however, can be an advantage as will be discussed below). Also, theoretically, shifts in ratios of species already present could give the same index value. However, Patten (1962) points out that if details are required traditional methods can be used to supply them. The concurrent use of a life history approach, for example, would be invaluable in studies of species diversity.

2. The indices are relatively insensitive to rare species (Sager and Hasler, 1969). Hurlbert (1971) has severely criticized the statement and at the same time, answered it. The index merely describes the distribution of numbers and kinds within the community examined and is not meant to assess the relative importance (that is, ecological function?) of any of the species it includes. It is a fundamental character of the index that the presence of many individuals distributed among few species will result in a lower index value. Such distributions mask the information generated by the few individuals of rare species and this shows in the value of the index. To claim, then, that the index does not reflect the influence of rare species is correct but, at the same time, this function should not be claimed for it. Because

the index is dimensionless (see below) it can be re-defined (for example, Lloyd, 1964, used reproductive value; Wilhm, 1968, 1970c, used biomass; Dickman, 1968, used relative productivity; and Watt, 1971, used volume and primary productivity) and its use adjusted so that the presence of individuals of rare species has more influence, if so desired.

3. When using the Shannon-Weaver form $H' = -\sum_{i=1}^{s} p_i \log p_i$

...where $p_i$ is the proportion of the *i*th species in the population (Pielou, 1966c), it is necessary to make assumptions of randomness or some other arrangement (Hairston, 1959). Sampling of non-randomly distributed animals influences the values of the diversity index. Uncertainty in predicting the next species encountered is influenced by patchy spatial distributions and limited vagilities (Lloyd *et al.*, 1968b). This is circumvented by the use of Brillouin's form (Pielou, 1966a; and Reiners, Worley, and Lawrence, 1971) (see below).

4. Contrary to the claims of some authors, the Shannon-Weaver formula and its estimator are not independent of sample size until a certain size of sample is reached. Wilhm (1970a,b) showed that the diversity of individual samples is highly variable and that more than one sample should be taken and the samples pooled. Levelling off of the diversity curve with progressive pooling of samples is due to balancing of the increase of diversity due to new species added with the decrease in diversity because common species already present are added more rapidly than rare species already present (Wilhm, 1970a). See Pielou (1966c), Lloyd, Inger, and King (1968a), Sager and Hasler (1969), Wilhm (1970a), McIntire and Overton (1971), Kohn (1971), and Kochsiek, Wilhm, and Morrison (1971) for examples of pooling of samples.

However, diversity indices derived from information theory have many advantages. That they do not attempt an explanation of observed phenomena and that they summarize vast amounts of information about species abundances have been mentioned above (see also Hairston, 1959; Patten, 1962; Mathis, 1968; and Wilhm, 1968) and in this regard, Patten (1962, p. 60) states that "they allow direct studies of communities at the community level". Also:

1. The only data required are recognizable taxa. Specific determinations are not essential (Wilhm and Dorris, 1966; and Wilhm, 1968, 1970c). This is important in diversity studies of freshwaters because in the absence of extensive rearing programs, most identifications of aquatic insects are above the species level.

2. The index is dimensionless (Wilhm, 1967, 1970a, b). Work in any units can be used (see above) as long as the units are kept consistent. Thus, samples taken by a variety of different equipment and methods can be used in the calculation of the index. Therefore, it becomes possible "to make objective comparisons of community structure between different [communities]...in different parts of the world" (Mathis, 1968; p. 172. See also Wilhm, 1970b).

Two related information theory formulae are currently in use (Cameron, 1972). According to Pielou (1966a, b, c), when all the members of a collection can be identified and counted, its diversity is best given by Brillouin's formula:

$$H = \frac{1}{N} \log \frac{N!}{N_1!\, N_2! \ldots N_s!}$$

where: H = diversity

N = total number of individuals

s = the number of species.

(See also Janzen and Schoener, 1968; Poulson and Culver, 1969; McClosky, 1970; Morris, 1971; and Cameron, 1972). However, since I do not regard the collection "as an entity to be studied for its own sake" but do regard it "as a representative sample from some much larger parent population whose diversity is to be estimated" (Pielou, 1966b; p. 371) and since the index has to be independent of sample size because of my change in biological sampling methods, and H is not, (see Pielou, 1966a, p. 167 point iii; and 1966b, p. 373), I have used the estimator formula:

$$H'' = -\sum_{i=1}^{s}\left(\frac{N_i}{N}\right)\log e\left(\frac{N_i}{N}\right)$$

(notation as above and add: H'' = diversity; and $N_i$ = the number of individuals in the *ith* species) according to the second interpretation given by both Pielou (1966d) and Wilhm (1968). (See also Wilhm and Dorris, 1966; Wilhm, 1967, 1970a, b, c; Lloyd *et al.*, 1968a, Mathis, 1968; Mathis and Dorris, 1968; Janzen and Schoener, 1968; Tramer, 1969; Watt, 1971; and Kohn, 1971).

Indices derived from information theory have been used extensively and effectively for studying the consequences of various kinds of water pollution on the diversity of aquatic invertebrates (Wilhm and Dorris, 1965, 1966; Wilhm, 1967, 1972; Mathis and Dorris, 1968; Storrs *et al.*, 1968; Bechtel and Copeland, 1970; and Ewing and Dorris, 1970) but not in community studies dealing with the effects of pesticides on the

diversity of freshwater invertebrates (for example, lotic studies--Ide, 1957; Bridges and Andrews, 1961; Hynes and Williams, 1962; Moye and Luckmann, 1964; Hitchcock, 1965; Kreis and Johnson, 1968; Hatfield, 1969; and Fredeen, 1972; for example, lentic studies--Cushing and Olive, 1957; Grzenda, Lauer, and Nicholson, 1962; Jones and Moyle, 1963; Kiser, Donaldson, and Olson, 1963; Edwards *et al.*, 1964; Harp and Campbell, 1964; Hilsenhoff, 1965; Anderson, 1970; Hurlbert *et al.*, 1970; Kennedy and Walsh, 1970; Kennedy, Eller, and Walsh, 1970; Way *et al.*, 1971; and Wojtalik, Hall, and Hill, 1971). There is a noticeable absence of pesticide studies in the review by Wilhm (1972). Diversity indices are not used in terrestrial studies (for example, Sheals, 1955; Menhinick, 1962; Patterson, 1966; Moye, Stannard, and Luckman, 1966; Fox, 1967; Edwards, Dennis, and Empson, 1967; and Edwards, Thompson, and Beynon, 1968; Davis, 1968; Burnett, 1968; Way and Scopes, 1968; and Malone, 1969) with the exception of Barrett (1968) who used Margalef's (1958) formula $\frac{S-1}{\ln N}$ to measure changes in "species-numbers diversity" as a result of Sevin (a carbamate insecticide) application.

The freshwater studies cited above share other features as well:

1. They usually deal with relatively high concentrations of pesticides.

2. Dieldrin is not used.

3. The invertebrates have not been analyzed for residue levels. (Unfortunately, studies of the effects of pesticides on the diversity of freshwater invertebrates are quite separate from studies which are done to give residue data).

With the advent of more sensitive analytical techniques (Moore, 1967; Edwards, 1970; Chesters and Konrad, 1971; Cope, 1971; and

Muirhead-Thomson, 1971) and the creation of national pesticide surveillance programs (Breidenbach and Lichtenberg, 1963; Stickel, 1968; Edwards, 1970; and Chesters and Konrad, 1971) residues have been detected in water in concentrations of tens of parts per billion and less (Breidenbach and Lichtenberg, 1963; Tarzwell, 1965; Westlake and Gunther, 1966; Edwards, 1970; Chesters and Konrad, 1971; Muirhead-Thomson, 1971). Of these residues, dieldrin is widespread and common (Buescher, Dougherty, and Skrinde, 1964; Green, Gunnerson, and Lichtenberg, 1967; Moore; 1967; Stickel, 1968; Edwards, 1970; and Chesters and Konrad, 1971). In fact, it was being widely used for crop protection at the start of this study.

Because of its widespread and common occurrence in freshwater ecosystems, and because its persistence was advantageous to a study which used a single application, dieldrin was chosen as the pesticide of this study.

The numerous sloughs dotting the Edmonton area make these important habitats for a variety of flora and fauna. Furthermore, sloughs located on farmland are likely to receive runoff containing pesticides (see Westlake and Gunther, 1966; and Van Middelem, 1966) and, because of their relatively small size, sloughs make community studies more manageable in a practical sense.

Unfortunately, the literature on the effects of pesticides on fauna is fraught with generalities. There exists a feeling that the use of pesticides automatically implies an effect on diversity. For example, Moore (1967) states: "In general, however, pesticides are applied to complex ecosystems and so it can be assumed that they normally cause a decrease in diversity" (p. 111); and "In general, pesticides reduce diversity..." (p. 113); and "It can be concluded that in general

pesticides are more likely to reduce species diversity in aquatic ecosystems than terrestrial ones" (p. 114); and "...it is clear from this work [Menhinick, 1962] that effects on diversity, population density, and biomass can vary between trophic levels" (p. 114); and finally, "Pesticides usually reduce diversity and since they have differential effects on taxa at different trophic levels they may affect production" (p. 125). The need to determine the levels of pesticide in fauna that will cause diversity changes is obvious. Several authors discuss this point but only indirectly (for example, see Tarzwell, 1965, p. 212; Moore, 1967; Stickel, 1968). However, Menzie (1972, p. 216) stated: "We have only scratched the surface in understanding the significance and the effects of low levels of pesticides". Implicit to such a study and subsidiary to it is a part of the energy approach to community studies mentioned previously, namely, trophic level effects (that is, the concentration of pesticides along food chains). These concentrations are a well-known result of pesticide use (for example, Hunt and Bischoff, 1960; Pillmore, in Rudd, 1964; Bridges, Kallman, and Andrews, 1963; Hickey, Keith, and Coon, 1966; see also reviews by Moore, 1967; Newsom, 1967; Stickel, 1968; Edwards, 1970; and Cope, 1971) but the study of these solely in invertebrates has been neglected.

This study, then, was undertaken in an attempt to describe the effects of a low concentration of dieldrin on the diversity of slough macroinvertebrates and to relate the dieldrin concentrations in macroinvertebrates of different trophic levels to possible changes in diversity.

## II. DESCRIPTION OF STUDY AREAS

Both sloughs are located in the parkland area of central Alberta in the County of Strathcona approximately 14.5 km (nine miles) southeast of the city of Edmonton and in an area of mixed farming. The treatment slough (hereinafter called "D") and the control slough (hereinafter called "C") are at 113° 22' 08" W, 53° 25' 27" N and approximately 738.1 m; and 113° 20' 27" W, 53° 24' 23" N and approximately 744.2 m respectively. The surrounding terrain has rolling moraines and kettlehole sloughs. Bayrock and Hughes (1962) described the geology of the area and Bowser *et al.* (1962) the soils. Both sloughs have an area of approximately one hectare.

D slough is in Twp. 51, Range 23, Sect. 19, in the northeast corner of the northeast quarter of the section. The land to the west and the south was being used as a hayfield. However, because the slough lies in a depression encircled by trees along the west, southwest and most of the south, and is passed by roads along the east and north sides, only the southeastern-most end of the slough--where there were no trees to block entrance from the adjoining field--was accessible to haying. That end was usually too wet to approach with a tractor. For size, shape, and depth contours of D slough as taken at the start of the study and just prior to dieldrin application see Figs. 1 and 2.

Murky white and yellow patches, sometimes colored green by algae, appeared usually in the deepest parts of D slough at the height of the

summer. These areas in D were usually devoid of higher vegetation and I could see in them water mites and specimens of *Diaptomus* and *Chaoborus*. There was a strong smell of $H_2S$ in water taken from these areas and oxygen concentrations were lower than at the same depths in surrounding water. For example, on August 10, 1967, oxygen concentrations were 0.55 mg/l in the murky area and 4.07 mg/l in the surrounding water. These areas were quite likely caused by colorless sulfur bacteria (see Reid, 1961, p. 194-195; and Ruttner, 1963, p. 147).

Algal blooms occurred during the period May to October in D slough over the three years of the study. In 1966 and 1967 the main blooms occurred during July and August and were over by September. However, in 1968 the main blooms occurred during June and July with a minor bloom (mainly *Oscillatoria* sp.) in August. Again, the blooms were finished by September. Names of algae identified are given in Table 1.

The main submergent vegetation of D slough was the hornwort (*Ceratophyllum demersum* L.). It was dispersed fairly evenly throughout the slough. Sago pondweed (*Potamogeton pectinatus* L.) was present in 1967. It became more common in 1968 especially in the northwest quarter of the slough. Ivy-leaved duckweed (*Lemna trisulca* L.) was the dominant species of floating vegetation and lesser duckweed (*L. minor* L.) was also present. The emergent vegetation was composed of stands of common cattail (*Typha latifolia* L.), great bulrush (*Scirpus validus* Vahl) and mare's tail (*Hippuris vulgaris* L.) which were discontinuously distributed around the periphery of the slough and faded shoreward into the sedges (*Carex rostrata* Stokes, *C. aquatilis* Wahlenb., and *C. atherodes* Spreng.) and Kentucky blue grass (*Poa pratensis* L.) which in turn continued from the water-land transition onto the land. Among the sedges and

Table 1. Algae present in C and D sloughs

| Date (1967) | Type of Sample | Identifications |
|---|---|---|
| C SLOUGH | | |
| June 19 | plankton net tow | *Anabaena spiroides* Klebahn; *Aphanizomenon flos-aquae* (L.) Ralfs. |
| June 27 | bloom collection | *Aphanizomenon flos-aquae*; *Mougeotia* sp. |
| D SLOUGH | | |
| May 23 | plankton net tow | *Closterium* sp.; *Cocconeis* sp.; *Cosmarium* sp.; *Cymbella* sp.; *Fragilaria* sp.; *Gomphonema* sp.; *Lyngbya* sp.; *Navicula* sp.; *Nodularia* sp.; *Oscillatoria* sp.; *Sphaerella lacustris* (Girod.) Wittrock; *Spirogyra* sp.; *Stigeoclonium* sp.; *Synedra* sp. |
| June 7 | bloom collection | *Aphanocapsa* sp.; *Cymbella* sp.; *Fragilaria* sp.; *Gomphonema* sp.; *Navicula* sp.; *Nodularia* sp.; *Oscillatoria* sp.; *Phacus* sp.; *Pinnularia* sp.; *Rhabdoderma* sp.; *Scenedesmus* sp.; *Trochiscia* sp. |

Table 1. (Continued)

| Date (1967) | Type of Sample | Identifications |
|---|---|---|
| June 29 | bloom collection | *Closterium* sp.; *Cymbella* sp.; *Fragilaria* sp.; *Mougeotia* sp.; *Navicula* sp.; *Pediastrum abtusum* Lucks. |
| July 7 | bloom collection | *Aphanocapsa* sp.; *Closterium* sp.; *Cylindrospermum* sp.; *Cymbella* sp.; *Euglena* sp.; *Fragilaria* sp.; *Merismopedia* sp.; *Microcystis* sp.; *Microspora* sp.; *Nodularia* sp.; *Oscillatoria* sp.; *Pediastrum tetras* (Ehrenb.) Ralfs; *Phacus* sp.; *Rhabdoderma* sp.; *Scenedesmus* sp.; *Staurastrum* sp. |

grass along the shore were moss, *Drepanocladius aduncus* (Hedw.) Warnst., and liverwort, *Rhicciocarpus natans* (L.) Corda. The sedges and grass, and over a very short dry zone the composites and mint, gave way to shrub willow, bush poplar, raspberry, chokecherry, Saskatoon, and snowberry which blended into a stand of mixed poplar (80:20 *Populus balsamifera* L.:*P. tremuloides* Michx.) surrounding the slough on the top of a steep rise on the northwest, west, and south sides. Also, there was a single poplar patch centrally located on the north side of the slough. The typical hydrarch succession has been altered where the roads pass the slough on the north and east sides, where there are no trees. Instead, especially on the north side and also extending into the northwest area, a disturbed roadside ditch succession composed mainly of composite weeds (for example, *Aster* sp., *Rumex* sp., and *Cirsium* sp.) extended from the road and met the hydrarch succession from the slough. The farmer had not disturbed the study site so a natural succession was evident.

C slough is in Twp. 51, Range 23, Sect. 16, centrally located along the west side of the northwest quarter of the section with a road running adjacent to the west side. The slough was in a pasture for dairy cattle and was accessible to the cattle. For size, shape, and depth contours of C slough at the start of the study see Fig. 3.

Areas in C slough similar to those described in D indicated the presence of colorless sulfur bacteria.

Phytoplankton blooms were not as extensive or prolonged as in D slough but occurred at similar times. The phytoplankton flora of C slough was considerably simpler than in D as can be seen in Table 1.

*Ceratophyllum demersum* was the dominant species of submergent

vegetation and initially was distributed peripherally leaving the deepest, central portion free of submergent vegetation. In 1967 and 1968 *Potamogeton pectinatus* became very common in the western part of the slough. As it began drying up in late summer 1967 and continued through the 1968 field season (May-October) the *C. demersum* eventually covered the previously bare central part of the slough. *Lemna trisulca* was the dominant floating plant. *L. minor* was also present. Succession like that of D slough had been interrupted by the proximity of cultivated fields and consequently C slough had fewer typical emergent slough plants and more grasses. The few bunches of *Typha latifolia* present in 1966 were gone by the end of the study. *Hippuris vulgaris* was present throughout the study but in low numbers. *Carex rostrata* was the single sedge species present. The other member of the sedge family present was the creeping spike-rush (*Eleocharis palustris* [L.]). Three species of grasses were present: *Calamagrostis canadensis* (Michx.) Beauv., *Glyceria grandis* S. Wats., and *Scolochloa festucacea* (Willd.) Link. A similar shrub willow-poplar succession to D slough existed at the start of the study. A grove of mixed poplar (*Populus tremuloides* being more abundant than *P. balsamifera*) existed around the northeast, east, and south sides of the slough and a smaller grove on the northwest, adjacent to the road. The *Salix-Populus* was removed halfway through the study (July 27, 1967). Only the grove on the northwest was left standing. By the end of the study, the grasses were replacing the sedge zone and the slough was drying from the margins inward. The climax vegetation having been removed, the original composition of the vegetation was being altered more to a plains type of climax than a forest type.

Winter observations are presented in Appendix II.

## III. METHODS

### A: Surveying and hydrography

D and C sloughs were surveyed, sounded, and mapped (Welch, 1948). The depth measurements were then divided into four classes: 30.5 cm to 58.4 cm; 59.4 cm to 88.9 cm; 89.9 cm to 119.4 cm; and 120.4 cm plus; and the depth contours for each slough drawn. (See Figs. 1-3).

### B: Physical and chemical measurements

1. Water level. Indicators were placed in each slough. Levels were recorded at each sampling date and the indicators moved to suitable positions if the sloughs dried around them.

In winter, measurements of ice thickness and distance between ice and mud were taken using the sounding pole mentioned above.

2. Temperatures. Vertical temperature profiles were taken in each slough using a Yellow Springs Instrument Co. Inc. (Yellow Springs, Ohio) single channel Tele-thermometer with a -17°C to 48°C dial and a stainless steel Tele-thermometer probe. The probe end of the probe cord was tied to the bottom of the sounding pole and thus the depth at which each temperature was taken could be measured accurately.

To record the maximum and minimum surface water temperature between sampling dates (usually weekly in 1966 and 1967 and every two weeks in 1968), a Taylor Sixes - type maximum-minimum thermometer was attached to the north level poles in each slough, below the water surface. As well as noting the maximum and minimum temperatures on each

Figure 1. Size, shape, and depth contours of D slough at the start of the study (end of May, 1966)

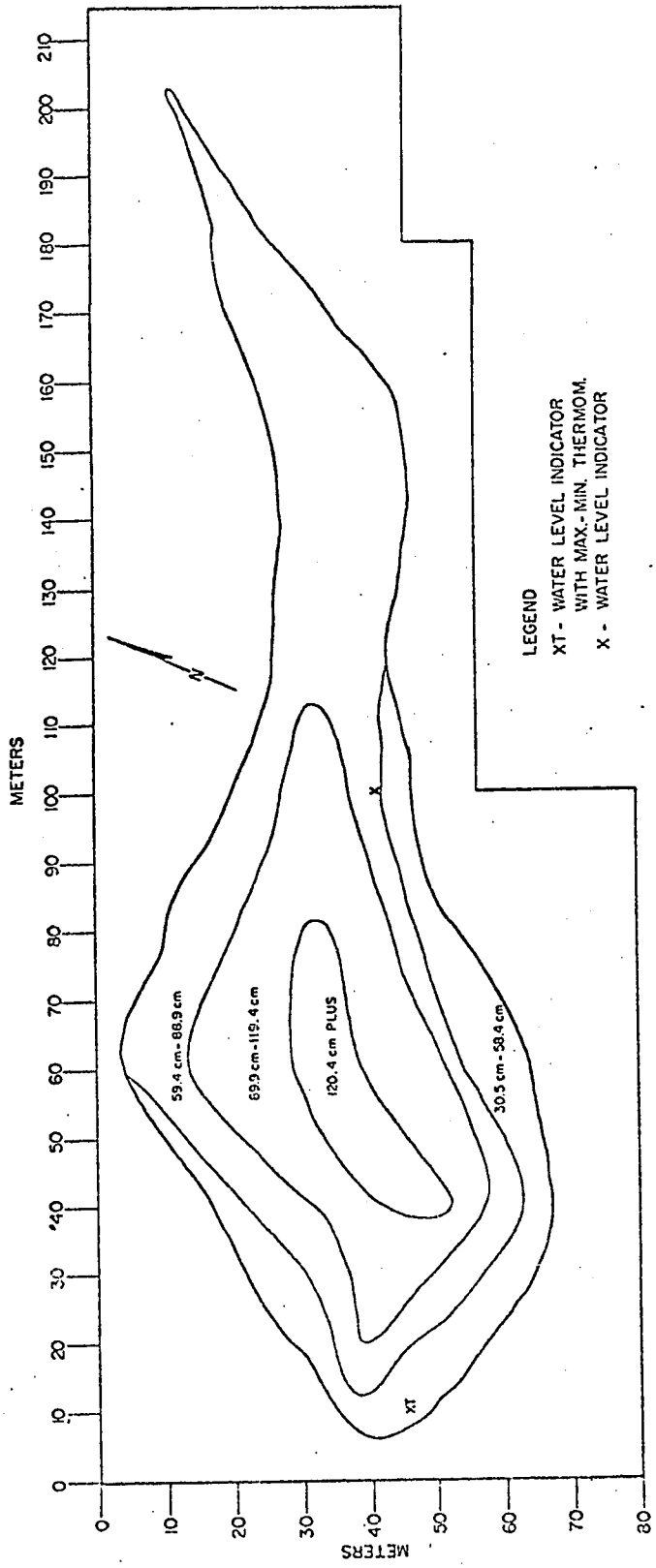

METERS
0
10
20
30
40
50
60
70
80
90
100
110
120
130
140
150
160
170
180
190
200
210
METERS
0
10
20
30
40
50
60
70
80
N
LEGEND
XT - WATER LEVEL INDICATOR
WITH MAX.-MIN. THERMOM.
X - WATER LEVEL INDICATOR
59.4 cm - 88.9 cm
89.9 cm - 119.4 cm
120.4 cm PLUS
30.5 cm - 58.4 cm
X
XT

Figure 1

Figure 2. Size, shape, and depth contours of D slough before dieldrin application (July 19, 1967); and pattern of dieldrin application

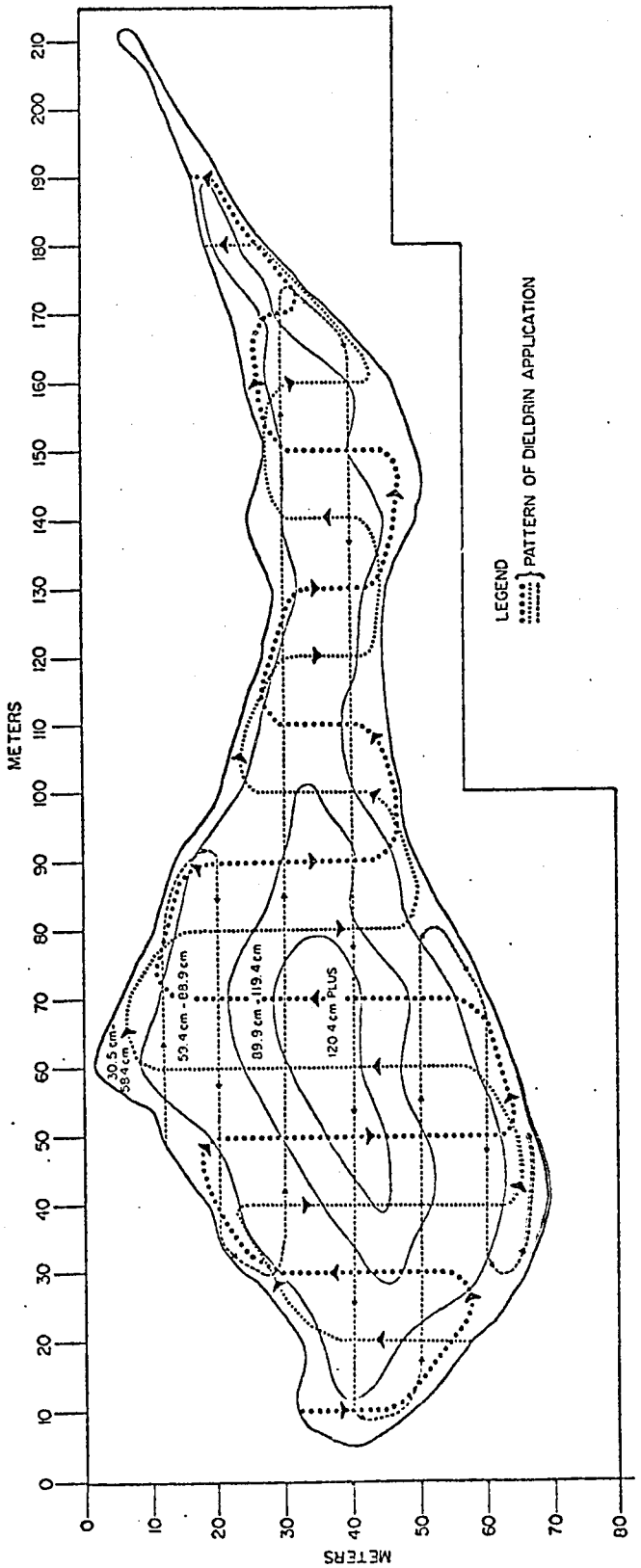
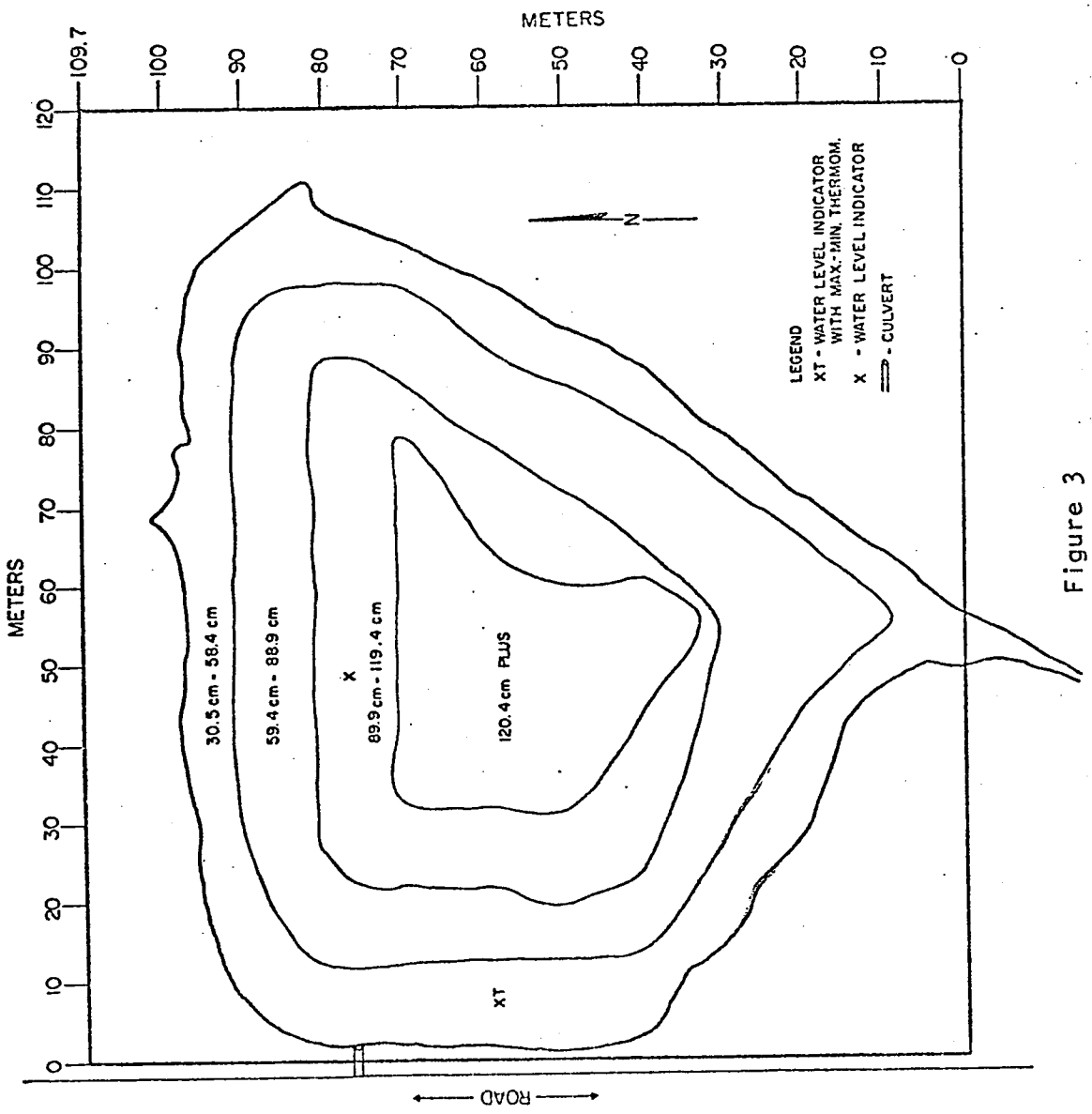

METERS
0
10
20
30
40
50
60
70
80
90
100
110
120
130
140
150
160
170
180
190
200
210
METERS
0
10
20
30
40
50
60
70
80
30.5 cm-59.4 cm
59.4 cm - 89.9 cm
89.9 cm - 119.4 cm
120.4 cm PLUS
LEGEND
PATTERN OF DIELDRIN APPLICATION

Figure 2

Figure 3. Size, shape, and depth contours of C slough at the start of the study (end of May, 1966)


METERS
109.7
100
90
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70
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50
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30
20
10
0
120
110
100
90
80
70
60
50
40
30
20
10
0
METERS
N
LEGEND
XT - WATER LEVEL INDICATOR WITH MAX.-MIN. THERMOM.
X - WATER LEVEL INDICATOR
- CULVERT
30.5 cm - 58.4 cm
59.4 cm - 88.9 cm
X
89.9 cm - 119.4 cm
120.4 cm PLUS
XT
ROAD

Figure 3

sampling date, surface temperature readings were taken near each level pole with a Weston Model 2261 stainless steel bimetallic thermometer usually in the period 1000 to 1400 hours. Also, temperatures of water and mud were taken through the ice in winter using the Yellow Springs Tele-thermometer together with the sounding pole.

3. Light penetration. Visibility was measured with a Secchi disc.

4. Turbidity. The Model DR-EL Direct Reading Engineer's Laboratory Hach Kit (Hach Chemical Co.; Ames, Iowa) was used to measure turbidity.

5. Water chemistry.

a) Dissolved oxygen. The Winkler iodometric method (American Public Health Association, 1960) was used to determine oxygen concentrations. Vertical oxygen profiles were taken approximately monthly, usually in the early afternoon. Temperature readings were taken along with each water sample by using the Tele-thermometer and sounding pole as described above. In the winter, holes were chopped in the ice and water samples and temperatures taken, as described for the open water period, from the water which filled the hole.

b) Dissolved solids and other dissolved gases. The Hach Kit was used to measure hardness, alkalinity, pH, carbon dioxide, orthophosphate, sulphate, nitrite and nitrate nitrogen, iron, manganese, silica, chlorine and chloride, chromate, copper, and fluoride.

Surface water was sampled for determinations of turbidity, dissolved gases other than oxygen, and dissolved solids. Analyses were done while in the boat on the slough.

6. Effects of tree removal on C slough. Water levels, turbidities, temperatures, and nutrients were compared for pre- and post-tree removal

periods in C slough to determine the effects of tree removal on C slough. An unpaired "t"-test was used for some of these comparisons.

C: Biological sampling

The program was designed to include samples from the three main areas of standing waters: littoral, limnetic, and benthic (Reid, 1961); and initially attempts were made to keep the sampling completely random. However, inadequacies of this plan led me to start a stratified random sampling plan (Southwood, 1966) part way through the second field season. Two different sets of sampling equipment were used at all times to prevent cross-contamination of the two sloughs. Limnetic and benthic samples are not considered here.

The littoral area was sampled in two ways: a standard length sweep with a dip net (hereinafter called "dip net sample") and a known volume removed from an area confined by a bottomless garbage can (hereinafter called "garbage can sample". See Kajak, 1971, for the principle of this kind of sample). The garbage can samples were taken between the dip net samples and the shore and usually within the emergent vegetation. The dip net samples were taken nearer to the limnetic area at the open water-emergent vegetation interface. The mouth of the dip net was a loop 33 cm wide by 38 cm long onto which was sewn netting with an aperture size of 0.9 mm (8.5 meshes/cm). Using the handle of the net, the bottom of the area to be sampled was stirred to activate the fauna and the net was swept approximately 107 cm laterally just above the bottom. The sample was fixed in 5% formalin.

A 43.2 cm top diameter, 36.8 cm bottom diameter, and 72.4 cm tall garbage can with the bottom cut out was used to take the garbage can

samples. The garbage can was put down over the area to be sampled, the bottom stirred with the dip net handle to activate the animals, and 10 one liter samples were removed at random within the garbage can and poured through a kitchen strainer which had a mesh aperture size of approximately 0.9 mm. The sample was then fixed in 5% formalin.

Samples were hand-sorted in the laboratory. All the animals from one sample were placed in the same vial in 70% ethyl alcohol. Those samples which had very high numbers of animals measuring 2 to 4 mm long were sometimes sub-sampled. After having sorted the main sample to remove the larger animals, the substrate containing the remaining animals was dispersed evenly in the enamel pan and spoonfuls taken at random removed until a known volume of substrate had been collected. All the animals 2 mm and longer were removed from the subsample and preserved in a vial in 70% ethyl alcohol. All samples (originals and subsamples) were resorted two or three times to ensure that all animals of suitable size had been removed. The volume of the original sample was measured and, knowing it and that of the subsample, a correction factor was applied as required to the taxonomic group under consideration:

$$\text{CORRECTION FACTOR} = \frac{\text{VOLUME OF ORIGINAL SAMPLE + VOLUME OF SUBSAMPLE}}{\text{VOLUME OF SUBSAMPLE}}.$$

The final number of individuals per taxon was obtained by multiplying the number of individuals in the subsample by the correction factor and adding this figure to the one already obtained for the original sample. Because of the mesh size of the original equipment (that is, the dip net and the strainer used in taking garbage can samples), because of the difficulty in quantitatively removing very small animals from a sample by hand sorting, and because of the difficulties

associated with the identification of early instars, specimens less than 2 mm long were disregarded. Examinations of these disregarded animals revealed that all Ostracoda species except *Megalocypris alba* and *Cypris pubera* and the water mite genus *Arrenurus* were the only taxa being selectively ignored for the analyses of diversity.

Four emergence traps per slough were used to collect emerging adult insects for taxonomic purposes. The traps were set along a transect. two over emergent vegetation in the littoral areas on each side of the slough and two in the limnetic area and periodically the traps were moved to a new transect. Emergence traps cannot be considered quantitative unless they are fixed into the substrate thus enclosing a known volume and not allowing migration in and out. The ones used were similar to those pictured in Edwards *et al.* (1964). The insects were aspirated through the top of the trap. This was done from the boat while the trap was left in the water.

Initially, samples were taken weekly and five consecutive dip net and garbage can samples were taken at 10 or 20 m intervals in the littoral area on one side of the slough. Normally. the same portion of side was not used for both kinds of sample and the same portion of side was never used for the same kind of sample for two consecutive weeks.

On June 27, 1967 a new sampling program was instituted and used until the end of the study in the fall of 1968. The hydrographic map of each slough (Figs. 1 and 3) was divided into quarters on approximately north-south and east-west axes. The quarters represented equal lengths of shoreline but not necessarily equal areas of open water. Each quarter of shoreline was divided into quarters and each of these quarters into thirds with the intention that one of the three thirds

would be where a dip net or garbage can sample would be taken on a sampling date. The third to be sampled was chosen randomly. The quarter in which to start, the border of the quarter (right or left), and the direction to go (clockwise or counterclockwise) were also chosen randomly. After having chosen the thirds to use, their individual positions in relation to the grid were listed using the hydrographic maps of each slough so each position could be found in the field. This new plan increased the numbers of dip net and garbage can samples to 16 each. To offset the increase, the length of the standard dip net sweep and the volume of garbage can sample were halved. The method of taking the two types of littoral sample, the areas from which they were taken, and their sorting remained the same.

As the sloughs dried the shorelines changed. Thus, the littoral samples were taken as closely as possible to the intended location. Any differences were recorded.

D: Identification of taxa

With the initial sorting, all the animals from one sample (or subsample) were in the same container. Secondary sorting consisted of sorting the animals from the container into easily recognized groups and placing all the individuals of one group into a shell vial in 70% ethyl alcohol. The numbers of littoral samples (garbage can and dip net) included in the secondary sorting were reduced by using a random selection scheme. Final sorting consisted of identifying the individuals within each shell vial to the lowest ranking taxon possible (usually genus) and recording the numbers of each.

Most specimens were identified in 70% ethyl alcohol using a stereobinocular microscope. A full description of any special methods used in

the identification of individuals of a particular group is given along with the discussion of the groups in Appendix IV.

Because of the large numbers of individuals, attempts were made to identify most of them from external features and with the least sample preparation possible.

Wherever possible, adults from the emergence traps were used for specific identifications. Specific identifications for the insect immatures were not possible.

Several groups of invertebrates had to be omitted from the analyses of diversity because of constraints in time, because of technical problems in identification and quantitation, and because of their relative scarcity in the sloughs throughout the study. Nevertheless, I tried to identify the main taxonomic components of most of these excluded groups to provide qualitative information (see Appendix IV).

E: Dieldrin application

To estimate the volume of water in D slough, it was re-surveyed and re-mapped using the original procedure two days before dieldrin application. The same four depth classes were used and, from the formula in Welch (1948), the volume was calculated to be approximately $2.4 \times 10^6$ liters. Allowing for the 0 to 30.5 cm depth class which was impossible to delimit in the field and hence quantify, a figure of $4.0 \times 10^6$ liters was used.

Since it was my intention to study the effects of low level dieldrin contamination on diversity of slough invertebrates, and to ensure that mass kills of fauna did not occur, I consulted the literature to get an idea of the range of dieldrin $LC_{50}$'s for some species of susceptible mosquito larvae (Hedeen, 1963; Burton, 1964; Flynn,

1964; Klassen, Keppler, and Kitzmiller, 1964; Mulla, 1964; Keppler, 1965; Johnsen, 1967; and Lofgren, Scanlon, and Israngura, 1967) and conducted $LC_{50}$ experiments according to the World Health Organization (1963) method on Chironomidae larvae and Corixidae collected from D slough. The results of the tests on the Chironomidae larvae were unusable and those on the Corixidae gave an $LC_{50}$ of between 0.00085 and 0.0085 ppm dieldrin, closer to the first. Thus, I decided to apply an amount of dieldrin that would yield a final concentration in the water of the slough of 0.001 ppm (1 ppb), a level below that of my $LC_{50}$ experiment and well below the $LC_{50}$'s reported for most susceptible species of mosquito larvae.

The dieldrin used (Shell Canada Ltd.) was an emulsifiable concentrate with an average concentration of $0.177 \times 10^6$ ppm (see Appendix I). The amount required to yield a concentration of 1 ppb in $4 \times 10^6$ liters of water was calculated to be 22.7 ml.

Three approximately equal volumes of emulsifiable concentrate (7.23, 7.76, and 7.73 ml) were added to separate 600 ml jars which were then filled with distilled water and taken to D slough.

To apply the pesticide a new 13.7 liter Universal compressed air sprayer (Leigh Products Inc., Universal Metal Products Div.; Sarnac, Mich.) was used. It required 17 pumpings every five minutes to ensure that its entire contents would be delivered at an even rate. Also by way of calibration, the 4.2 m boat used could be rowed over the entire slough in the patterns shown in Fig. 2, and in approximately the same time as it took for the sprayer to empty, at a rowing rate of 17 strokes per three minutes. Three successive applications of the pesticide were made. For each, the emulsifiable concentrate from one of the 600 ml jars was added to approximately 13.7 liter of water in the

sprayer and while the boat was in motion the nozzle of the sprayer was moved in a zig-zag fashion about five cm below the water surface. The boat was rowed north to south in the first two applications and east to west in the last. The application pattern (Fig. 2) was intended to ensure even application of the pesticide. Also, because the slough was shallow its water would usually be thoroughly mixed by the wind.

It rained heavily during application of the pesticide.

F: Sampling program for gas chromatography

Eleven sets of dieldrin analyses were done on mud, water, vegetation, and invertebrates: once before application; eight times after application during the open-water period (at approximately monthly intervals after application until September, 1967, from May to September, 1968, and in June, 1969); and twice during winter (once each in the winters of 1968 and 1969).

Mud and water samples were collected from each slough according to a random sampling plan. For the collection of mud, five core samples were taken, using a Moore (Pfleger) sampler with a glass tube inside, from each quarter of C and in the northwest and southwest quarters of D and three samples in the northeast and southeast quarters of D. The corer was dropped into the mud three times per sample to ensure collection of a sufficient volume of mud. The corer sampled the top 7.6 to 10.2 cm of the slough bottom. After each sample was taken, the glass tube containing the mud was removed, both ends corked, and transported to the laboratory in a specially built case. Samples were pooled by quarter and a subsample taken for analysis.

Six, five, four, and four water samples were taken respectively from the shallowest to the deepest of the four depth classes used for

drawing the depth contours on the hydrographic maps. These numbers were altered as water levels dropped over the season. Water samples were taken with a Kemmerer bottle, and the bottle emptied into an empty, 20 l pesticide-free ether pail designated for each depth class.

Four kinds of vegetation were collected for dieldrin analysis: submergent (*C. demersum*), floating (*L. trisulca*), emergent (*C. rostrata*), and algae. Algae samples were collected whenever possible in 1968 (usually during a bloom). The sampling plan for littoral invertebrates was used to establish the areas from which each type of vegetation was collected. The samples of each type and from each quarter were put into separate plastic freezer bags for return to the laboratory.

The mud, water, and vegetation samples were stored at 7 to 8°C and, usually, gas chromatographic analysis was completed within a few days of their collection.

The sampling plan for littoral invertebrates was used to determine the areas from which invertebrates were collected for gas chromatographic analysis. Sampling was done with the dip net. Its contents were placed into an enamel pan and the invertebrates sorted in the boat. Similar taxa were put in the same vials which were immediately put into a portable freezer containing dry ice. Vials were stored in the laboratory in a -23°C freezer room until their contents were analyzed. Zooplankton was collected from the enamel pan using a pipette; and by towing the small Wisconsin plankton net in each quarter of the slough. Chironomid immatures were also collected from the unpreserved benthic samples taken with a 15.2 x 15.2 x 15.2 cm Ekman grab (taken under the biological sampling program). Gastropods were

collected at random in addition to those collected as described above. It was unnecessary to make quantitative collections of invertebrates. However, it was important that enough biomass be collected for gas chromatographic analyses. Normally, only two quarters of the slough could be sampled for invertebrates in one day and this was all that was done per sampling date. Dates and types of samples taken for gas chromatographic analyses during the open water periods of the study, are listed in Table 2.

Mud and ice were collected on February 9, 1968 from C and D and on March 6, 1969 from D for gas chromatographic analysis (on the same trips on which water samples were taken for oxygen analysis). One shallow and one deep site on each slough were usually chosen for sampling. Frozen mud and ice were collected by picking up the chunks chopped free with the auger and/or unfrozen mud with the Ekman grab. Each sample was put into a separate plastic freezer bag which was stored in the -23°C freezer room until analyzed.

A detailed account of the methods used for the gas chromatographic analysis of the various ecosystem components is given in Appendix I.

G: Use of H''

Only the dip net and garbage can samples are included in the analyses of diversity.

Despite the fact that complete quantitative information is available for the adult Hemiptera and adult Coleoptera, they have not been included in the analyses of diversity. I have assumed that they would be poor indicators of changes in diversity because they can freely migrate in and out of the sloughs whether due to the pesticide

Table 2. Samples taken during the open-water season for dieldrin analysis

| Slough | Date | Number of Days after Application of Dieldrin (D only) | Type of Sample | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | | Mud | Water | Vegetation* Sub. | Float. | Em. | Algae | Invertebrates |
| C | July 5/67 | | + | + | | | | | |
| | July 11/67 | | | | + | | + | | + |
| D | July 7/67 | | + | + | | | | | |
| | July 13/67 | | | | + | | + | | |
| | July 14/67 | | | | | | | | + |
| | July 22/67 | 1 | + | + | + | + | + | | |
| | July 23/67 | 2 | | | | | | | + |
| C | July 25/67 | | + | + | + | | + | | |
| | August 9/67 | | + | + | + | | + | | |
| D | August 10/67 | 20 | + | + | + | + | + | | |
| | August 11/67 | 21 | | | | | | | + |
| C | September 5/67 | | + | + | + | | + | | |
| D | September 6/67 | 47 | + | + | + | + | + | | |
| | September 7/67 | 48 | | | | | | | + |

Table 2. (Continued)

| Slough | Date | Number of Days after Application of Dieldrin (D only) | Mud | Water | Type of Sample Vegetation* | | | | Invertebrates |
|---|---|---|---|---|---|---|---|---|---|
| | | | | | Sub. | Float. | Em. | Algae | |
| | May 29/68 | 313 | | | | | | | + |
| C | May 30/68 | | + | + | | | | | |
| D | May 31/68 | 315 | + | + | + | + | + | + | |
| C | July 2/68 | | + | + | + | + | | | |
| D | July 3/68 | 348 | + | + | + | + | + | + | |
| | July 4/68 | 349 | | | | | | | + |
| C | July 29/68 | | + | + | + | + | | | |
| D | July 30/68 | 375 | + | + | + | + | + | | |
| | July 31/68 | 376 | | | | | | | + |
| | September 17/68 | 424 | | | | | | | + |
| | June 2/69 | 682 | + | + | | +** | + | | |

* Sub. = submergent; Float. = floating; Em. = emergent.

** Mixed with algae.

or not.

The species level or nearest possible taxon to species level was used for the analyses of diversity. Use of the species level would give the highest sensitivity to the index in the measurement of faunal change (assuming faunal changes occur at and will be reflected at the species level). Use of a higher level, however, would merely reduce sensitivity. Because of difficulties in identification, composite taxa were sometimes used. (See Section IV, part C). The assumption in using the composite taxon is that all taxa included have an equal chance of occurring in it. And, on any one sampling date, if any part of the composite taxon was present in addition to the composite taxon itself, the latter was not used. That is, the composite taxon was only used in analyses of diversity when, for example, for the Coenagrionidae...

a) *Enallagma - Coenagrion*--none of the five Coenagrionidae species were present (including the composite taxon *E. cyathigerum - C. resolutum*);

b) *E. cyathigerum - C. resolutum*--neither *E. cyathigerum* nor *C. resolutum* were present. This treatment relates back to the nature of the diversity index derived from information theory. That is, the index uses only numbers and kinds. If the lowest taxon (for example, *E. cyathigerum*) is used, one "kind" is established. If a higher taxon (for example, *Enallagma - Coenagrion*) is used, another "kind" is established. Clearly, *E. cyathigerum* can occur within the *Enallagma - Coenagrion* taxon so the establishment of the latter as another "kind" is illogical.

The alternatives to this treatment are:

1. To discard the composite taxon *Enallagma - Coenagrion*

completely. This would represent a loss of information when none of the five coenagrionid species were present and the composite taxon was; and

2. To use only the composite taxon which, for the Coenagrionidae, would mean loss of the information (and hence sensitivity) generated by the five species.

Finally, use of the diversity index does not require that all taxa be of the same level (for example, see Wilhm and Dorris, 1966; and Wilhm, 1968, 1970c). Whether you establish a genus as a "kind", or a species as a "kind" does not matter to the diversity index. Thus, the use of *Enallagma - Coenagrion* along with, for example, *Sympetrum costiferum* is acceptable.

That the diversity of individual samples is highly variable (Wilhm, 1970a, b) was certainly true of my samples. Keeping the dip net and garbage can samples apart, all the samples taken on the same date were pooled. Several sampling dates were then chosen to check when in the progressive pooling the asymptote of diversity was reached. Poolings were triplicated: one replicate according to the order in which the samples were taken and two in a random order. Lloyd *et al.*, (1968a) randomized their pooling order by shuffling IBM cards; I used a table of random numbers. The minimum number of samples pooled was five (except for one date in C and D for which four were pooled).

For calculating H", a Fortran program developed at the University of Alberta and an IBM 360-67 were used. Four different H" 's were calculated for the invertebrate taxa which were used: total H", Chironomidae H", primary consumer H", and secondary consumer H". The four different H" 's were graphed yearly for both sloughs for both types

of samples. Total H" included all taxa and was meant to give an overall diversity measure. The total H" of D versus that of C, and the total H" of D pre-dieldrin application and post-dieldrin application versus those of C were compared. The pre- and post-dieldrin application periods of D corresponded exactly to the pre- and post-tree removal periods of C. I will refer to both periods as pre- and post-treatment for both sloughs. Table 3 shows the within-slough comparisons of total H" that were done. Unpaired "t"-tests were used to determine whether differences between these comparisons were significant.

Chironomidae H" included just the chironomid taxa. The midges being the most diverse group in the sloughs, I wanted to see whether they alone would mirror total H". By implication, if there was a positive correlation between total H" and Chironomidae H" perhaps future studies of the effect of toxic compounds on macroinvertebrate fauna could concentrate on the single most diverse group in the community. Total H" versus Chironomidae H" were plotted and correlation coefficients calculated. In addition, one within-slough comparison (see Table 3) was made and an unpaired "t"-test used to test for significance.

Since the gas chromatographic analyses showed that primary and secondary consumers had virtually the same levels of dieldrin, I wanted to know whether or not the dieldrin affected the diversities of the primary and secondary consumers in different ways. All the taxa of invertebrates used in the diversity analyses were arbitrarily separated into primary and secondary consumers (Pennak, 1953) as follows: primary consumers: Chironomidae (Chironominae and

Table 3. Within-slough comparisons of H'' for C and D sloughs; and dip net and garbage can samples

| | | |
|---|---|---|
| total, pre-treatment | vs. | total, post-treatment |
| Chironomidae, pre-treatment | vs. | Chironomidae, post-treatment |
| 1° consumer, pre-treatment | vs. | 1° consumer, post-treatment |
| 2° consumer, pre-treatment | vs. | 2° consumer, post-treatment |
| 1° consumer | vs. | 2° consumer |
| 1° consumer, pre-treatment | vs. | 2° consumer, pre-treatment[1] |
| 1° consumer, post-treatment | vs. | 2° consumer, post-treatment[1] |

[1] Not done for C slough.

Orthocladiinae)--25 taxa; Hirudinea (Erpobdellidae)--4 taxa; Ephemeroptera--3 taxa; Amphipoda--2 taxa; Ostracoda--2 taxa; Corixidae--2 taxa; Haliplidae--1 taxon. Secondary consumers: Odonata--13 taxa; Coleoptera (Dytiscidae, Gyrinidae, and Hydrophilidae)--12 taxa; Hirudinea (Glossiphoniidae)--8 taxa; Chironomidae (Tanypodinae)--6 taxa; water mites--5 taxa; Notonectidae--2 taxa; Gerridae--1 taxon. Unfortunately, the number of taxa of primary and secondary consumers were not equal. A number of within-slough comparisons (see Table 3) were made using unpaired "t"-tests again and those results refined by using a two-way analysis of variance to indicate whether or not the primary and secondary consumer diversities differed due to the treatment.

# IV. RESULTS

## A: Physical and chemical measurements

C and D sloughs were similar throughout the study with respect to the physical and chemical parameters measured.

There was an overall decline in the level of water in both sloughs during the three years of the study, probably caused mainly by the below-average precipitation over the study period.

From the vertical temperature profiles done in each slough no thermocline was evident and no thermal stratification existed. Overall, the sloughs showed similar maximum and minimum, and surface water temperature regimes. Maximum and minimum temperatures generally increased and decreased respectively throughout the study, probably reflecting the inability of the reduced water volume in both sloughs to buffer air temperature change.

The Secchi disc could always be seen at the bottom of the deepest part of each slough on a clear day and turbidity levels were in the 0 to 25.0 ppm range for both sloughs.

Oxygen concentrations were similar for both sloughs within each year, and, generally, never exceeded 20 ppm. Anaerobic conditions were found in C slough in February, 1968 and in D slough in November and December, September, and February of 1966, 1967, and 1968 respectively. The only evidence of stratification came from D slough in 1967. Oxygen concentrations usually varied among depth classes.

Analyses of dissolved solids, and other dissolved gases continued to reflect the similarity of the two sloughs. Total hardness was in the 300 to 400 ppm range and overall mean calcium to magnesium ratios were 2.17 and 1.84 for C and D sloughs respectively. Daborn (1969) reported a mean value for his slough of 1.49. Hartland-Rowe (1966) has reported tremendous variations in calcium and magnesium concentrations in permanent ponds of the Canadian prairies so the differences reported here are insignificant. Alkalinity was mainly due to the bicarbonate ion in both sloughs which agrees with the findings of Daborn (1969). The pH varied from 7.40 to 9.50 and 7.65 to 9.30 with overall means of 8.57 and 8.55 for C and D sloughs respectively. Daborn (1969) reported a range of 8.50 to 9.60 and a mean of 8.95. Free $CO_2$ concentrations were generally within the 0 to 10 ppm range. Values for orthophosphate usually remained below 1.0 ppm throughout the study and, in general, levels approximated those found by Daborn (1969). He reported sulphate to be the second most abundant anion in the slough of his study but in the sloughs of this study it was the most abundant. Again, such divergence is not surprising in view of the results reported by Hartland-Rowe (1966). Concentrations of sulphate were generally in the 200 to 350 ppm range. Nitrite and nitrate nitrogen were generally in the 0 to 0.020 ppm and 10 to 25 ppm range respectively for both sloughs. Nitrate concentrations reported by Daborn (1969) were similar to those reported here.

Considerations of the remaining dissolved solids (iron, manganese, silica, chlorine and chloride, chromate, copper, and fluoride) as well as further details of the other physical and chemical parameters measured, including figures, tables, and discussions can be

found in Appendix III.

B: Effects of tree removal on C slough

Bodies of water within clear-cut areas can suffer the following effects:

1. Increased water level (Bormann *et al.*, 1968; Lull and Sopper, 1969; and Likens *et al.*, 1970);

2. Increased turbidity (Lieberman and Hoover, 1948; Tebo, 1955; King and Ball, 1964; Sheridan and McNeil, 1968; and Fredricksen, 1971);

3. Increased maximum summer water temperatures (Gray and Edington, 1969; Likens *et al.*, 1970; and Swift and Messer, 1971);

4. Changes in nutrient concentrations (Bormann *et al.*, 1968; and Likens *et al.*, 1970).

In the three years of the study, C had three successive water level declines and these were reflected by D. C suffered a greater reduction in level after the trees had been removed than before, as did D. Note, however, that C is situated in an area of more gentle relief than D and that precipitation for the three years of the study was below average.

Mean turbidities for pre- and post-tree removal periods were 13.4 and 8.6 ppm respectively for D; and 10.5 and 12.2 ppm respectively for C. There was no significant difference in turbidities in C before and after tree removal ($t = 0.402$ for 6 DF).

Surface water temperatures in C were the coldest of the three years of the study in 1968, the year following tree removal (see Appendix III, Fig. 4, and Table 4). Mean surface water temperature of C for the period immediately after tree-removal and until early September,

1967 was 20.7°C which was slightly above the mean surface water temperature for 1967 (20.1°C). However, this higher value was paralleled by D slough and was probably due to an unusually warm August. Pre- and post-tree removal means show that C was about 1°C colder after tree-removal. C slough had a mean maximum temperature for 1968 that fell between the 1966 and 1967 means. The mean post-tree removal period maximum temperature was almost 3°C higher than that for the pre-tree removal period. These means were significantly different at the 2% level ($t = 2.43$ for 38 DF). However, the difference in mean maximum temperatures for D slough for pre- and post-tree removal periods was over 4°C. Thus, it seems unlikely that the removal of trees from C slough was the cause of the increased maximum temperatures. The increase is more likely attributable to decreased precipitation and increased air temperatures over the long-term averages.

Among the main nutrients examined by Bormann *et al.* (1968) and Likens *et al.* (1970) concentrations of $Ca^{++}$ and $Mg^{++}$ increased; $SO_4^{=}$ decreased; and $HCO_3^{-}$ showed no change. For C slough there was no significant difference between pre- and post-tree removal means of $Ca^{++}$ ($t = 1.87$ for 6 DF), $Mg^{++}$ ($t = 1.02$ for 6 DF), and $SO_4^{=}$ ($t = 2.01$ for 6 DF). $HCO_3^{-}$ showed a decrease in concentration that was significant at the 5% level ($t = 2.62$ for 6 DF). The lack of significant change in the concentrations of three of the four main nutrients leads to the conclusion that tree removal did not affect the balance of nutrient concentrations in C slough.

In summary, no evidence was found that water level, turbidity, surface and maximum temperatures, and nutrient concentrations were

affected by the removal of trees from C slough.

C: Taxa used in analyses of diversity

1. Hirudinea

   a) Glossiphoniidae

      *Glossiphonia complanata* (L.)

      *Glossiphonia heteroclita* (L.)

      *Helobdella fusca* (Castle)

      *Helobdella fusca-Oculobdella lucida*

      *Helobdella stagnalis* (L.)

      *Oculobdella lucida* Meyer and Moore

      *Placobdella ornata* (Verrill)

      *Theromyzon meyeri* (Livahow)

      *Theromyzon meyeri-Theromyzon rude*

      *Theromyzon rude* (Baird)

   b) Erpobdellidae

      *Dina parva* Moore

      *Erpobdella punctata* (Leidy)

      *Mooreobdella fervida* (Verrill)

      *Nephelopsis obscura* (Verrill)

2. Crustacea

   a) Amphipoda

      *Hyallela azteca* (Saussure)

      *Gammarus lacustris* Sars

   b) Ostracoda

      *Cypris pubera* Müller

      *Megalocypris alba* (Dobbin)

3. Insecta

a) Odonata

(i) Lestidae

*Lestes congener* Hagen

*Lestes congener-Lestes disjunctus*

*Lestes disjunctus* Selys

(ii) Coenagrionidae

*Coenagrion angulatum* Walker

*Coenagrion resolutum* Hagen

*Enallagma civile?* (Hagen)

*Enallagma-Coenagrion*

*Enallagma cyathigerum* (Charpentier)

*Enallagma cyathigerum-Coenagrion resolutum*

*Enallagma ebrium* (Hagen)

(iii) Aeshnidae: *Aeshna interrupta* Walker

(iv) Libellulidae

*Leucorrhinia borealis* Hagen

*Leucorrhinia intacta* Hagen

*Sympetrum costiferum* (Hagen)

*Sympetrum costiferum-Sympetrum internum*

*Sympetrum internum* Montgomery

b) Hemiptera

(i) Corixidae

*Cymatia americana* Hussey

other immature Corixidae

(ii) Gerridae: *Gerris*

(iii) Notonectidae

*Notonecta*

*Notonecta kirbyi* Hungerford

*Notonecta undulata* Say

c) Ephemeroptera

*Caenis*

*Callibaetis*

*Callibaetis-Cloeon*

*Cloeon*

d) Coleoptera

(i) Dytiscidae

*Agabus*

*Dytiscus*

*Graphoderus*

*Hydroporus-Hygrotus*

*Illybius*

*Laccophilus*

*Oreodytes-Deronectes*

*Rhantus-Colymbetes*

*Thermomectus*

(ii) Gyrinidae

*Gyrinus*

*Gyretes*

(iii) Haliplidae: *Haliplus*

(iv) Hydrophilidae

*Berosus*

*Enochrus*

*Hydrobius*

e) Chironomidae

(i) Tanypodinae

*Ablabesmyia*

*Guttipelopia?*

*Thienemannimyia* grp.

*Procladius*

*Psectrotanypus*

*Tanypus*

(ii) Chironominae

1. Chironomini: *Chironomus*

*Cryptochironomus*

*Cryptocladopelma*

*Dicrotendipes*

*Einfeldia*

*Endochironomus*

*Glyptotendipes*

*Microtendipes*

*Parachironomus*

*Phaenopsectra*

*Polypedilum*

*Pseudochironomus*

*Xenochironomus*

2. Tanytarsini: *Cladotanytarus*

*Micropsectra-Tanytarsus*

*Paratanytarsus*

(iii) Orthocladiinae

*Acricotopus*

*Corynoneura*

*Cricotopus*

*Eucricotopus* type

*Paratrichocladius* type

*Trichocladius* type

*Metriocnemus*

*Psectrocladius*

nr. *Chaetocladius*

nr. *Krenosmittia*

4. Water mites

*Eylias*

*Hydrachna*

*Hydrodroma*

*Limnesia*

*Piona*

See Appendix IV for discussion of the qualitative aspects of some of these taxa.

D: Fate of dieldrin in the slough

1. Gas chromatography

a) General remarks. Mud, water, and vegetation of C slough did not have detectable levels of dieldrin at any time during the study. Nor were any levels detectable in D slough prior to application. Dieldrin concentrations shown in Tables 5 and 8 have been corrected to 100% recovery. Each histogram in Fig. 4 is a mean value of dieldrin concentration for each class of material for each sampling date. Confidence limits for sampling dates which have three or more replicates

of the same type of sample are given in Table 22.

Because mud, water, and vegetation of C slough did not have detectable levels of dieldrin at any time during the study, invertebrates were not collected for gas chromatographic analyses from C slough after July 11, 1967 (see Table 2). Samples of *Hyallela azteca* from C slough were used for the invertebrate recovery studies. The sample used as a blank showed no detectable dieldrin levels. No dieldrin was detectable in invertebrates from D slough prior to dieldrin application.

Although pesticide concentrations and rates of loss vary, similar declines in other chlorinated hydrocarbon[2] residues to those of my study are reported by Edwards *et al.* (1964) for DDD in mud and water, Bridges (1961) and Croker and Wilson (1965) for endrin and DDT respectively in mud, water, and submergent vegetation; Meeks (1968) for DDT in water, emergent and submergent vegetation, and invertebrates; and Bridges, Kallman, and Andrews (1963) for DDT in mud, water, submergent vegetation, and crayfish. (Fates of pesticides other than chlorinated hydrocarbons in ecosystem constituents were described by the following: Abate--Bowman and Orloski, 1966; and Brooks, Smith, and Miles, 1967; Diazinon--Miller, Zuckerman, and Charig, 1966; Dursban--Hurlbert *et al.*, 1970; Paraquat--Way *et al.*, 1971; Parathion--Miller *et al.*, 1966; Toxaphene--Kallman, Cope, and Navarre, 1962; and Terriere *et al.*, 1966; and 2,4-D--Smith and Isom, 1967; and

---

[2] I use "chlorinated hydrocarbons" to designate DDT and its related compounds, the cyclodienes (excluding toxaphene which is not a true cyclodiene; O'Brien, 1967), and the hexachlorocyclohexanes.

Wojtalik *et al.*, 1971).

b) Mud, water, and vegetation.

(i) Mud. Table 4 summarizes some of the parameters of the chlorinated hydrocarbon studies cited above and compares rates at which maximum concentrations are reached and pesticide is no longer detectable. "Length of Time until Maximum Concentration" should be interpreted with caution because the different authors did not use equivalent time intervals in their analyses. Maximum concentration has been used here because for most studies, the actual amount of pesticide that entered the water after application is not known. Residues in the mud of D slough went below detectable levels between 47 days after application (September 6, 1967) and the next date of sampling, 203 days after application (February 9, 1968). The actual time was probably closer to the first date given because concentrations were less than 1 ppb at that time (see Table 5). Data are insufficient to correlate maximum concentration with length of time until residues were undetectable. However, there is an indication that the lower concentrations became undetectable faster (see Croker and Wilson, 1965). I found the same. Again, caution should be used in making such conclusions because sensitivity of the analytical methods used by workers is unknown.

(ii) Water. Table 6 summarizes similar data as in Table 4, only for water. The cautions just given in the section on mud for interpretation of Table 4 apply to Table 6 as well. It is apparent that maximum concentrations and the time until residues are undetectable are reached sooner than in any other ecosystem constituent and these rates would seem to be independent of concentration. The water

Table 4. Some parameters of and decline of chlorinated hydrocarbon pesticide residues in mud and/or sediment of studies cited

| Reference | Pesticide Used | Application Rate | Maximum Concentration | Time to Maximum Concentration | Time until Residues Undetectable |
|---|---|---|---|---|---|
| Bridges (1961) | endrin | 6 oz/acre | 0.80 ppm | 53 days* | 61 to 75 days |
| Bridges *et al.* (1963) | DDT | 0.02 ppm in water | 8.30 ppm | 1 day | No mud samples taken after 8 weeks; level at that time: 0.19 ppm. |
| Edwards *et al.* (1964) | DDD | 1.0 lb/acre | 1.02 lb/acre | 7 days | Study terminated after 9 months; level at that time: 0.12 lb/acre. |
| Croker and Wilson (1965) | DDT | 0.2 lb/acre | 3.35 ppm | 6 weeks | Study terminated after 11 weeks; level at that time: 0.76 ppm. |

* Mud not sampled until 16 days after application of endrin.

Table 4. (Continued)

| Reference | Pesticide Used | Application Rate | Maximum Concentration | Time to Maximum Concentration | Time until Residues Undetectable |
|---|---|---|---|---|---|
| Meeks (1968) | DDT-$Cl^{36}$ | 0.2 lb/acre | Not applicable. Topsoil analyzed. | | |
| this study | dieldrin | 1.0 ppb in water | 4.15 ppb | 1 day | 7 to 29 weeks |

Table 5. Dieldrin concentrations (ppb) in mud and water of D slough

| Days after Application | Mud (quarters) SW | SE | NW | NE | Water (depth classes-cm) 30.5-58.4 | 59.4-88.9 | 89.9-119.4 | 120.4 plus |
|---|---|---|---|---|---|---|---|---|
| 1 | 4.56 | 4.70* | 3.20 | | 0.21 | 0.15 | 0.56 | 0.46 |
| 20 | 0.54† | <el Ψ | <el | <el | 0.12** | 0.12 | <el | |
| 47 | <el | 0.53 | 0.59 | 0.72 | <el | <el | <el | |

* Solid underlining = confirmed with boron trifluoride etherate.

** Broken underlining = boron trifluoride etherate conversion unclear due to excessively dirty sample or sample with insufficient dieldrin for confirmatory procedure.

† Five times usual volume injected to get value.

Ψ Below experimental limits of detection.

Table 6. Decline of chlorinated hydrocarbon pesticide residues in water of studies cited

| Reference | Maximum Concentration of Pesticide (ppm) | Time to Maximum Concentration | Time until Residues Undetectable |
|---|---|---|---|
| Bridges (1961) | 0.04 | 4 days† | 26 to 34 days |
| Bridges *et al.* (1963) | 0.08 | 30 minutes | 3 to 4 weeks |
| Edwards *et al.* (1964) | 0.05 to 0.10 | 1 day | 2 weeks |
| Croker and Wilson (1965)* | 0.05 | 1 day | 5 to 7 days |
| Meeks (1968) | 0.003 | 1 hour | 2 weeks to 1 month |
| this study | approx. 0.00035 | 1 day | 2 to 3 weeks |

† Water not sampled until 4 days after endrin applied.

* This data: from holding sites. (See original publication).

in D slough showed maximum concentration the day after application of the dieldrin (Table 5, Fig. 4). The 0.35 ppb was below the concentration intended (1.0 ppb). However, Bridges *et al.* (1963) and Meeks (1968) showed that the maximum concentration of DDT in the water samples studied by them was reached in the first hour after treatment and by the following day, levels were approximately 1/25 and 1/2 the maximum concentration respectively. Thus, almost certainly the maximum concentration of dieldrin in the water of D slough was greater than 0.35 ppb and possibly it was close to the intended 1 ppb. The rapid decline of chlorinated hydrocarbon concentrations is due to two major processes: their relative insolubility in water which causes them to attach to organic matter and be removed from the water (for example, by settling to the bottom) (Edwards, 1970; Muirhead-Thomson, 1971; and Cope, 1971) and co-distillation (Eberhardt, Meeks, and Peterle, 1971). The latter process will be further discussed below.

(iii) Vegetation. Table 7 summarizes similar data as in Tables 4 and 6, only for vegetation. The cautions given previously must also be used for Table 7. The maximum concentrations given for Meeks' (1968) study is the highest of the many species of submergent and emergent vegetation he analyzed. Similarly, the length of time until residues could not be detected is the time of the final sample for the species which had the lowest level of pesticide. Residues in the submergent vegetation of my slough went below detectable levels sometime between 47 days after application (September 6, 1967) and the first sampling of the following spring, 315 days after application (May 31, 1968). As in the mud samples, the time was probably closer to the former because of the relatively low levels present at that

Figure 4. Decline of dieldrin in mud, water, and vegetation of D slough during the study period

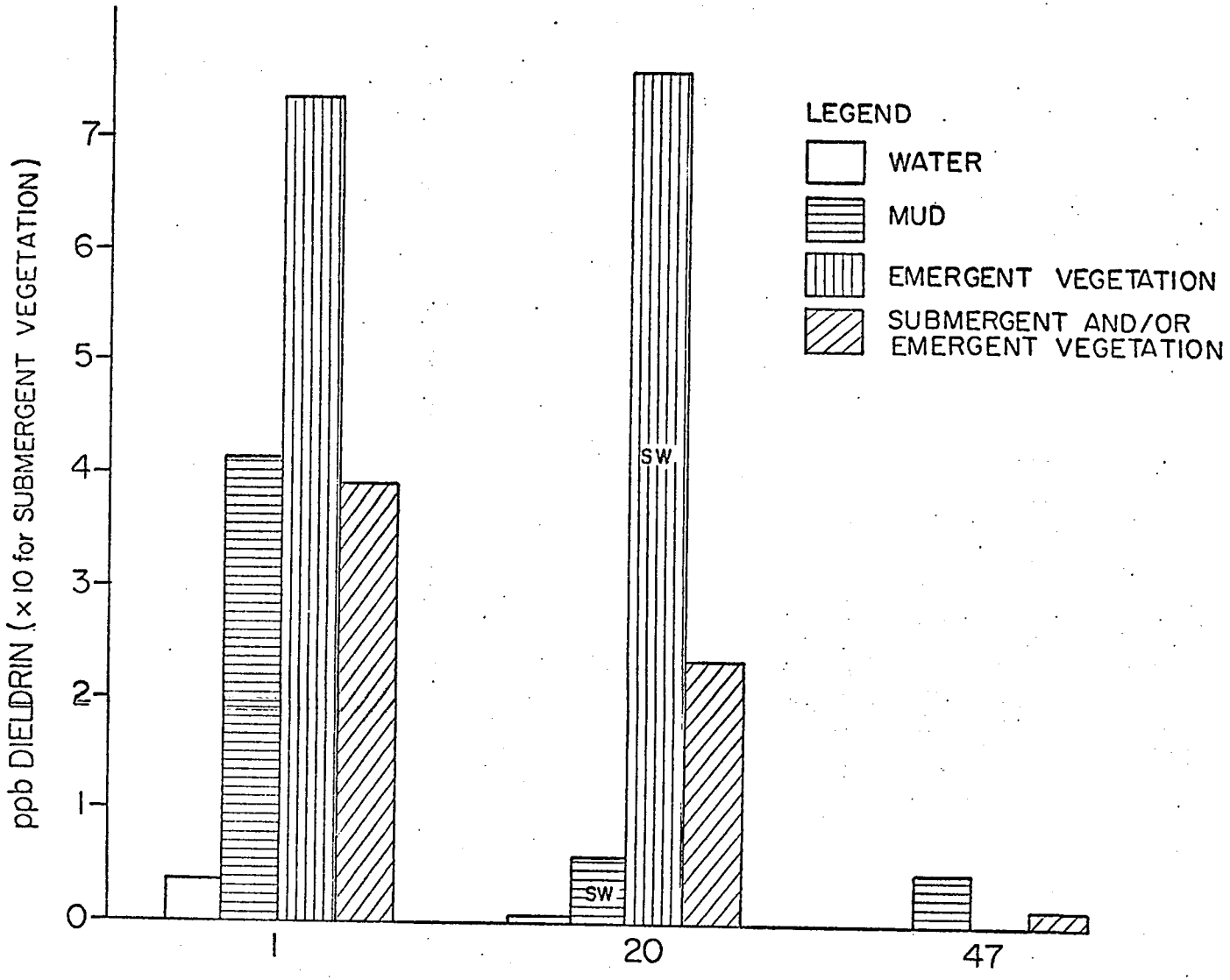
LEGEND
WATER
MUD
EMERGENT VEGETATION
SUBMERGENT AND/OR EMERGENT VEGETATION
ppb DIELDRIN (x 10 for SUBMERGENT VEGETATION)
0
1
2
3
4
5
6
7
SW
SW
1
20
47
DAYS AFTER APPLICATION

Figure 4

Table 7. Decline of chlorinated hydrocarbon pesticide residues in submergent and emergent vegetation of studies cited

| Reference | Type of Vegetation Sub. | Em. | Maximum Concentration (ppm) | Time to Maximum Concentration | Time until Residues Undetectable |
|---|---|---|---|---|---|
| Bridges (1961) | + | | 0.55 | 16 days* | 44 to 53 days |
| Bridges *et al.* (1963) | + | | 30.7 | 30 minutes | Study terminated after 12 months; level: 0.6 ppm (pre-treatment level: 0.8 ppm). Therefore, 8 weeks to 12 months. |
| Croker and Wilson (1965) | + | | 75.0 | 3 to 4 weeks | No samples taken after 7 weeks; level: 9.1 ppm. |
| Meeks (1968)Ψ | + | | 96.1 (*Cladophora* sp.) | 3 days† | Study terminated 15 months; level: 0.1 ppm. |
| | | + | 11.4 (*Sagittaria latifolia* Willd.) | 1 day | Study terminated 15 months; level: 0.1 ppm. |

* No vegetation samples taken until 16 days after endrin applied.

† Sample not taken until 3 days after application.

Ψ See discussion in text.

Table 7. (Continued)

| Reference | Type of Vegetation Sub. | Em. | Maximum Concentration (ppm) | Time to Maximum Concentration | Time until Residues Undetectable |
|---|---|---|---|---|---|
| this study | + | | 0.0408 | 1 day | 47 to 323 days |
| | | + | 0.0075 | 1 day | 20 to 47 days |

time (see Table 8). Bridges *et al.* (1963) and Meeks (1968) continued to detect residue levels in submergent and emergent vegetation in the year following application whereas I did not. This could be a function of the low initial concentration of my study. As in Meeks (1968), submergent vegetation of my study had higher levels of residues than emergent. This is a function of the surface area available for the pesticides to be adsorbed (Meeks and Peterle, 1967). Among the studies, "Time to Maximum Concentration" varies but indications are that it occurs within the first day after application. Also, there are indications that the higher initial concentrations persist longer than the lower ones.

c) Invertebrates. The analysis of invertebrates was started with the Gastropoda and the sample size was arbitrarily set at 2.00 g of gastropod tissue. After having realized that dieldrin was present in the gastropod tissue in the year following application (unlike mud, water, and vegetation) and that it was thus likely to be present in other invertebrates as well, the weight of the invertebrate samples was increased by pooling specimens (usually from each quarter) whenever necessary and possible. In such instances, attempts were made to keep lower ranking taxa separate but where it was obvious that it would be impossible to detect any residue unless a larger sample was used, lower taxa were combined. Primary and secondary consumers were kept separate. Generally there was insufficient invertebrate material for replication. Confidence limits for the samples which were replicated are given in Table 22. Points on each of the graphs (Figs. 5 to 11) are single or mean values. The former are unmarked; the latter

Table 8. Dieldrin concentrations (ppb) in vegetation of D slough

| Days after Application | Emergent (quarter) | | | | Submergent (quarter) | | | | Floating (quarter) | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | SW | SE | NW | NE | SW | SE | NW | NE | SW | SE | NW | NE |
| 1 | 4.03 | 12.81† | 4.57 | 5.54, 10.59 | | 41.24 | 32.55, 58.23* | | 51.25 | | | 18.11 |
| 20 | 7.60 | <el Ψ | <el | <el | | 21.36 | 19.61 | | 23.68 | | | 29.76 |
| 47 | <el | <el | <el | <el | 0.49 | | | 0.91 | | 2.78 | 2.65 | |

* Solid underlining = confirmed with boron trifluoride etherate.

† Broken underlining = boron trifluoride etherate conversion unclear because of excessively dirty sample or sample with insufficient dieldrin for confirmatory procedure.

Ψ Below experimental limits of detection.

carry the notation "$\bar{x}$". Individual values composing each mean are given in the table that accompanies each graph. Since recoveries were close to 100% none of the dieldrin concentrations that appear in the tables or graphs have been corrected.

(1) Zooplankton (Table 9; Fig. 5). The samples analyzed were composed mainly of *Daphnia* sp., *Diaptomus* sp., and *Cyclops* sp.

In order to have a sufficient weight of dieldrin for microcoulometric confirmation, the plankton samples from 349 and 376 days after application (July 4 and 31, 1968) and 424 days after application (September 17, 1968) were combined.

Dieldrin concentrations in zooplankton were at a maximum on the day after treatment and thereafter they declined steadily (Table 9, Fig. 5). The initial concentration of dieldrin was the highest recorded for any ecosystem constituent for the study. Crosby and Tucker (1971) reported accumulations of DDT from dilute suspensions in water of 16,000 to 23,000 times by *Daphnia magna* Strauss. Wojtalik *et al.* (1971) reported very high uptake of 2, 4-D by plankters; and Johnson *et al.* (1971) reported the rapid direct uptake of aldrin and DDT from water by the freshwater invertebrates of his study and that *D. magna* and *Culex pipiens* L. showed the greatest degree of magnification. The relative insolubility of chlorinated hydrocarbon insecticides causes them to move directly to organic matter as soon as they are applied to water (Dustman and Stickel, 1969; Edwards, 1970; Muirhead-Thomson, 1971; and Cope, 1971) and it has been shown that these hydrophobic compounds adhere to suspended organic particles in the water (Nicholson, 1967; Stickel, 1968; Wurster, 1969; and Edwards, 1970). Reinert (1967) showed that *Daphnia* accumulate more

Table 9. Dieldrin concentrations in zooplankton of D slough

| Days after Application | Sample & Size (g) | Dieldrin Concentration (ppb) | Confirmation | |
|---|---|---|---|---|
| | | | Microcoulometric | Boron Trifluoride Etherate |
| 2 | 0.16 | 362.88 | | |
| 21 | 2.45 | 41.55 | positive | positive |
| 48 | #1 2.04 | 24.84 | | |
| | 2 3.06 | 41.31 | positive | |
| 349 | 0.84 | 5.14 | positive | |
| 376 | 0.52 | 6.65 | positive | |
| 424 | 1.17 | 5.27 | positive | |

Figure 5. Decline of dieldrin in zooplankton of D slough during the study period

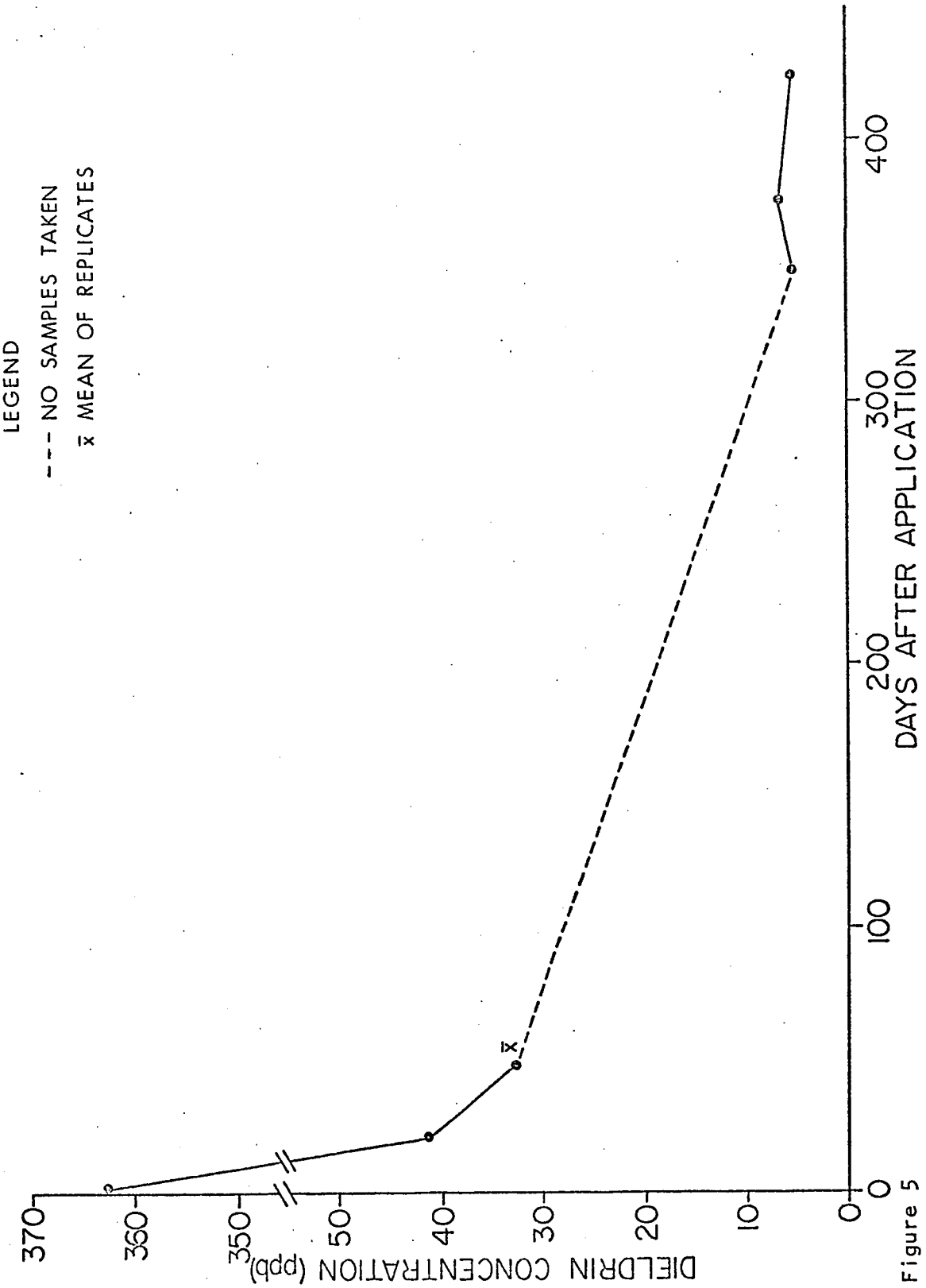
LEGEND
--- NO SAMPLES TAKEN
x̄ MEAN OF REPLICATES
DIELDRIN CONCENTRATION (ppb)
370
360
350
50
40
30
20
10
0
0
100
200
300
400
DAYS AFTER APPLICATION
x̄

Figure 5

dieldrin from water than from food. Plankton, therefore, merely serve as immediately accessible suspended organic particles to which chlorinated hydrocarbons move directly when applied to water. In fact, because of lipid content, plankton may be preferential to other organic seston (Cope, 1971; see also Kawatski and Schmulbach, 1971).

(ii) Gastropoda (Table 10; Fig. 6). Residues in *L. stagnalis* samples numbers 3 and 4 for 348 and 349 days after application (July 3 and 4, 1968), and numbers 2 to 4 and 6 to 8 for 424 days after application (September 17, 1968); and the *L. elodes* sample for 424 days after application had no detectable residues because an insufficient weight of snail tissue was originally used for extraction and cleanup. Therefore, Fig. 6 does not include these samples.

*L. stagnalis* and *L. elodes* individuals for 313 days after application (May 29, 1968) were combined to get sufficient tissue for residue analysis.

Only one individual of *L. stagnalis* in sample number 1 and two in number 2 for 48 days after application (September 7, 1967) were analyzed. It is likely that the great difference in residue concentrations between these two samples was due to a difference between individual snails and this suggests why the confidence limits shown in Table 22 can be so wide. Variability in determinations of pesticide residues is discussed by Anderson and Fenderson (1970), Taylor, Freeman, and Edwards (1971), and Frere (1971).

The negative confirmation for *L. stagnalis* sample number 2 for 348 and 349 days after application and *H. trivolvis* for 424 days after application was due to the injection of an insufficient volume

Table 10. Dieldrin concentrations in Gastropoda of D Slough

| Days after Application | Species | Sample & Size (g)* | Dieldrin Concentration (ppb) | MC** | Confirmation SE30† | Confirmation $BF_3$ Etherate |
|---|---|---|---|---|---|---|
| 2 | *L. stagnalis* | #1 (SW) 2.00 | 105.39 | positive | | |
| | | 2 (SW) 2.01 | 114.92 | | | |
| | | 3 (SE) 2.01 | 111.23 | positive | | |
| | | 4 (SE) 2.01 | 121.62 | | | |
| | | 5 (NW) 2.00 | 162.31 | | | |
| | | 6 (NW) 2.00 | 193.90 | positive | | |
| | | 7 (NE) 2.01 | 198.27 | positive | | |
| | | 8 (NE) 2.01 | 200.18 | | | |
| 21 | *L. stagnalis* | #1 (SW) 2.00 | 99.01 | | | |
| | | 2 (SE) 2.01 | 120.28 | positive | | |
| | | 3 (NW) 2.01 | 120.37 | | | |
| | *L. elodes* | (NW) 1.33 | 47.37 | | positive | |
| | *H. trivolvis* | (SW) 0.69 | 51.82 | | | |
| 48 | *L. stagnalis* | #1 (SE) 0.29 | 145.47 | | | |

Table 10. (Continued)

| Days after Application | Species | Sample & Size (g)* | Dieldrin Concentration (ppb) | MC** | Confirmation SE30† | Confirmation $BF_3$ Etherate |
|---|---|---|---|---|---|---|
| | | 2 (NW) 1.43 | 10.49 | | positive | |
| 313 | *L. stagnalis* | (SW, NW, | | | | |
| | *& L. elodes* | & NE) 1.71 | 35.24 | positive | | |
| 348 | | | | | | |
| & 349 | *L. stagnalis* | #1 (NE) 6.64 | 22.31 | positive | | positive |
| | | 2 (NE) 2.01 | 4.98 | negative | | |
| | | 3 (NE) 2.00 | <el Ψ | negative | | |
| | | 4 (NE) 2.01 | <el | negative | | |
| 376 | *L. stagnalis* | (NE) 3.50 | 10.64 | | | |
| | *L. elodes* | (NE) 4.13 | 9.41 | | | |
| | *H. trivolvis* | (SW & NE) | | | | |
| | | 3.81 | 5.03 | | | |
| 424 | *L. stagnalis* | #1 (SE) 5.91 | 4.02 | | | |
| | | 2 (SE) 2.00 | <el | | | |

Table 10. (Continued)

| Days after Application | Species | Sample & Size (g)* | Dieldrin Concentration (ppb) | MC** | Confirmation SE30† | Confirmation $BF_3$ Etherate |
|---|---|---|---|---|---|---|
| | | 3 (SE) 2.00 | <el | | | |
| | | 4 (SE) 2.00 | <el | | | |
| | | 5 (NW) 5.03 | 6.80 | positive | | |
| | | 6 (NW) 2.01 | <el | | | |
| | | 7 (NW) 2.01 | <el | | | |
| | | 8 (NW) 2.00 | <el | | | |
| | *L. elodes* | (SW & NE) | | | | |
| | | 2.02 | <el | | | |
| | *H. trivolvis* | (SW) 2.01 | 2.07 | negative | | |

* Quarter of slough given in brackets.

** Microcoulometric.

† Varian Aerograph 2100 using 3% SE-30 on 100/120 mesh Aeropak 30 column packing.

Ψ Below experimental limits of detection.

Figure 6. Decline of dieldrin in Gastropoda of D slough during the study period

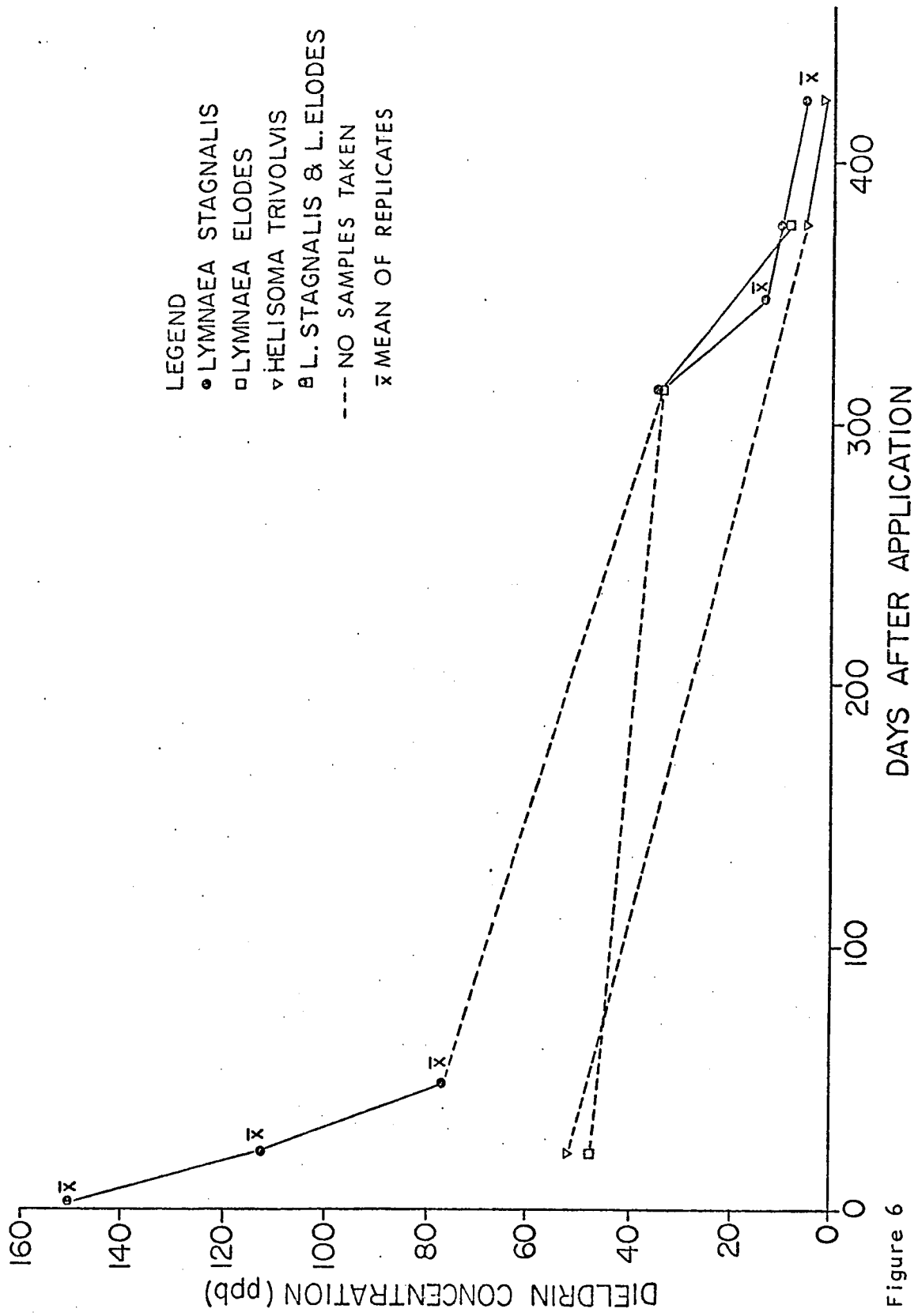
LEGEND
LYMNAEA STAGNALIS
LYMNAEA ELODES
HELISOMA TRIVOLVIS
L. STAGNALIS & L. ELODES
NO SAMPLES TAKEN
MEAN OF REPLICATES
DIELDRIN CONCENTRATION (ppb)
160
140
120
100
80
60
40
20
0
0
100
200
300
400
DAYS AFTER APPLICATION

Figure 6

of sample (and hence weight of dieldrin) into the microcoulometric apparatus.

Residues in the planorbids and *Lymnaea* sp. of Meeks' (1968) study reached a maximum concentration one and three days respectively after application of the DDT-$Cl^{36}$. The snails of my study reached maximum observed residue concentrations on the first sampling date, which was two days after application. Maximum concentrations in Meeks' study were among the lowest of all the invertebrates. Those of the *L. stagnalis* of my study were second only to the zooplankton. I used only soft tissues for analysis whereas Meeks probably used the whole body. Meeks subsequently separately analyzed whole bodies, soft tissues, and shells of the planorbid snails and found that the soft tissues had the highest residues whereas the shells had none. Because the shell is such a large percentage of the total weight, the concentrations reported by Meeks are likely underestimates. Meeks reported the presence of residues in both kinds of snails at the end of the study (13 months after application). Levels were still detectable in *L. stagnalis* and *H. trivolvis* at the end of my study (approximately 14 months after application).

Uptake and metabolism of DDT, DDE, DDD, and methoxychlor by *Physa* sp. in a model ecosystem is discussed by Metcalf, Sangha, and Kapoor (1971). Total concentrations of these chlorinated hydrocarbons were usually higher in snails than in larval *Culex pipiens quinquefasciatus* Say.

(iii) Hemiptera (Tables 11 and 12; Fig. 7). Residues in notonectids of Meeks' (1968) study were at a maximum one week after application whereas in my study, maximum concentrations were reached

Table 11. Dieldrin concentrations in Corixidae of D slough

| Days after Application | Species or Group | Sample Size (g)* | Dieldrin Concentration (ppb) | Confirmation MC** | SE30† | $BF_3$ Etherate |
|---|---|---|---|---|---|---|
| 2 | *C. audeni* | #1 (SW & NW) | | | | |
| | | 2.00 | 51.37 | | positive | |
| | | 2 (SW & NW) | | | | |
| | | 2.00 | 55.45 | | positive | |
| | | 3 (SE) 2.00 | 182.81 | | positive | |
| | | 4 (SE) 2.00 | 156.58 | | | |
| 21 | 4 species†† | (SW, SE, | | | | |
| | | & NW) 1.14 | 35.66 | | | |
| 48 | *C. audeni* | #1 (SW & NW) | | | | |
| | | 2.39 | 11.99 | positive | | |
| | | 2 (SE) 1.94 | 18.44 | | | positive |
| 313 | *C. audeni* | 0.58 | <el Ψ | | | |
| 349 | immatures | 1.96 | <el | | | |
| | *C. audeni* | 3.79 | <el | | | |

Table 11. (Continued)

| Days after Application | Species or Group | Sample Size (g)* | Dieldrin Concentration (ppb) | Confirmation MC** | SE30† | $BF_3$ Etherate |
|---|---|---|---|---|---|---|
| 376 | *C. audeni* | #1 1.96 | <el$^{\Psi}$ | | | |
| | | 2 3.20 | <el | | | |
| 424 | *C. audeni* | #1 (SE) 2.52 | <el | | | |
| | | 2 (NW) 2.87 | <el | | | |

* Quarter of slough given in brackets.

** Microcoulometric.

† Varian Aerograph 2100 using 3% SE-30 on 100/120 mesh Aeropak 30 column packing.

$^{\Psi}$ Below experimental limits of detection.

†† *C. audeni*, *C. alaskensis*, *H. atopodonta*, *S. decoratella*.

Table 12. Dieldrin concentrations in *Notonecta undulata* of D slough

| Days after Application | Life Stage | Sample & Size (g) | Dieldrin Concentration (ppb) | MC* | Confirmation $BF_3$ Etherate |
|---|---|---|---|---|---|
| 2 | adults | 2.63 | 88.42 | positive | positive |
| 21 | adults | 2.40 | 45.27 | | |
| 48 | adults | 0.38 | 37.11 | | |
| 376 | adults | 2.57 | <el[Ψ] | negative | |
| 424 | adults | 0.39 | <el | | |
| 376 | Immatures | #1 3.18 | 2.17 | | |
| | | 2 2.42 | 1.62 | | |

* Microcoulometric.

Ψ Below experimental limits of detection.

Figure 7. Decline of dieldrin in Hemiptera of D slough during the study period

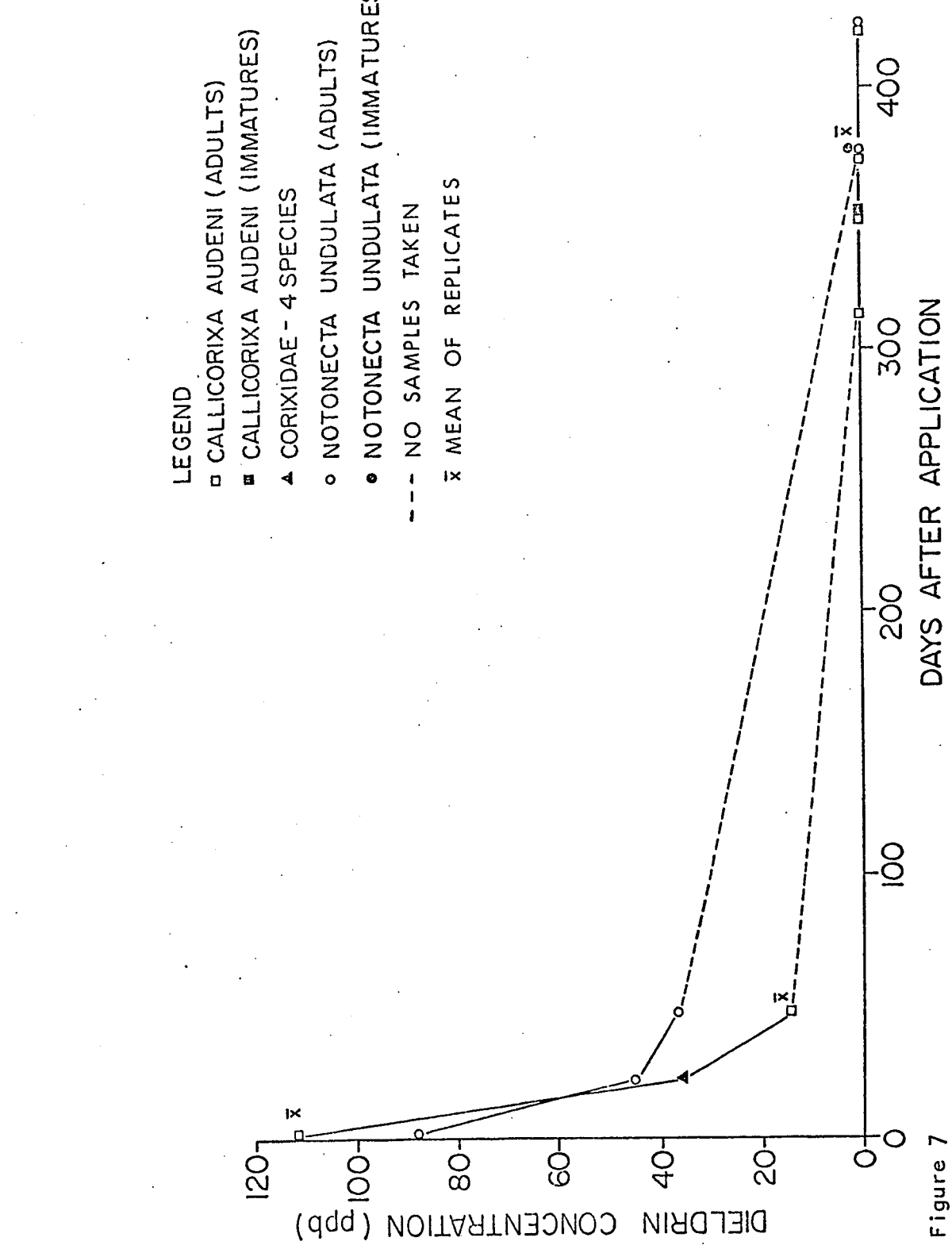
LEGEND
□ CALLICORIXA AUDENI (ADULTS)
■ CALLICORIXA AUDENI (IMMATURES)
▲ CORIXIDAE - 4 SPECIES
○ NOTONECTA UNDULATA (ADULTS)
● NOTONECTA UNDULATA (IMMATURES)
--- NO SAMPLES TAKEN
x̄ MEAN OF REPLICATES
DIELDRIN CONCENTRATION (ppb)
120
100
80
60
40
20
0
0
100
200
300
400
DAYS AFTER APPLICATION

Figure 7

in adults on the second day after application.

Residues were below detectable levels in the immature corixids 349 days after application (July 4, 1968) probably because the sample used was too small. The larger sample of *N. undulata* immatures 376 days after application (July 31, 1968) gave positive results. However, the absence of detectable levels of dieldrin in adult *C. audeni* and *N. undulata* in 1968 probably reflects a true absence because some of the samples analyzed were relatively quite large (see Table 11, 349 days after application; and Table 12, 376 days after application). Adult corixids and notonectids are capable of leaving and entering habitats and so the absence of detectable dieldrin in 1968 is not surprising. Meeks (1968) recorded no residue levels in the notonectid samples he studied in the second and twelfth months after application, and a relatively low level in the thirteenth month. Unfortunately, Meeks did not indicate whether the notonectids were adults or immatures. Because adult corixids and notonectids are capable of transience, their reliability as indicators of pesticide levels in habitats is questionable.

(iv) Chironomidae (Table 13; Fig. 8). Genera of chironomid larvae usually had to be combined to get sufficient tissue for residue analysis. Nevertheless, primary and secondary consumers were kept separate. No levels were detected in the secondary consumers probably because sample size was too small.

Analyses on samples from 6 and 13 days after application (July 27, 1967 and August 3, 1967) were done considerably after the rest of the analyses. The mean value fits the slope of the curve well (Fig. 8).

Table 13. Dieldrin concentrations in larval Chironomidae of D slough

| Days after Application | Genus | Sample Size (g) | Dieldrin Concentration (ppb) | MC* | Confirmation $BF_3$ Etherate |
|---|---|---|---|---|---|
| | Primary consumers: | | | | |
| 2 | *Chironomus* | 0.84 | 44.13 | positive | positive |
| 6 & 13** | 5 genera† | 0.81 | 64.45 | | positive |
| 21 | 7 genera†† | 0.10 | 82.75 | | |
| 48 | 5 genera††† | 0.21 | 34.24 | | |
| 313 | *Chironomus* | 1.44 | 9.84 | | |
| 343 | *Chironomus* | 6.05 | 11.86 | positive | |
| 349 | *Chironomus* & *Glyptotendipes* | 1.80 | 5.10 | | |
| 362 | *Chironomus* & *Glyptotendipes* | 2.66 | 7.64 | | |
| 376 | *Chironomus* | 2.23 | 4.99 | | |
| | *Glyptotendipes* | 5.61 | 6.89 | positive | |
| 378 | *Chironomus* | 4.40 | 6.67 | | |

Table 13. (Continued)

| Days after Application | Genus | Sample Size (g) | Dieldrin Concentration (ppb) | Confirmation MC* | Confirmation $BF_3$ Etherate |
|---|---|---|---|---|---|
| 390 | *Chironomus* | 3.32 | 4.26 | | |
| 424 | *Glyptotendipes* | 4.51 | 2.95 | | |
| | Secondary consumers: | | | | |
| 313 | *Psectrotanypus* | 0.07 | <el[Ψ] | | |
| 349 | *Psectrotanypus* | 0.44 | <el | | |
| 376 | *Psectrotanypus* | 0.11 | <el | | |
| 424 | *Psectrotanypus* | 0.39 | <el | | |

* Microcoulometric.

** These two dates were combined.

† *Chironomus*, *Dicrotendipes*, *Einfeldia pagana* & *pectoralis* grps., *Glyptotendipes*, *Paratanytarsus*.

†† *Acricotopus*, *Chironomus*, *Glyptotendipes*, *Parachironomus*, *Cricotopus* ("*Paratrichocladius*" type), *Psectrocladius*, unidentified Orthocladiinae genus.

††† *Chironomus*, *Dicrotendipes*, *Endochironomus*, *Glyptotendipes*, *Psectrocladius*.

Ψ Below experimental limits of detection.

Figure 8. Decline of dieldrin in larval Chironomidae (primary consumers) of D slough during the study period

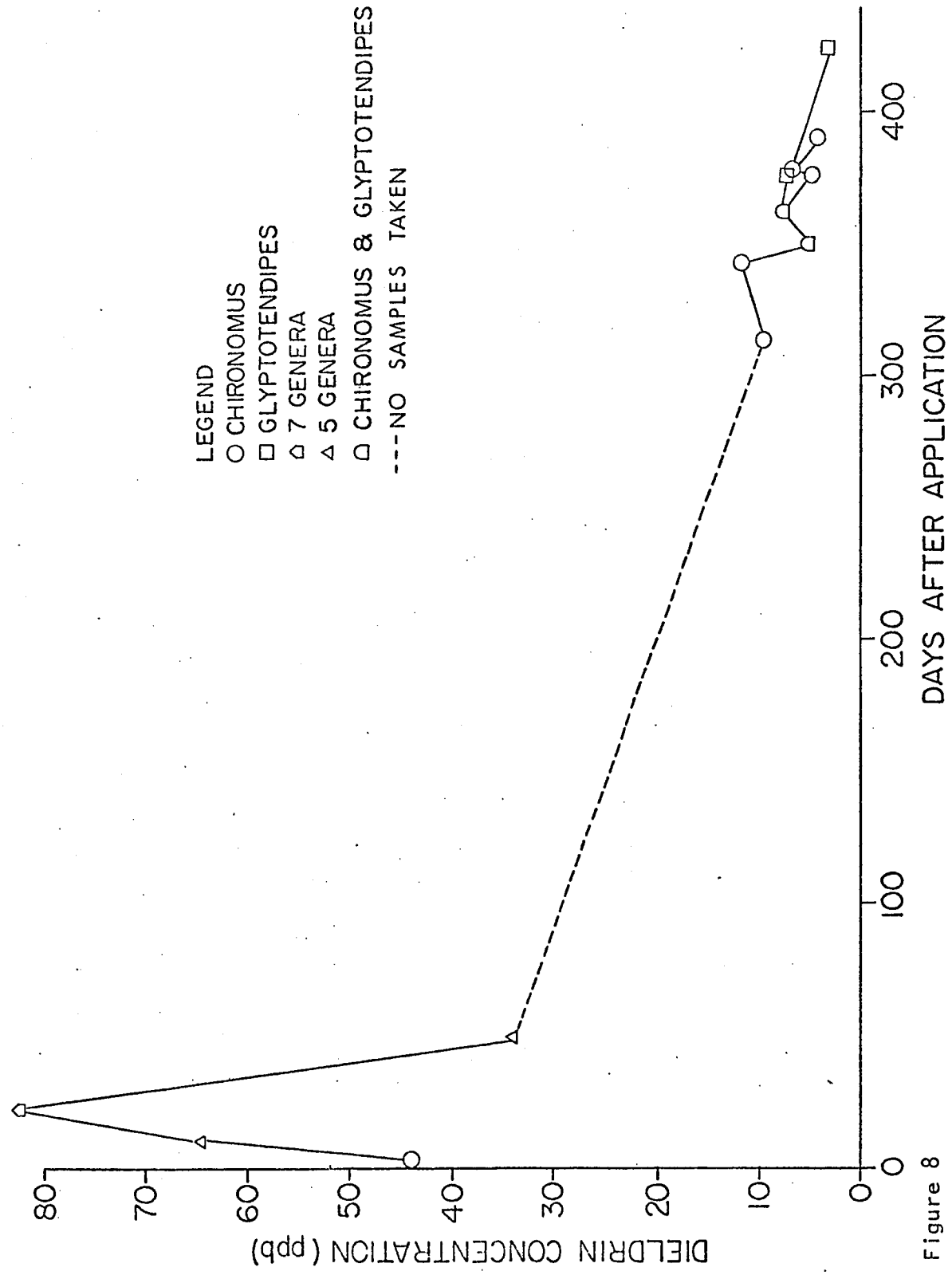
LEGEND
○ CHIRONOMUS
□ GLYPTOTENDIPES
△ 7 GENERA
▲ 5 GENERA
□ CHIRONOMUS & GLYPTOTENDIPES
---NO SAMPLES TAKEN
DIELDRIN CONCENTRATION (ppb)
0
10
20
30
40
50
60
70
80
0
100
200
300
400
DAYS AFTER APPLICATION

Figure 8

The maximum concentration of residues in the bloodworm (*Tendipes* sp.) of Meeks' (1968) study was reached one week after application. In my study, maximum concentration was reached in three weeks. This delay is also shown by the Libellulidae, *Aeshna interrupta*, and adult Dytiscidae of my study (see below).

Uptake and concentration of aldrin and DDT from water by *Chironomus* sp. larvae in the laboratory is discussed by Johnson *et al.* (1971).

Unfortunately, analysis of chironomids in Meeks (1968) was ended one month after application. The residues in the chironomid primary consumers of my study were still present at the end of the study (approximately 14 months after application).

(v) Hirudinea (Tables 14 and 15; Fig. 9). The sample for 349 days after application (July 4, 1968) was too small to yield a detectable dieldrin level (see Fig. 9). The Erpobdellidae and Glossiphoniidae for 424 days after application (September 17, 1968) were combined because samples of each were too small for individual analysis.

Meeks (1968) analyzed *Erpobdella punctata*, a species present in D slough and used in my analyses of residues (see Table 15). Meeks reported that a maximum concentration of residue was reached two weeks after application of the pesticide and that *E. punctata* had the highest residues of all the invertebrates analyzed. Maximum residue concentrations were reached in the leeches of my study three weeks after application, the first date after application that leeches could be collected. The Erpobdellidae, the family to which *E. punctata* belongs, had lower residue levels in general than the Glossi-

Table 14. Dieldrin concentrations in Hirudinea of D slough

| Days after Application | Family | Sample Size (g)* | Dieldrin Concentration (ppb) | Confirmation MC** | Confirmation $BF_3$ Etherate |
|---|---|---|---|---|---|
| 21 | Erpobdellidae | (SW) 0.72 | 71.41 | positive | |
| | Glossiphoniidae | (NW) 0.39 | 131.42 | | |
| 48 | Erpobdellidae | (SE & NW) 1.36 | 46.65 | | positive† |
| | Glossiphoniidae | (SW & NW) 1.39 | 58.11 | positive | positive |
| 349 | Glossiphoniidae | (SE & NW) 0.28 | <e1Ψ | | |
| 376 | Glossiphoniidae | (SW & NE) 1.92 | 4.56 | | |
| 424 | Erpobdellidae & Glossiphoniidae | (SE & NW) 3.84 | 3.73 | | |

* Quarter of slough given in brackets.

** Microcoulometric.

† Unclear.

Ψ Below experimental limits of detection.

Table 15. Species of Hirudinea used in gas chromatographic analyses of dieldrin concentrations in D slough

| Days after Application | Family | Species in Sample |
|---|---|---|
| 21 | Erpobdellidae | *E. punctata*, *M. fervida* |
| | Glossiphoniidae | *G. complanata*, *H. fusca*, *H. stagnalis*, *Theromyzon* sp. |
| 48 | Erpobdellidae | *E. punctata*, *M. fervida* |
| | Glossiphoniidae | *G. complanata*, *H. fusca*, *Theromyzon* sp. |
| 349 | Glossiphoniidae | *G. complanata*, *H. fusca*, *O. lucida*, *Theromyzon* sp. |
| 376 | Glossiphoniidae | *G. complanata*, *H. fusca*, *O. lucida*, *Theromyzon* sp. |
| 424 | Erpobdellidae & | *M. fervida* |
| | Glossiphoniidae | *G. complanata*, *H. fusca*, *H. stagnalis*, *O. lucida*, *Theromyzon* sp. |

Figure 9. Decline of dieldrin in Hirudinea of D slough during the study period

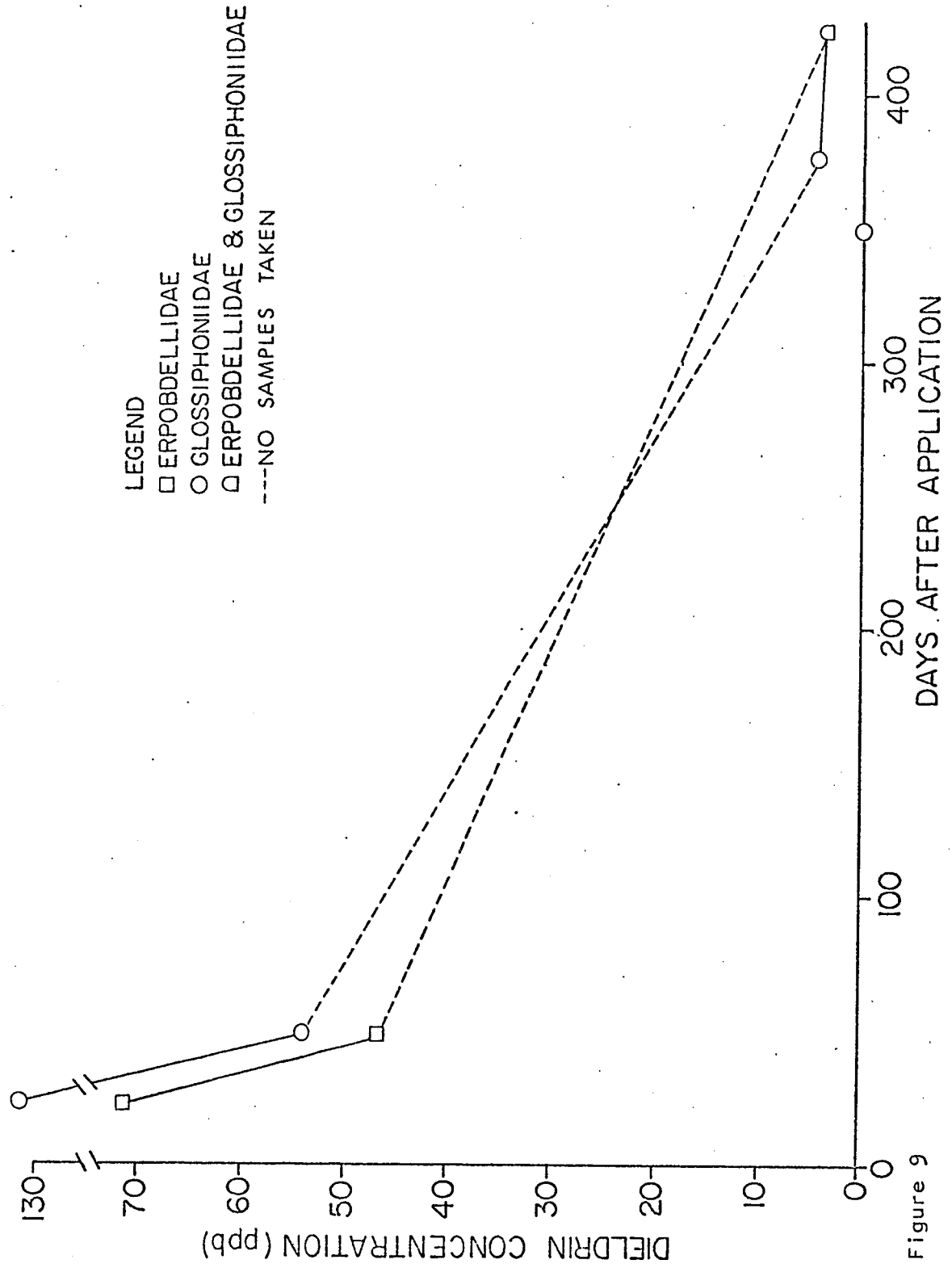
LEGEND
□ ERPOBDELLIDAE
○ GLOSSIPHONIIDAE
Δ ERPOBDELLIDAE & GLOSSIPHONIIDAE
---NO SAMPLES TAKEN
DIELDRIN CONCENTRATION (ppb)
130
70
60
50
40
30
20
10
0
0
100
200
300
400
DAYS AFTER APPLICATION

Figure 9

phoniidae and the leeches of my study did not have the highest residues of the invertebrates. (Absorption of DDT by two species of leeches not present in D slough is discussed by Kimura, Keegan, and Haberkorn, 1967).

Residues were still present in leeches of both studies when the studies were terminated (Meeks'--15 months; and mine--approximately 14 months after application).

(vi) Odonata (Tables 16, 17, and 18; Fig. 10). In Fig. 10, the Zygoptera are all *Enallagma-Coenagrion* except for:

1. 2 days after application: the highest value is for *L. congener*, the lowest is for *L. disjunctus*.

2. 21 days after application: the lowest value is for *L. congener*.

3. 349 days after application: the sample was a composite of Lestidae and Coenagrionidae.

Points used on the graph for 2 and 21 days are overall means.

Names of Zygoptera and Libellulidae used in gas chromatographic analyses for each date are given in Tables 17 and 18.

Residues in the Anisoptera and Zygoptera larvae of Meeks' (1968) study reached maximum concentrations one week after pesticide application whereas in my study, maximum concentrations were detected in Anisoptera in three weeks and in Zygoptera in two days. Residues were still present in the Odonata at the termination of both studies (Meeks'--13 months; and mine--14 months after application).

Laboratory studies on the uptake and concentration of DDT from water by Anisoptera have been done by Johnson *et al.* (1971), and Wilkes and Weiss (1971); and on Zygoptera by Johnson *et al.* (1971).

Table 16. Dieldrin concentrations in larval Odonata of D slough

| Days after Application | Sample Size (g)* | Dieldrin Concentration (ppb) | Confirmation $BF_3$ Etherate |
|---|---|---|---|
| | A. *Aeshna interrupta* | | |
| 2 | 1.26 | 10.36 | |
| 21 | 1.34 | 36.37 | positive |
| 48 | 1.12 | 8.89 | |
| 313 | 1.95 | 2.63 | |
| 349 | 4.26 | 3.95 | positive |
| 376 | 1.06 | 3.15 | |
| | B. Libellulidae | | |
| 2 | (NW, SW, & SE) 2.12 | 82.83 | |
| 21 | (NW & SE) 1.13 | 87.17 | positive |
| 48 | (NW) 0.94 | 8.15 | |
| 349 | (NW & SE) 3.25 | 4.09 | |
| 376 | (NE & SW) 1.34 | 4.38 | |

Table 16. (Continued)

| Days after Application | Taxon | Sample & Size (g)* | Dieldrin Concentration (ppb) | Confirmation $BF_3$ Etherate |
|---|---|---|---|---|
| | | C. Zygoptera | | |
| 2 | *L. congener* | #1 (SE & SW) 1.81 | 56.76 | |
| | | 2 (NW) 2.51 | 45.30 | positive |
| | | 3 (NW) 2.79 | 32.08 | |
| | *L. disjunctus* | (NW & SE) 1.09 | 32.13 | |
| | *Enallagma-* | | | |
| | *Coenagrion* | (NW, SE, & SW) 0.29 | 35.04 | |
| 21 | *L. congener* | (NW, SE, & SW) 0.90 | 9.31 | |
| | *Enallagma-* | | | |
| | *Coenagrion* | (NW, SE, & SW) 2.14 | 22.45 | |
| 48 | *Enallagma-* | | | |
| | *Coenagrion* | (NW, SE, & SW) 4.09 | 8.23 | |
| 313 | *Enallagma-* | | | |
| | *Coenagrion* | (NW, NE, & SW) 3.26 | 1.91 | |

Table 16. (Continued)

| Days after Application | Taxon | Sample & Size (g)* | Dieldrin Concentration (ppb) | Confirmation $BF_3$ Etherate |
|---|---|---|---|---|
| 349 | mixture | (NW & SE) 1.58 | 0.68 | |
| 376 | *Enallagma-* | | | |
| | *Coenagrion* | (NE & SW) 0.59 | 7.57 | |
| 424 | *Enallagma-* | | | |
| | *Coenagrion* | (NW & SE) 1.37 | 1.83 | |

* Quarter of slough given in brackets.

Table 17. Species of Libellulidae used in gas chromatographic analyses of dieldrin concentrations in D slough

| Days after Application | Species in Sample |
|---|---|
| 2 | *L. intacta*, *S. costiferum*, *S. internum* |
| 21 | *L. intacta*, *S. costiferum*, *S. internum* |
| 48 | *L. intacta* |
| 349 | *S. costiferum* |
| 376 | *S. costiferum* |

Table 18. Species of Zygoptera used in gas chromatographic analyses of dieldrin concentrations in D slough

| Days after Application | Taxon | Species in Sample |
|---|---|---|
| 2 | *Enallagma-Coenagrion* | *C. angulatum*, *C. resolutum*, *E. cyathigerum*, *E. hageni*, *Enallagma-Coenagrion* |
| 21 | *Enallagma-Coenagrion* | *C. angulatum*, *C. resolutum*, *E. cyathigerum*, *E. hageni*, *Enallagma-Coenagrion* |
| 48 | *Enallagma-Coenagrion* | *C. angulatum*, *C. resolutum*, *E. civile*, *E. cyathigerum*, *E. hageni*, *C. resolutum-E. cyathigerum*, *Enallagma-Coenagrion* |
| 313 | *Enallagma-Coenagrion* | *C. angulatum*, *C. resolutum*, *E. civile*, *E. cyathigerum*, *C. resolutum-E. cyathigerum*, *Enallagma-Coenagrion* |
| 349 | Zygoptera | Lestidae: *L. congener*, *L. disjunctus* Coenagrionidae: *C. angulatum*, *C. resolutum*, *E. civile*, *E. cyathigerum*, *C. resolutum-E. cyathigerum*, *Enallagma-Coenagrion* |

Table 18. (Continued)

| Days after Application | Taxon | Species in Sample |
|---|---|---|
| 376 | *Enallagma-Coenagrion* | *C. angulatum, C. resolutum, E. cyathigerum, C. resolutum-E. cyathigerum, Enallagma-Coenagrion* |
| 424 | *Enallagma-Coenagrion* | *C. angulatum, C. resolutum, E. cyathigerum, E. hageni, C. resolutum-E. cyathigerum, Enallagma-Coenagrion* |

Figure 10. Decline of dieldrin in larval Odonata of D slough during the study period

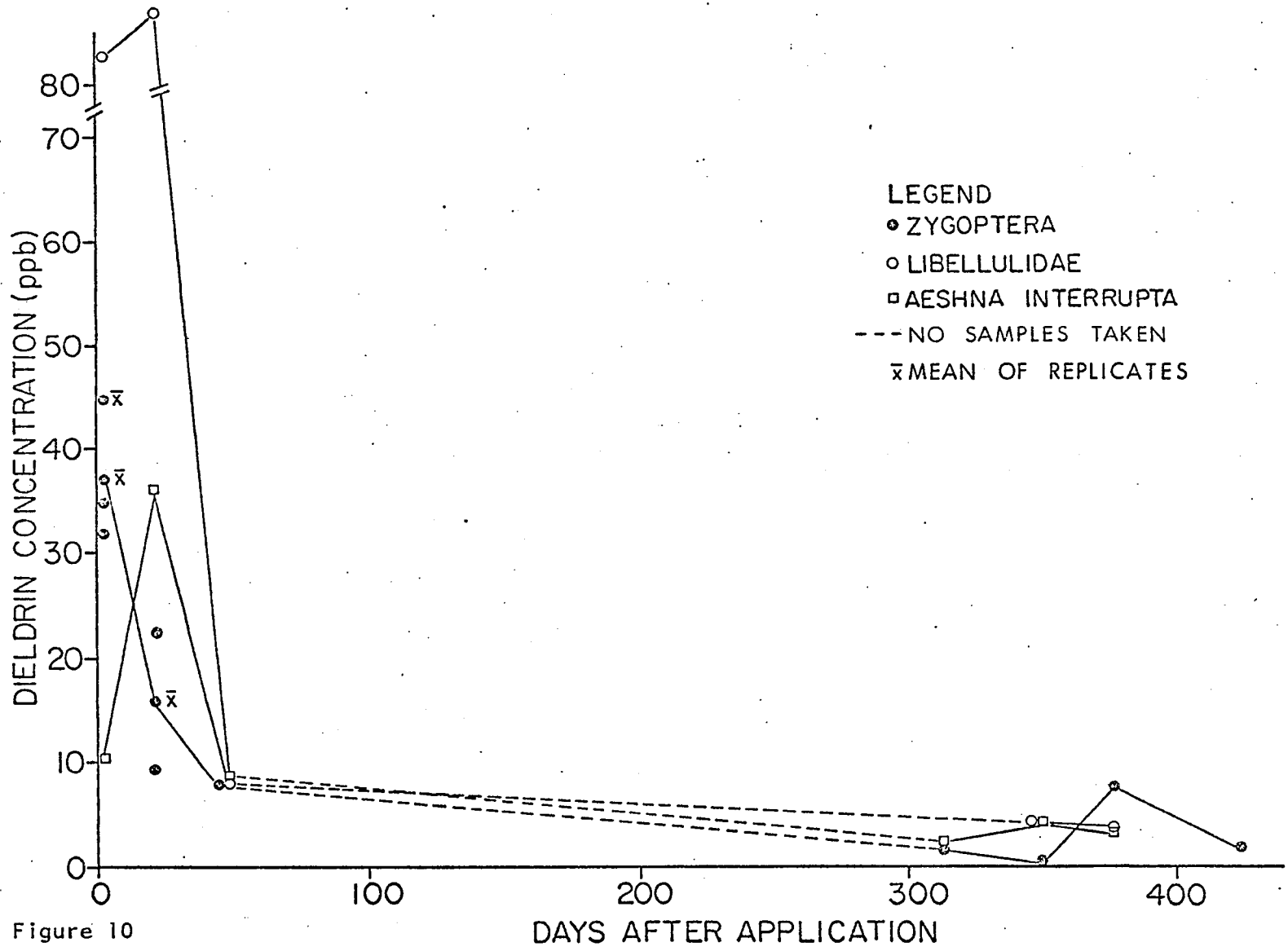
DIELDRIN CONCENTRATION (ppb)
80
70
60
50
40
30
20
10
0
0
100
200
300
400
DAYS AFTER APPLICATION
LEGEND
ZYGOPTERA
LIBELLULIDAE
AESHNA INTERRUPTA
NO SAMPLES TAKEN
MEAN OF REPLICATES

Figure 10

Uptake and concentration of toxaphene by Zygoptera was studied by Schoettger and Olive (1961).

(vii) Dytiscidae (Tables 19, 20, and 21; Fig. 11). As with the adult Corixidae and Notonectidae, adult Dytiscidae are capable of moving in and out of habitats. Therefore, the origin of the high residue value in the sample from 352 days after application (July 7, 1968) is questionable.

Names of larvae and adults used in gas chromatographic analyses for each date are given in Tables 20 and 21.

In summary, levels of dieldrin were below detection in mud, water, and vegetation of D slough after 47 days after application (the September 6, 1967 sampling) (see Tables 5 and 8; Fig. 28). Dieldrin levels were detectable in zooplankton (Table 9; Fig. 5), Gastropoda (Table 10; Fig. 6), larval Chironomidae (Table 13; Fig. 8), Hirudinea (Table 14; Fig. 9), larval Odonata (Table 16; Fig. 10), and larval and adult Dytiscidae (Table 19; Fig. 11) at the end of the study, but were below detection in adult Corixidae and Notonectidae before the end of the study (Tables 11 and 12; Fig. 7). In general, the declines of dieldrin residues in mud, water, vegetation, and invertebrates in D slough follows the form of the first order kinetics model described for acute applications by Eberhardt *et al.* (1971) and discussed by Spencer (1965) and Chesters and Konrad (1971).

2. Ecosystem kinetics of dieldrin. "Despite the apparent concentration of chlorinated hydrocarbons in food chains, the environmental fate of pesticides is a downhill process" (Crosby, 1969b; p. 203). The decline of pesticides in an ecosystem (for example, dieldrin concentrations in mud, water, vegetation, and invertebrates of D slough)

Table 19. Dieldrin concentrations in Dytiscidae of D slough

| Days after Application | Sample Size (g)* | Dieldrin Concentration (ppb) | Confirmation $BF_3$ Etherate |
|---|---|---|---|
| | A. Larvae | | |
| 2 | (NW, SW, & SE) 0.61 | 112.02 | positive |
| 313 | (NW & SW) 0.10 | 24.65 | |
| 349 | (NW & SE) 0.93 | 22.96 | positive |
| 376 | (NE & SW) 0.79 | 6.40 | |
| | B. Adults | | |
| 2 | (NW, SW, & SE) 1.25 | 99.02 | |
| 21 | (NW, SW, & SE) 2.04 | 110.42 | positive |
| 48 | (NW, SW, & SE) 0.77 | 142.63 | |
| 313 | (NW, NE, & SW) 3.07 | 43.95 | |
| 349 | (NW & SE) 1.41 | 16.41 | |
| 376 | (NE & SW) 1.07 | 44.63 | positive |

* Quarter of slough given in brackets.

Table 20. Genera of Dytiscidae larvae used in gas chromatographic analyses of dieldrin concentrations in D slough

| Days after Application | Genera in Sample |
|---|---|
| 2 | *Agabus*, *Dytiscus*, *Graphoderus*, *Laccophilus*, *Rhantus* or *Colymbetes* |
| 313 | *Agabus*, *Graphoderus*, *Rhantus* or *Colymbetes* |
| 349 | *Agabus*, *Graphoderus*, *Hydroporus* or *Hygrotus*, *Laccophilus*, *Rhantus* or *Colymbetes* |
| 376 | *Laccophilus*, *Rhantus* or *Colymbetes* |

Table 21. Species of Dytiscidae adults used in gas chromatographic analyses of dieldrin concentrations in D slough

| Days after Application | Species in Sample |
|---|---|
| 2 | *C. sculptilis*, *G. perplexus*, *H. dispar*, *R. frontalis* |
| 21 | *C. sculptilis*, *D. ooligbucki*, *G. perplexus*, *R. frontalis* |
| 48 | *C. sculptilis*, *R. consimilis*, *R. frontalis* |
| 313 | *A. antennatus*, *C. sculptilis*, *D. ooligbucki*, *H. dispar*, *I. subaeneus*, *L. biguttatus*, *R. consimilis*, *R. frontalis*, *R. wallisi* |
| 349 | *A. semisulcatus?*, *C. sculptilis*, *G. occidentalis*, *G. perplexus*, *H. sayi*, *R. consimilis*, *R. frontalis* |
| 376 | *C sculptilis*, *G. occidentalis*, *G. perplexus*, *H. dispar*, *I. subaeneus*, *L. biguttatus*, *R. frontalis* |

Figure 11. Decline of dieldrin in Dytiscidae of D slough during the study period

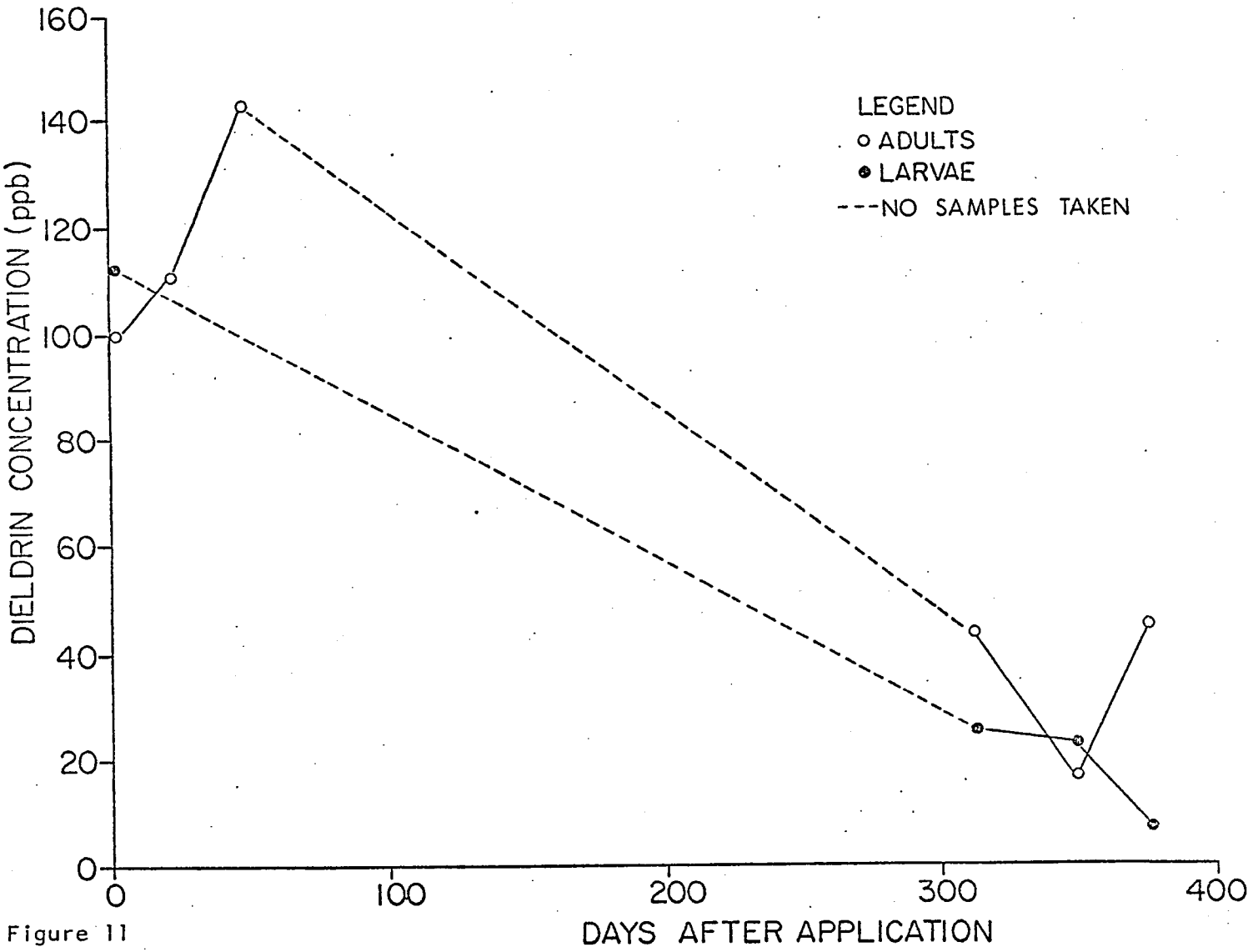
160
140
120
100
80
60
40
20
0
DIELDRIN CONCENTRATION (ppb)
0
100
200
300
400
DAYS AFTER APPLICATION
LEGEND
o ADULTS
LARVAE
---NO SAMPLES TAKEN

Figure 11

Table 22. Confidence limits for dieldrin concentrations in mud, water, vegetation, and invertebrates from sampling dates with three replicates or more

| Material | Sample Date | Mean Concentration (ppb) & Confidence Limits |
|---|---|---|
| mud | July 22, 1967 | 4.15 ± 2.06 |
| | Sept. 6, 1967 | 0.61 ± 1.93 |
| water | July 22, 1967 | 0.35 ± 0.99 |
| vegetation | | |
| -emergent* | July 22, 1967 | 7.51 ± 4.89 |
| -submergent** | July 22, 1967 | 40.28 ± 19.57 |

* *C. rostrata*

** *C. demersum* and *L. trisulca*

Table 22. (Continued)

| Material | Sample Date | Mean Concentration (ppb) & Confidence Limits |
|---|---|---|
| | Aug. 10, 1967 | 23.61 ± 7.06 |
| | Sept. 6, 1968 | 1.71 ± 1.88 |
| invertebrates | | |
| -*L. stagnalis* | July 23, 1967 | 150.98 ± 35.31 |
| | Aug. 11, 1967 | 113.22 ± 52.93 |
| -*C. audeni* | July 23, 1967 | 111.55 ± 108.12 |
| -Zygoptera | July 23, 1967 | 40.26 ± 13.29 |

is a result of complex interactions of physical and biological processes. Examples are given by Kearney *et al.* (1969) and Lichtenstein (1969) for pesticides in soils and by Foy and Bingham (1969) for herbicides in the environment.

Such pesticide declines may be of two types: apparent and real. An example of the first is the transfer of chlorinated hydrocarbon insecticides from water to organic matter as discussed previously. The chlorinated hydrocarbon is thus present in water in less than the calculated concentration or even "disappears" from the water (Edwards, 1970; Cope, 1971; Muirhead-Thomson, 1971). Dustman and Stickel (1969, p. 162) describe another apparent decline, this one in bottom sediments: "Where invertebrates were abundant, relatively small quantities of organochlorine remained to settle out, and concentrations on bottom sediments were lower than on floating material". Another type is the presence of well dispersed and below detectable levels of residues (Lichtenstein and Schultz, 1970). Analytical techniques are unable to detect these pesticides but they are present, in total, in substantial amounts (Meeks and Peterle, 1967).

By a "real" decline I mean an actual exit of pesticide from the slough or a change in the pesticide such that it no longer is the same chemical as was originally applied. The latter refers to metabolic and non-metabolic degradation (Van Middelem, 1966; and Schechter, 1969). Co-distillation was probably the most important avenue of exit for the pesticide from the water of the slough (Weidhaus, Schmidt, and Bowman, 1960; Acree, Beroza, and Bowman, 1963; Bowman *et al.*, 1959, 1964; Buescher *et al.*, 1964; Mitchell, 1966; Meeks and Peterle, 1967; Crosby, 1969b; Newland, Chesters, and Lee, 1969; Wheeler, 1969;

Lichtenstein and Schultz, 1970; Crosby and Tucker, 1971; Eberhardt *et al.*, 1971; Hamelink, Waybrant, and Ball, 1971; and Willis, Parr, and Smith, 1971). The slough is shallow and relatively small and could be thoroughly mixed by the wind. This probably enhanced co-distillation. The possible exit of dieldrin with plant evapotranspiration water was reported by Meeks and Peterle (1967). Further, some of the dieldrin could have eluted into the shore (Guthrie and Scott, 1969). Soil samples were not taken from the shore for gas chromatographic analyses. Birds feeding, insects emerging, and scientific collecting could account for more pesticide losses (Meeks and Peterle, 1967).

The non-metabolic degradation, or weathering, of pesticides has been very adequately reviewed by Crosby (1969a) and the photodecomposition aspect further elaborated by Crosby (1969c), Henderson and Crosby (1968), Plimmer, Klingebiel, and Hummer (1970), Zabik *et al.* (1971), and Menzie (1972); and summarized for aldrin and dieldrin by Sutherland and Rosen (1968).

Metabolism of insecticides, fungicides, and herbicides is reviewed by O'Brien (1967), Fukuto and Metcalf (1969), Owens (1969), Freed and Montgomery (1963, 1969), and Menzie (1972). The review by Fukuto and Metcalf is particularly good for the insect metabolism of chlorinated hydrocarbons. Spencer (1965) and Menzie (1972) reviewed the metabolism of insecticides by plants.

In summary, the decline of dieldrin residues in D slough are both apparent and real, the former being influenced by the hydrophobic nature of chlorinated hydrocarbons and the latter by the interaction of physical (co-distillation and weathering) and biological (metabolism) processes. However, I cannot provide quantitative estimates, for

D slough, of the types of pesticide losses considered here.

3. Trophic level effects. It is evident from Tables 23 and 24 that the primary and secondary consumers have similar ranges of maximum and final pesticide concentrations. (I hesitate to accept the results of the adult Dytiscidae analyses because they are the only group that showed a dramatic rise at the end of the study; and because they are capable of entering and leaving the slough so their role as indicators of pesticide relationships in the slough is open to question). It is surprising that no trophic level effect is evident. Despite the findings of Godsil and Johnson (1967) that a low concentration of endrin in the lake of their study did not result in food chain concentration, the works of Hunt and Bischoff (1960), Pillmore (in Rudd, 1964), Hunt (in Rudd, 1964), Bridges *et al.* (1963), and Hickey *et al.* (1966), among others, have demonstrated a trophic level effect resulting from pesticide applications to aquatic ecosystems. Rudd (1964) has discussed instances of trophic level effects in terrestrial ecosystems. However, in each of these studies, invertebrates have been used as a single step in the food chain and usually they are of a single species or are zooplankton. Other studies (Terriere *et al.*, 1966; Keith, 1966; and those reviewed and summarized in Table IV of Moore, 1967) which have also used aquatic invertebrates as a single step, have presumably lumped a number of species of aquatic invertebrates. As Wilkes and Weiss (1971; p. 223) state: "...the final location of the pesticide in the food chain has been the object of most investigations rather than the actual contributions made by each food chain organism to the level of biological magnification achieved". Of course, aquatic invertebrates have their own trophic

Table 23. Maximum and final DDT concentrations (ppm) in invertebrates of Meeks (1968)

| Taxon | Maximum Concentration | Final Concentration |
|---|---|---|
| Primary consumers: | | |
| Gastropoda - Planorbidae | 1.1 | 0.2 |
| - *Lymnaea* sp. | 2.2 | 1.2 |
| Chironomidae | 5.2 | 2.0 |
| Erpobdellidae* | 12.6 | 2.3 |
| Amphipoda | 6.2 | 0 |
| crayfish | 3.8 | 0.3 |
| Secondary consumers: | | |
| Notonectidae | 3.2 | 0.2 |
| Odonata - Zygoptera | 3.8 | 0.9 |
| - Anisoptera | 1.7 | 0.2 |

* Arbitrarily called primary consumers. They are scavengers or feed on aquatic invertebrates (Pennak, 1953; Smith, unpublished). That is, they are "opportunistic" feeders.

Table 24. Maximum and final dieldrin concentrations (ppb) in invertebrates of this study

| Taxon | Maximum Concentration | Final Concentration |
|---|---|---|
| Primary consumers: | | |
| zooplankton | 362.9 | 5.3 |
| Gastropoda - *L. stagnalis* | 151.0 | 5.4 |
| - *L. elodes* | 47.4 | 9.4* |
| - *H. trivolvis* | 51.8 | 2.1 |
| Corixidae (adults) | 51.4 | 15.2** |
| Chironomidae - mixture | 82.8 | |
| - *Chironomus* | 44.1 | 4.3†† |
| - *Glyptotendipes* | | 3.0 |
| Erpobdellidae | 71.4 | 3.7 |

* July 31, 1968.
** September 7, 1967.
†† August 14, 1968.

NOTE:
All other dates for "Maximum Concentration" are either July 23, 1967 or August 11, 1967 and those for "Final Concentration" are July 13, 1968 or September 17, 1968.

Table 24. (Continued)

| Taxon | Maximum Concentration | Final Concentration |
|---|---|---|
| Secondary consumers: | | |
| Glossiphoniidae | 131.4 | 3.7 |
| Notonectidae - adults | 88.4 | <e1[†] |
| - immatures | | 2.2 |
| Odonata - Zygoptera | 37.3 | 1.8 |
| - Libellulidae | 87.2 | 4.4 |
| - *A. interrupta* | 36.4 | 3.2 |
| Dytiscidae - adults | 142.6[Ψ] | 44.6 |
| - larvae | 112.0 | 6.4 |

[†] Below experimental limits of detection.

[Ψ] September 7, 1967. (See NOTE, previous page).

interrelationships (for example, see Jones, 1949).

Hannon *et al.* (1970) separated the aquatic invertebrates of their study into three unlikely groups: plankton-algae, crayfish, and aquatic insects (composed of midge larvae and Gyrinidae) so no information on trophic distribution of the chlorinated hydrocarbons is available. Woodwell, Wurster, and Isaacson's (1967) study of the DDT residues in an east coast estuary gives an extensive list of residue data for various species of invertebrates but, unfortunately, none can be classed as secondary consumers. The same is true of the review and summary presented in Table 12 of Edwards (1970) except for the 1964 United States Department of the Interior study which gives a concentration factor for a crab that is the lowest for the entire study. Also, there is a lack of secondary consumers among the terrestrial invertebrates in Table 10 of Edwards except for Davis and Harrison's (1966) work which will be considered below.

Moubry, Helm, and Myrdal (1968) reported similar DDT, DDT-metabolites, dieldrin, and endrin levels in *Gammarus* sp., *Limnephilus rhombicus* (L.) larvae, and *Sialis* sp. larvae. The last, of course, are predators. Robinson et al. (1967) reported similiar concentrations of DDT and DDE in primary and secondary consumer marine invertebrates except in macrozooplankton which they classed as a secondary consumer and which had extraordinarily high concentrations. Robinson et al.'s results are shown diagramatically in Fig. 3 of Edwards (1970). The similarity in pesticide levels between trophic levels 2 (= primary consumer) and 3 (= secondary consumer) is striking.

The number of adequate studies on uptake of pesticides in different trophic levels of terrestrial invertebrates is equally as low

as for aquatic invertebrates. The residue values presented by El Sayed, Graves, and Bonner (1967) show conflicting patterns probably because of a lack of collection consistency more than anything else. However, the studies of Davis and Harrison (1966) and Davis (1968) have shown that "...worms and slugs usually contain higher amounts and a greater range of organochlorine compounds than beetles" (Davis, 1968; p. 43 to 44). The beetles he referred to were mostly Carabidae as well as some Staphylinidae and Elateridae. Korschgen (in Dustman and Stickel, 1969) reported similar levels of dieldrin in earthworms, crickets, and carabids in a Missouri field which had had chronic, long term aldrin applications.

Thus, it appears that of the studies which have adequately dealt with residues in different trophic levels of aquatic or terrestrial invertebrates, a trophic level effect or food chain concentration does not exist. Yet, unqualified generalizations about food chain concentration of pesticides keep appearing in the literature. (For example, Wilkes and Weiss, 1971, p. 223; Wurster, 1969, p. 125; and Moore, 1967, p. 113).

Aquatic organisms acquire pesticides through their food and from their surroundings (Moore, 1967; Chadwick and Brocksen, 1969; Dustman and Stickel, 1969; Edwards, 1970; Cope, 1971; Hamelink *et al.*, 1971; Kawatski and Schmulbach, 1971; and Wilkes and Weiss, 1971). To speak of a trophic level effect automatically assumes that food is the more important of the two. Hamelink *et al.* (1971) have proposed that exchange equilibria control the degree of accumulation of chlorinated hydrocarbons by organisms in lentic environments. This is supported by the earlier findings of Reinert (1967) and Chadwick and Brocksen

(1969) that the major uptake of DDT by *Daphnia* and dieldrin by *Cottus perplexus* Gilbert and Evermann respectively was from water and not food. (See also Edwards, 1970). Crosby and Tucker (1971, p. 715) state: "Ingestion probably represents a relatively unimportant route by which *Daphnia* are exposed to suspended chemicals". Exchange equilibria depend on the "fat content of the animals, the species sampled, and the time available for exchange" (Hamelink *et al.*, 1971; p. 213) and, no doubt, many other factors. Unfortunately, the invertebrates used in the Hamelink *et al.* study were lumped but Johnson *et al.* (1971) have shown that there is quite a difference in accumulation of DDT and aldrin among ten species of freshwater invertebrates which included primary and secondary consumers.

Quite assuredly, other factors influence the accumulation of pesticide residue by aquatic invertebrates. In trying to explain the lack of consistent food chain buildup in their study, Robinson et al. (1967) wrote of the possibility of a differential ability of vertebrates and invertebrates to metabolize and excrete the pesticide. Pharmacokinetics greatly influence the pesticide levels in organisms (Moore, 1967; Stickel, 1968; Chadwick and Brocksen, 1969; Dustman and Stickel, 1969; Moriarty, 1969; Edwards, 1970; Cope, 1971; Hamelink *et al.*, 1971; Kawatski and Schmulbach, 1971; and Wilkes and Weiss, 1971). I have already listed reviews of the metabolism of pesticides by invertebrates. And finally, extrinsic factors must affect pesticide levels in aquatic invertebrates: (a) varying concentrations (for example, see Chadwick and Brocksen, 1969; Hamelink *et al.*, 1971; and Wilkes and Weiss, 1971); (b) length of time of exposure (for example, see Chadwick and Brocksen, 1969; Cope, 1971; Johnson *et al.*, 1971; and Wilkes and

Weiss, 1971); and (c) whether exposure is acute or chronic (for example, see Moore, 1967; Stickel, 1968; Chadwick and Brocksen, 1969; Moriarty, 1969; Edwards, 1970; and Johnson *et al.*, 1971).

In summary, concentrations of chlorinated hydrocarbons in aquatic invertebrates as reported in the literature do not reveal a trophic level effect. This is supported by my study. Accumulation of pesticides is more likely a function of exchange equilibria than food but is also affected by pharmacokinetics and extrinsic factors such as concentration of the pesticide, length of exposure, and whether exposure is acute or chronic. It is clear that a good deal more work has to be done with pesticide kinetics at the individual level before we can hope to explain pesticide kinetics at the ecosystem level (Stickel, 1968; Chadwick and Brocksen, 1969).

E: Diversity (H')

1. Progressive pooling of samples. Values shown in Table 25 and Figs. 12 and 13 are means of the three poolings done for each sampling date. The curves in Figs. 12 and 13 show that the initial rise for most of the samples was usually finished by the fifth pooled sample. However, to ensure that I was well within the asymptote, the minimum should have been set at six or seven (see McIntire and Overton, 1971). For the dates in which more than five samples were pooled, the differences in H' between the fifth pooled sample and the final one, expressed as a percent of the fifth pooled one, were negligible except for D slough, June 29, 1967, garbage can samples (see Table 26). Thus, the varying numbers of samples pooled per date were not changed. Finally, there was no obvious correlation between the

Table 25. H'' values for progressively pooled samples

| Locality, Date, & Type of Sample | Number of Samples Pooled | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 |
| D slough: | | | | | | | | | | | | | | | |
| June 15, 1966 DN* | 2.28 | 2.56 | 2.59 | 2.76 | 2.82 | | | | | | | | | | |
| June 29, 1967 DN | 1.61 | 1.62 | 1.67 | 1.74 | 1.76 | 1.82 | 1.82 | 1.82 | | | | | | | |
| June 15, 1966 gc** | 1.42 | 1.86 | 2.22 | 2.32 | 2.38 | | | | | | | | | | |
| June 29, 1967 gc | 1.37 | 1.60 | 1.70 | 1.79 | 1.83 | 1.92 | 1.86 | 1.92 | 1.94 | 1.99 | 2.01 | 2.08 | 2.10 | 2.07 | 2.11 |
| July 13, 1967 gc | 2.06 | 2.43 | 2.44 | 2.49 | 2.52 | 2.59 | 2.67 | 2.70 | | | | | | | |
| C slough: | | | | | | | | | | | | | | | |
| June 16, 1966 DN | 1.92 | 1.85 | 1.80 | 1.99 | 2.04 | | | | | | | | | | |
| June 12, 1967 DN | 1.67 | 1.70 | 1.74 | 1.79 | 1.82 | 1.87 | 1.87 | 1.92 | 1.93 | | | | | | |
| June 27, 1967 DN | 2.15 | 2.48 | 2.47 | 2.47 | 2.49 | 2.49 | 2.44 | 2.47 | | | | | | | |
| June 16, 1966 gc | 1.17 | 1.33 | 1.60 | 1.70 | 1.48 | | | | | | | | | | |
| June 27, 1967 gc | 1.57 | 1.78 | 1.92 | 2.07 | 2.21 | 2.31 | 2.33 | 2.29 | 2.28 | 2.28 | 2.26 | 2.25 | 2.21 | 2.23 | 2.23 |
| July 11, 1967 gc | 1.48 | 1.18 | 1.16 | 1.20 | 1.45 | 1.45 | 1.43 | 1.50 | | | | | | | |

* Dip net sample. ** Garbage can sample.

Figure 12. Curves of H'' for progressively pooled dip net samples from C and D sloughs

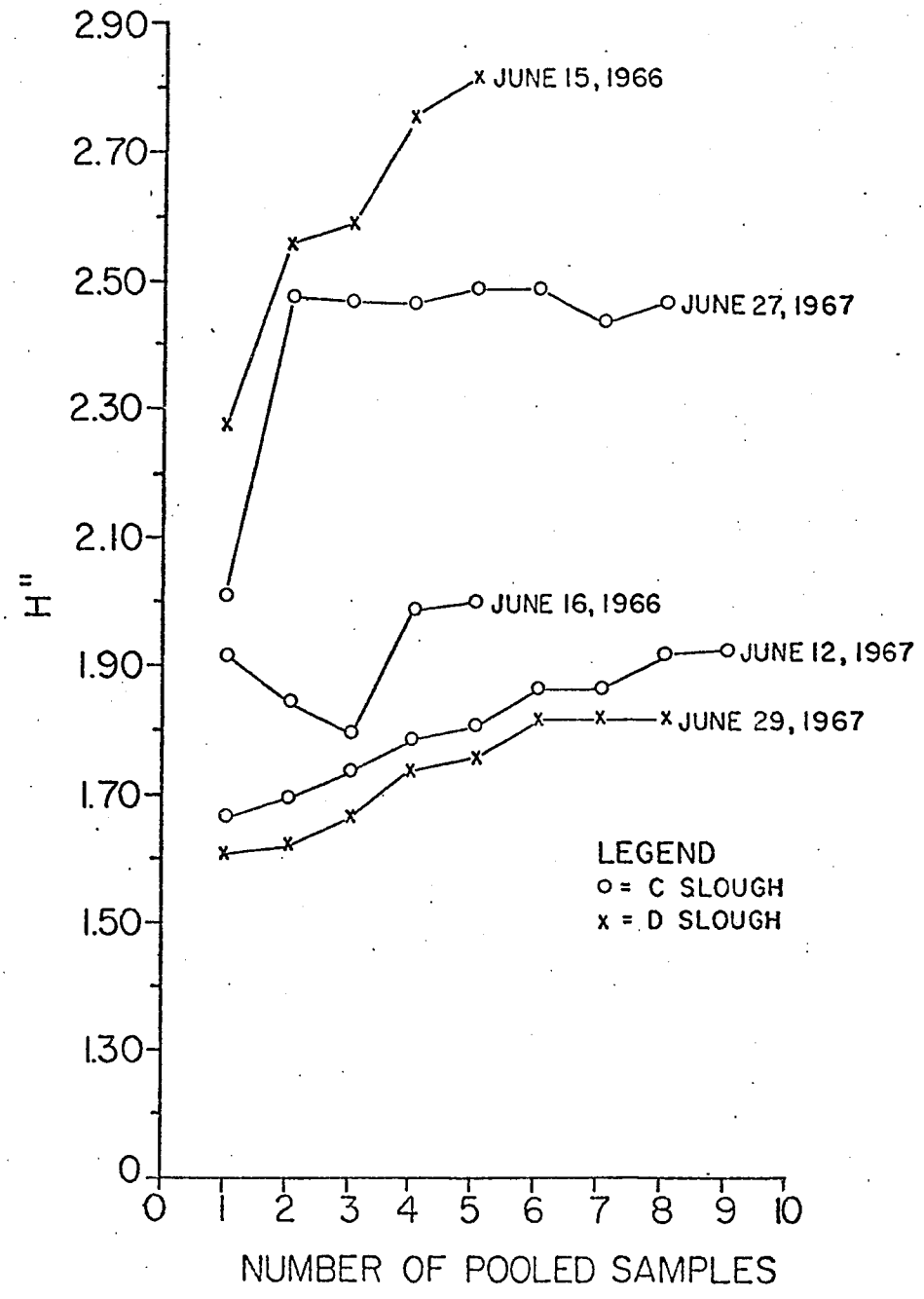
2.90
2.70
2.50
2.30
2.10
1.90
1.70
1.50
1.30
0
H =
JUNE 15, 1966
JUNE 27, 1967
JUNE 16, 1966
JUNE 12, 1967
JUNE 29, 1967
LEGEND
o = C SLOUGH
x = D SLOUGH
0 1 2 3 4 5 6 7 8 9 10
NUMBER OF POOLED SAMPLES

Figure 12

Figure 13. Curves of H'' for progressively pooled garbage can samples from C and D sloughs

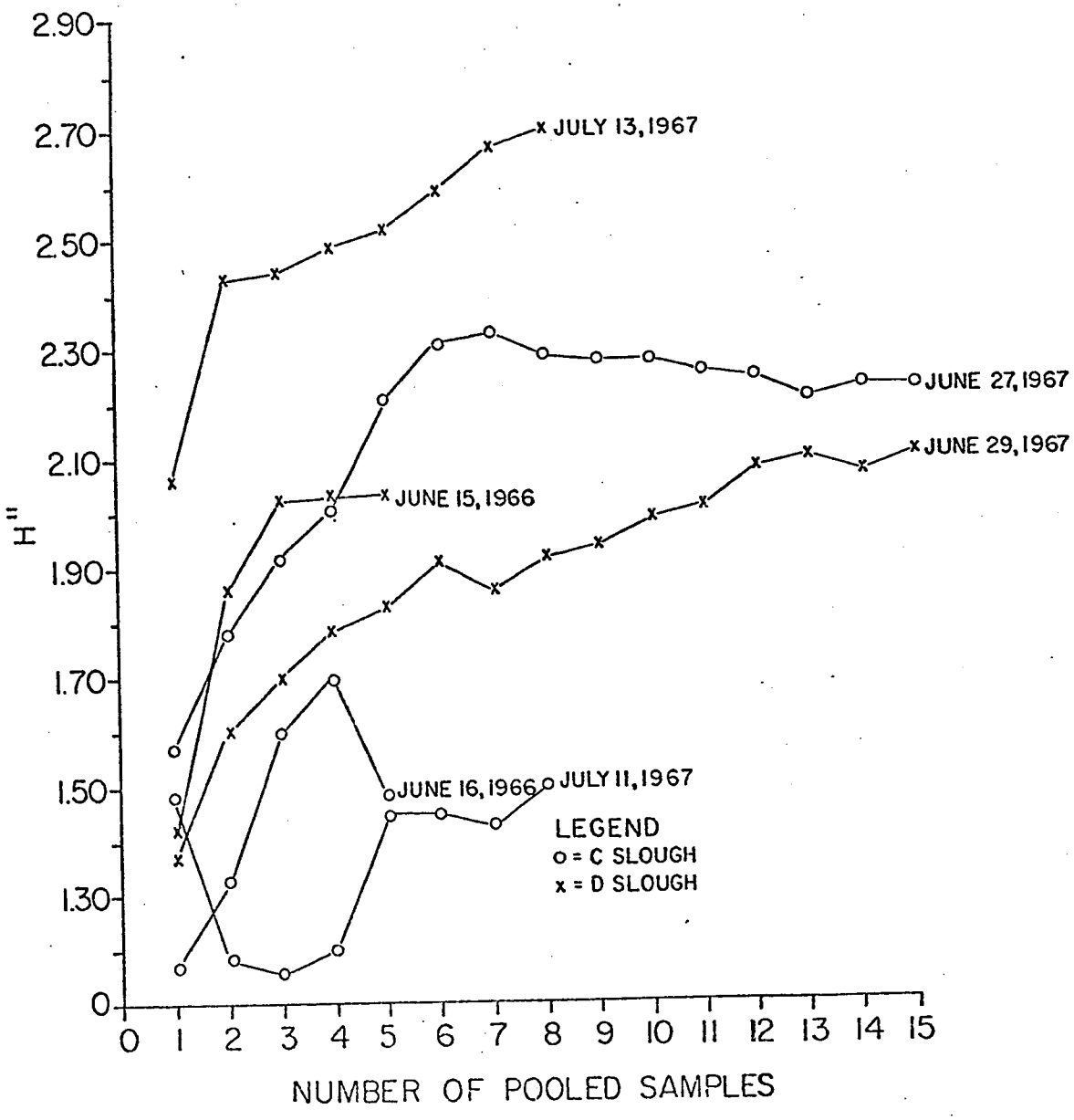
2.90
2.70
2.50
2.30
2.10
1.90
1.70
1.50
1.30
0
H'
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15
NUMBER OF POOLED SAMPLES
JULY 13, 1967
JUNE 27, 1967
JUNE 29, 1967
JUNE 15, 1966
JUNE 16, 1966
JULY 11, 1967
LEGEND
o = C SLOUGH
x = D SLOUGH

Figure 13

Table 26. Percent difference in H'' between fifth pooled and last pooled sample*

| Locality, Date,& Type of Sample | Percent Difference |
|---|---|
| D slough: | |
| June 15, 1966 DN** | not applicable |
| June 29, 1967 DN | 2.71 |
| June 15, 1966 gc† | not applicable |
| June 29, 1967 gc | 15.28 |
| July 13, 1967 gc | 7.20 |
| C slough: | |
| June 16, 1966 DN | not applicable |
| June 12, 1967 DN | 6.39 |
| June 27, 1967 DN | -0.82†† |
| June 16, 1966 gc | not applicable |
| June 27, 1967 gc | 0.78 |
| July 11, 1967 gc | 3.59 |

* Expressed as the difference divided by the fifth pooled sample.

** Dip net sample.

† Garbage can sample.

†† The fifth pooled sample had a higher H'' than the last pooled sample.

samples of the first and second biological sampling methods (first: C, June 16, 1966, dip net and garbage can; C, June 12, 1967, dip net; D, June 15, 1966, dip net and garbage can; second: C, June 27, 1967, dip net and garbage can; C, July 11, 1967, garbage can; D, June 29, 1967, dip net and garbage can; D, July 13, 1967, garbage can) and the values of H''.

2. Comparisons of H'' 's between and within C and D sloughs. Graphs of the four different kinds of H'' 's calculated for both types of samples and both sloughs and plotted on a yearly basis are shown in Figs. 14 to 29.

Total and primary consumer H'' 's for dip net samples in C slough (Figs. 14 and 16, respectively) show dramatic declines coincident with tree removal. A number of factors lead me to believe that tree removal was not the cause of these declines. First, I could not demonstrate that tree removal affected certain chemical and physical parameters of the slough that might, in turn, have an effect on the fauna (see Part IV, Section B). Second, there was no lag period between tree removal and the decline (see Figs. 14 and 16). Third, H'' 's went up again during the 1968 field season--in the absence of trees (for example, see Figs. 14 to 17)! Last, Figs. 17, 18, 20, and 21 show H'' declines well before the trees were removed. This indicates that a general seasonal decline was in progress. Daborn (1969) reported major within- and between-season faunal changes in the slough of his study at approximately the same time as those in C and discussed the biological implications of morphometric variations caused by the exceptionally low precipitation during 1967. It is plausible that the faunal changes in C occurred as a result of the

Figure 14. Values of total H'' for dip net samples from C slough for 1966, 1967, and 1968

Figure 15. Values of Chironomidae H'' for dip net samples from C slough for 1966, 1967, and 1968

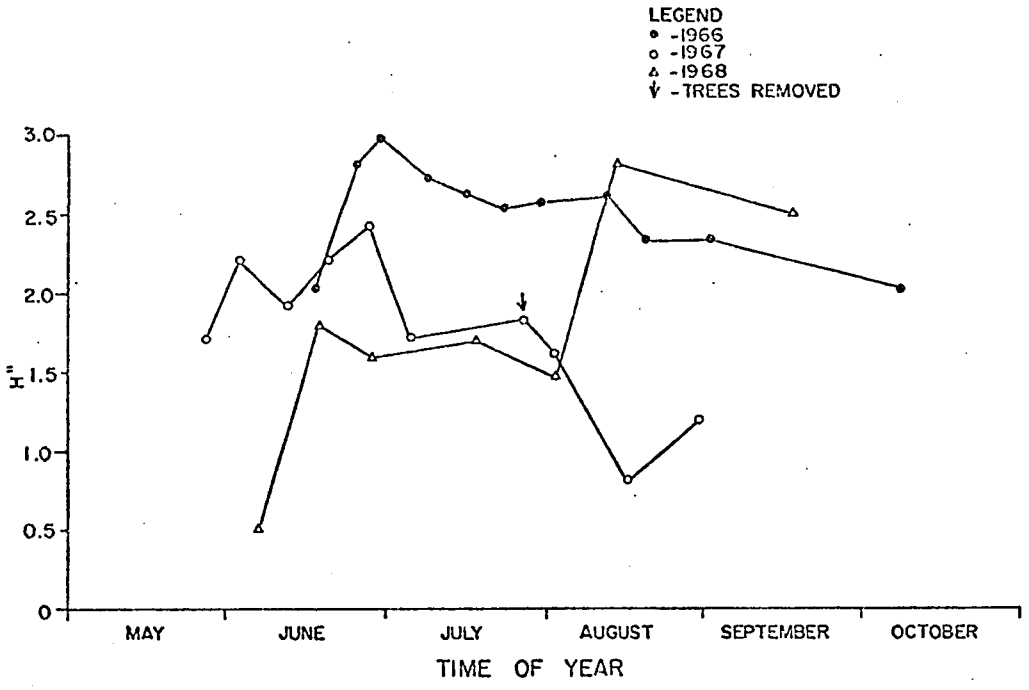


Figure 14

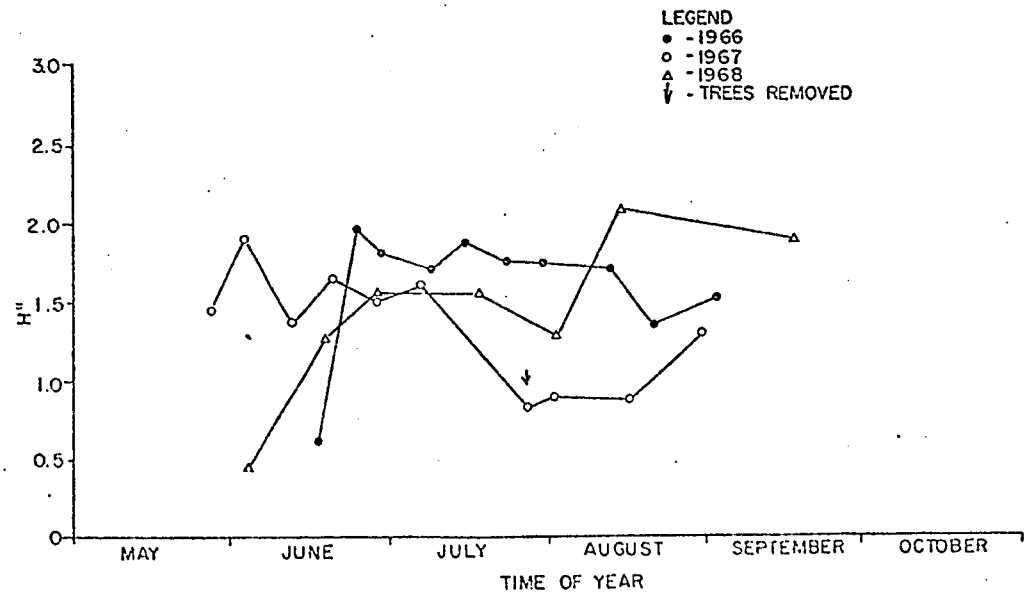


Figure 15

Figure 16. Values of primary consumer H'' for dip net samples from C slough for 1966, 1967, and 1968

Figure 17. Values of secondary consumer H'' for dip net samples from C slough for 1966, 1967, and 1968

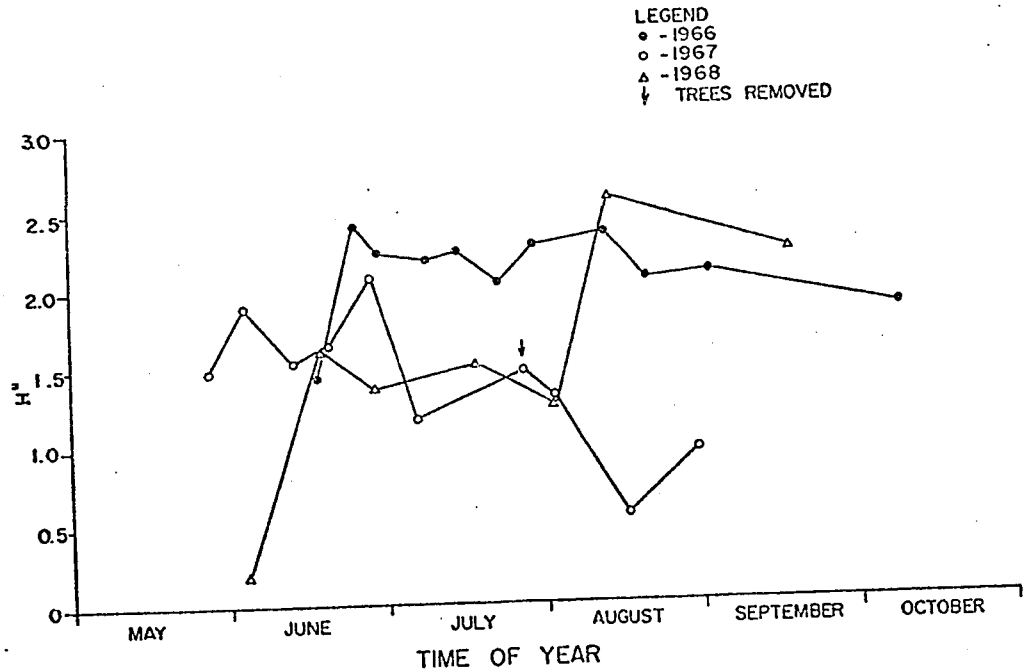


Figure 16

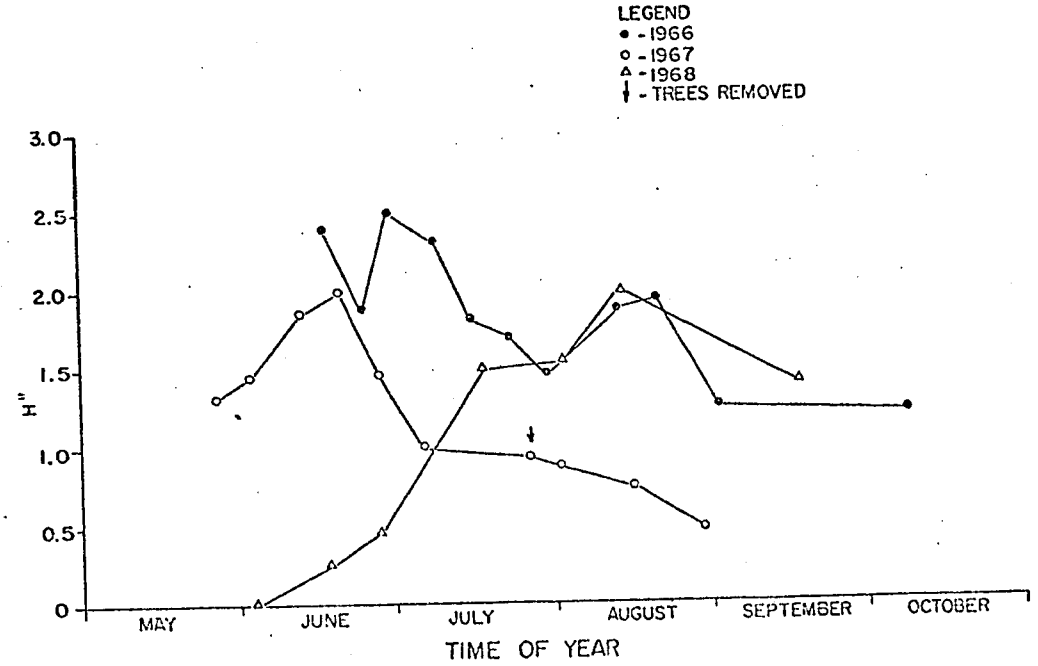


Figure 17

Figure 18. Values of total H'' for garbage can samples from C slough for 1966, 1967, and 1968

Figure 19. Values of Chironomidae H'' for garbage can samples from C slough for 1966, 1967, and 1968

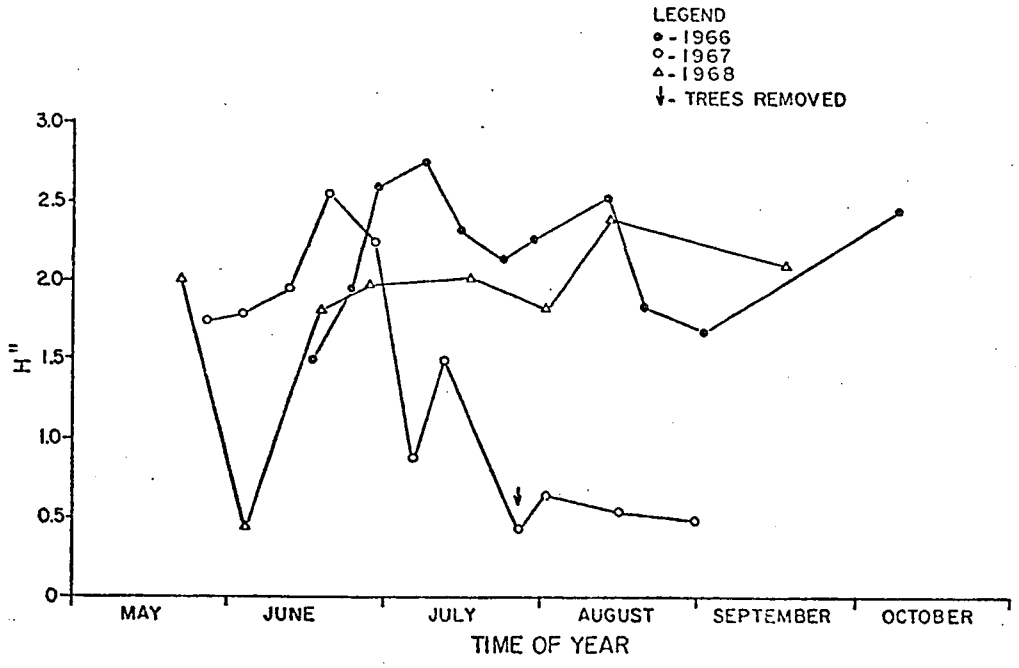


Figure 18

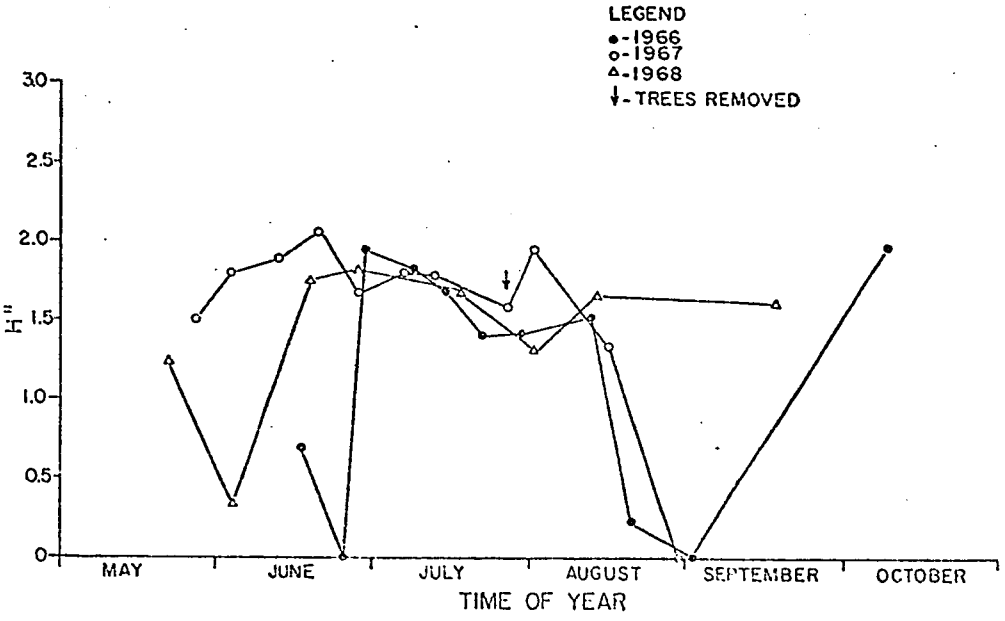


Figure 19

Figure 20. Values of primary consumer H'' for garbage can samples from C slough for 1966, 1967, and 1968

Figure 21. Values of secondary consumer H'' for garbage can samples from C slough for 1966, 1967, and 1968

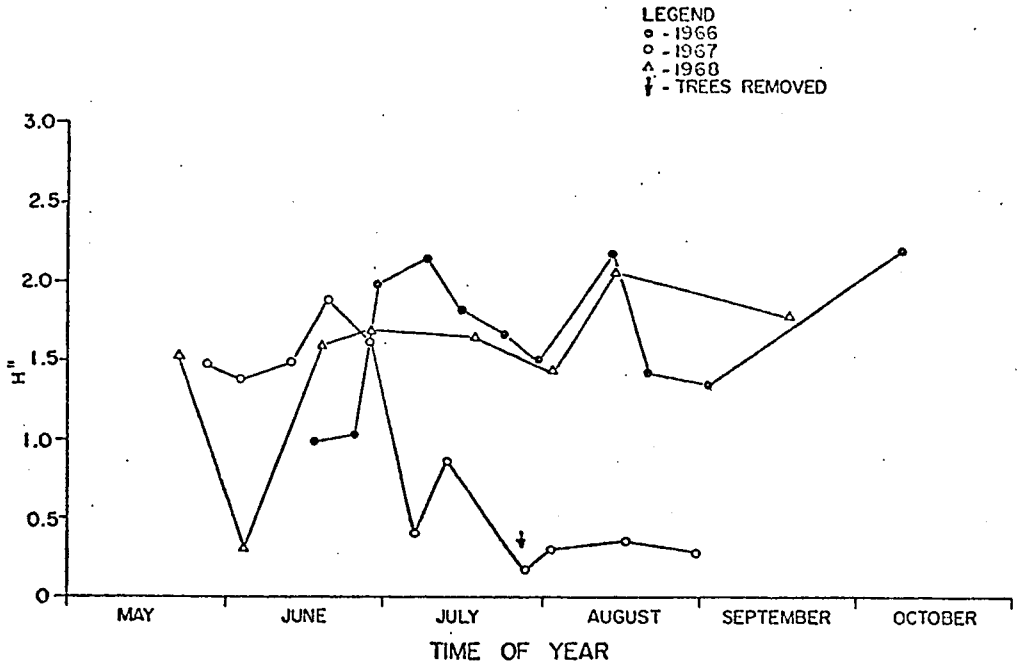


Figure 20

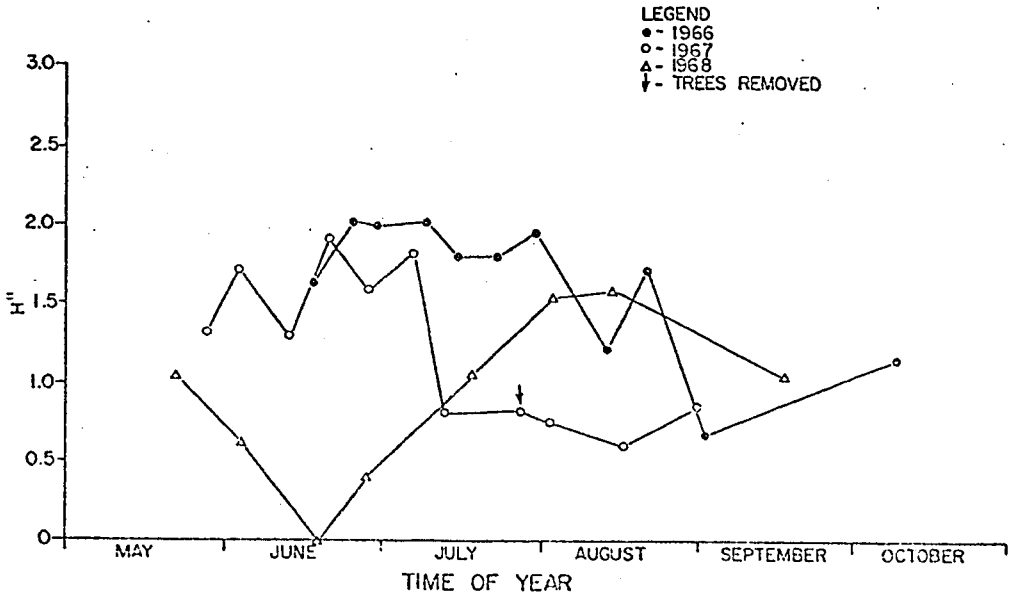


Figure 21

Figure 22. Values of total H'' for dip net samples from D slough for 1966, 1967, and 1968

Figure 23. Values of Chironomidae H'' for dip net samples from D slough for 1966, 1967, and 1968

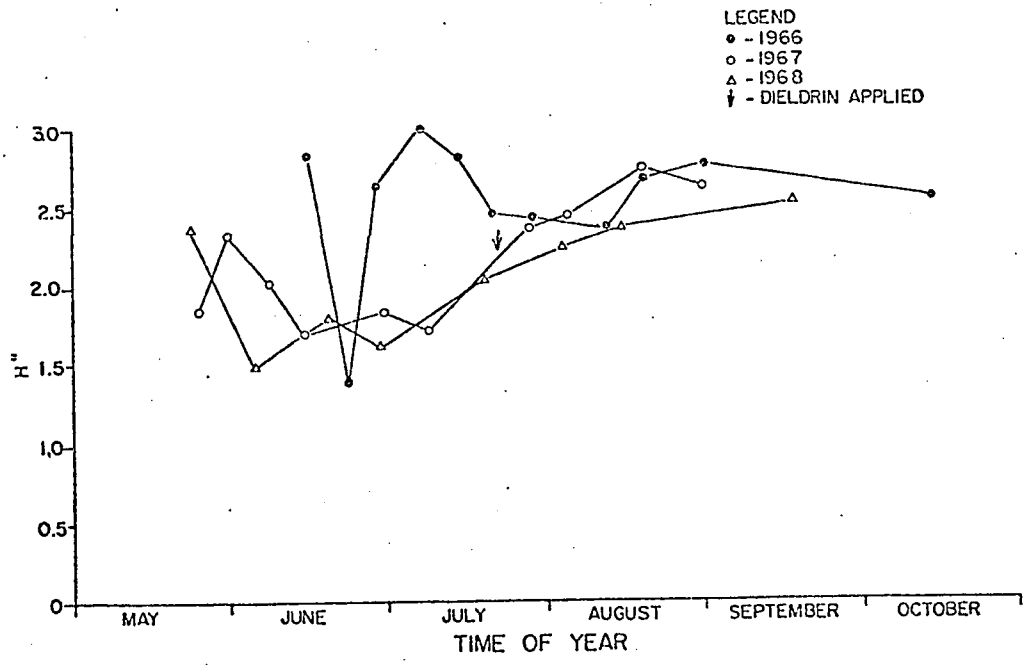


Figure 22

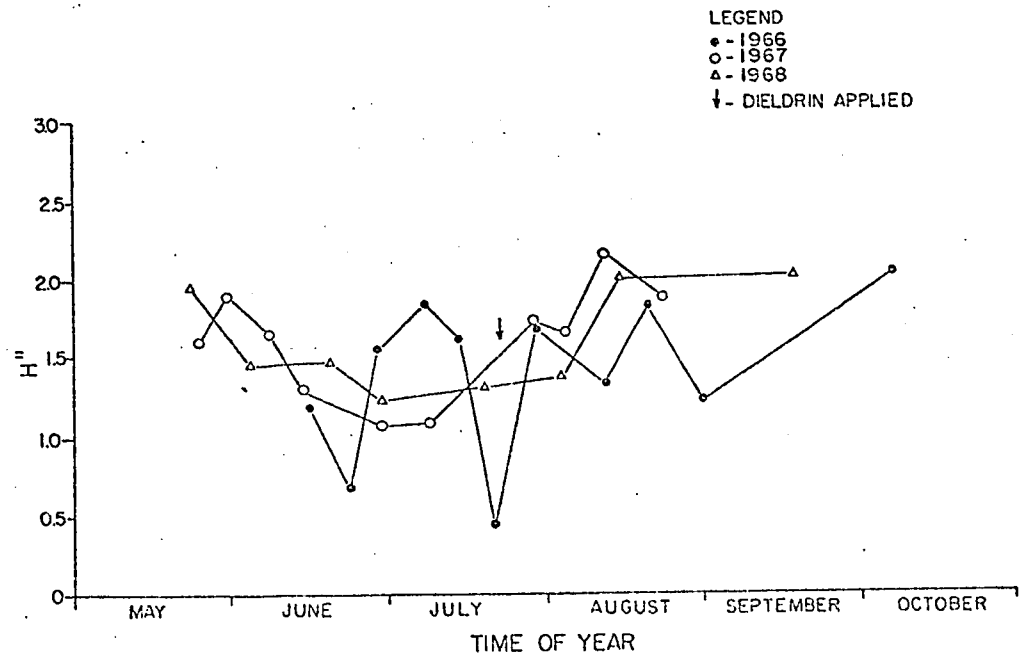


Figure 23

Figure 24. Values of primary consumer H'' for dip net samples from D slough for 1966, 1967, and 1968

Figure 25. Values of secondary consumer H'' for dip net samples from D slough for 1966, 1967, and 1968

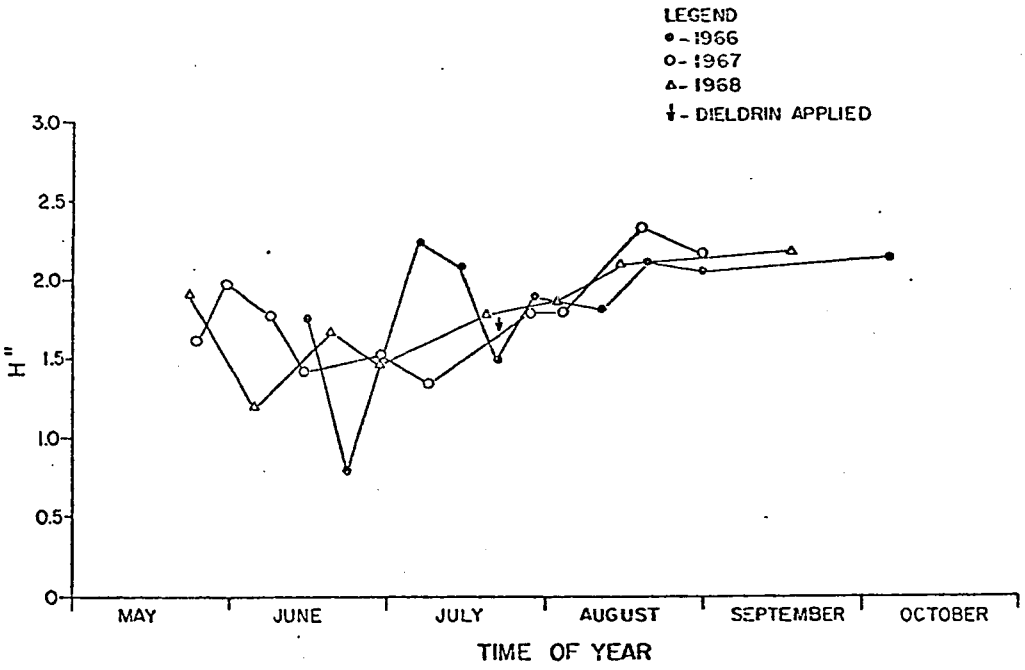


Figure 24

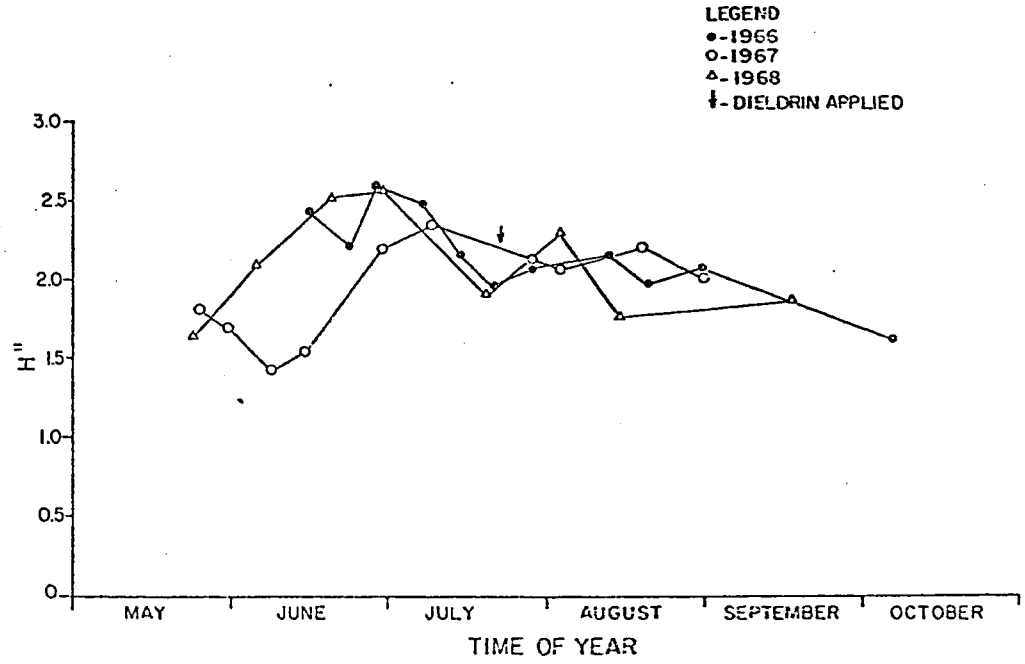


Figure 25

Figure 26. Values of total H'' for garbage can samples from D slough for 1966, 1967, and 1968

Figure 27. Values of Chironomidae H'' for garbage can samples from D slough for 1966, 1967, and 1968

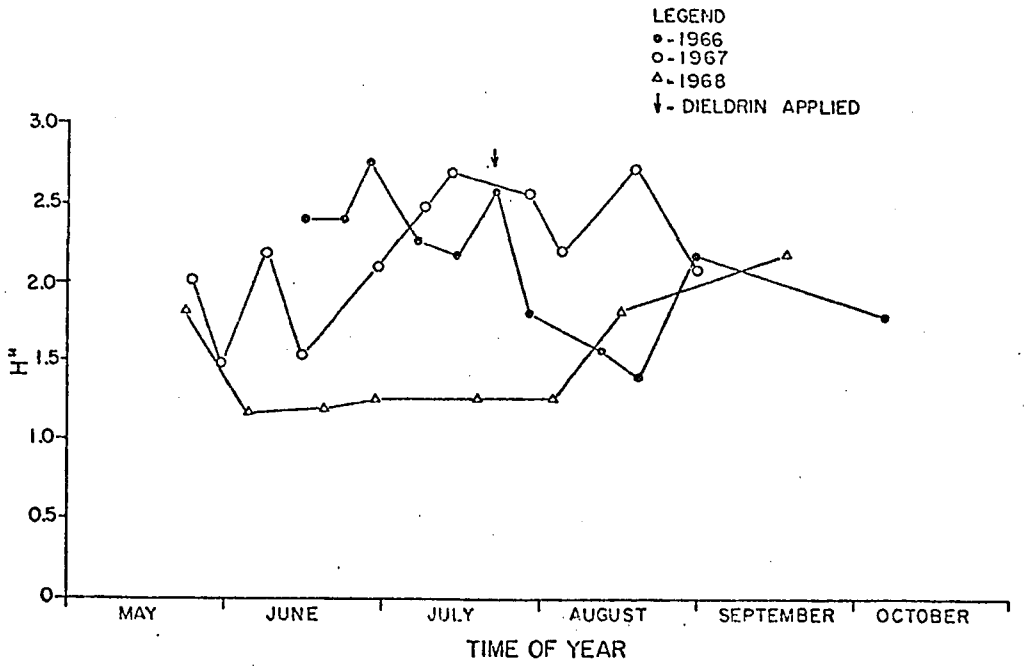


Figure 26

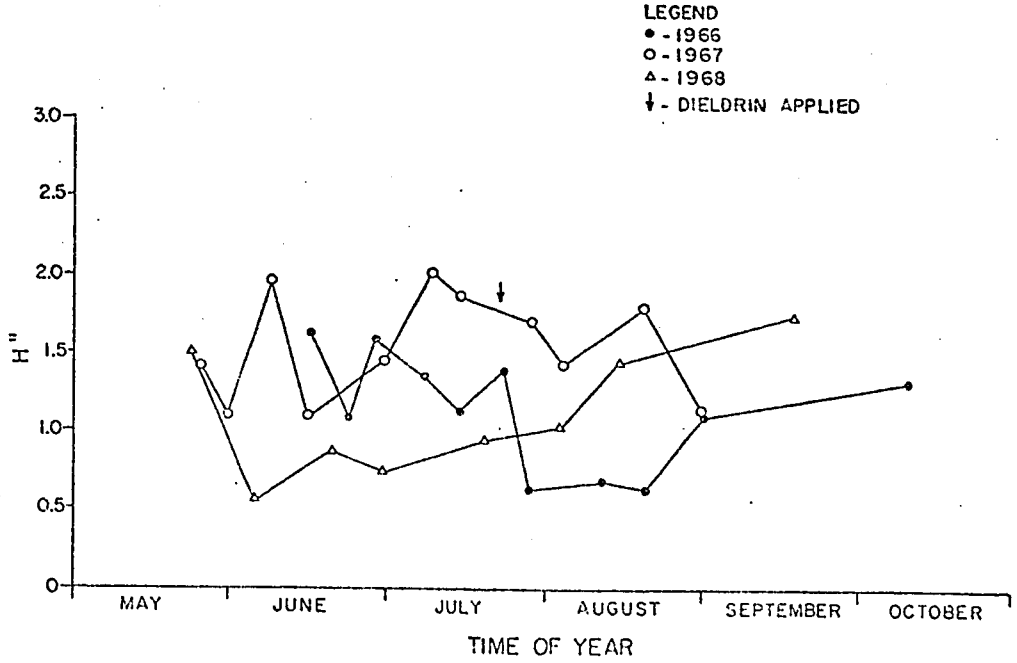


Figure 27

Figure 28. Values of primary consumer H'' for garbage can samples from D slough for 1966, 1967, and 1968

Figure 29. Values of secondary consumer H'' for garbage can samples from D slough for 1966, 1967, and 1968

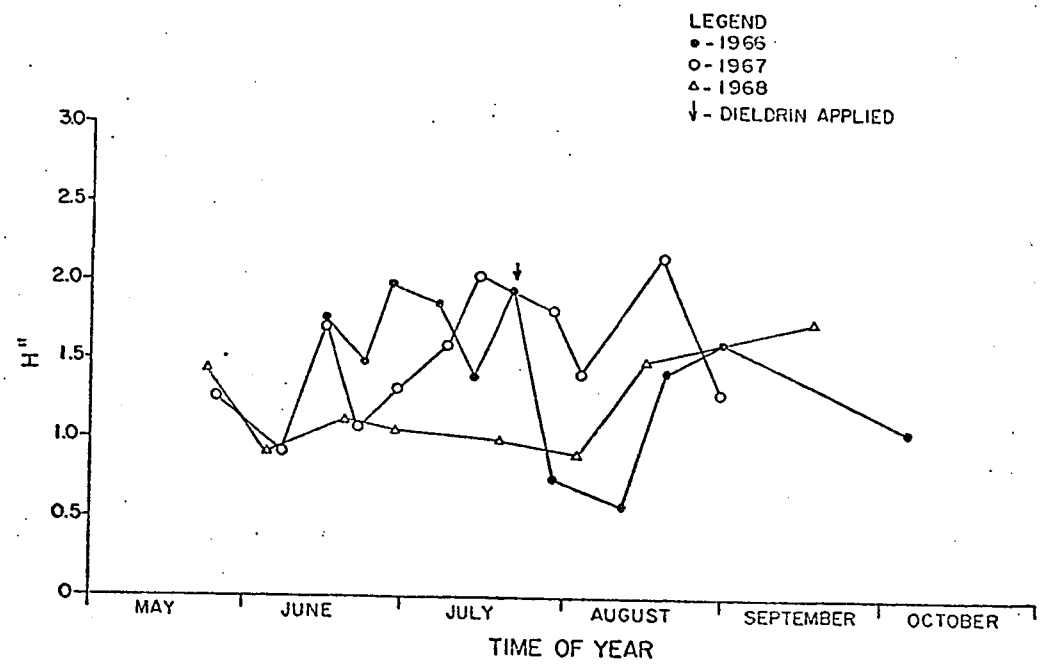


Figure 28

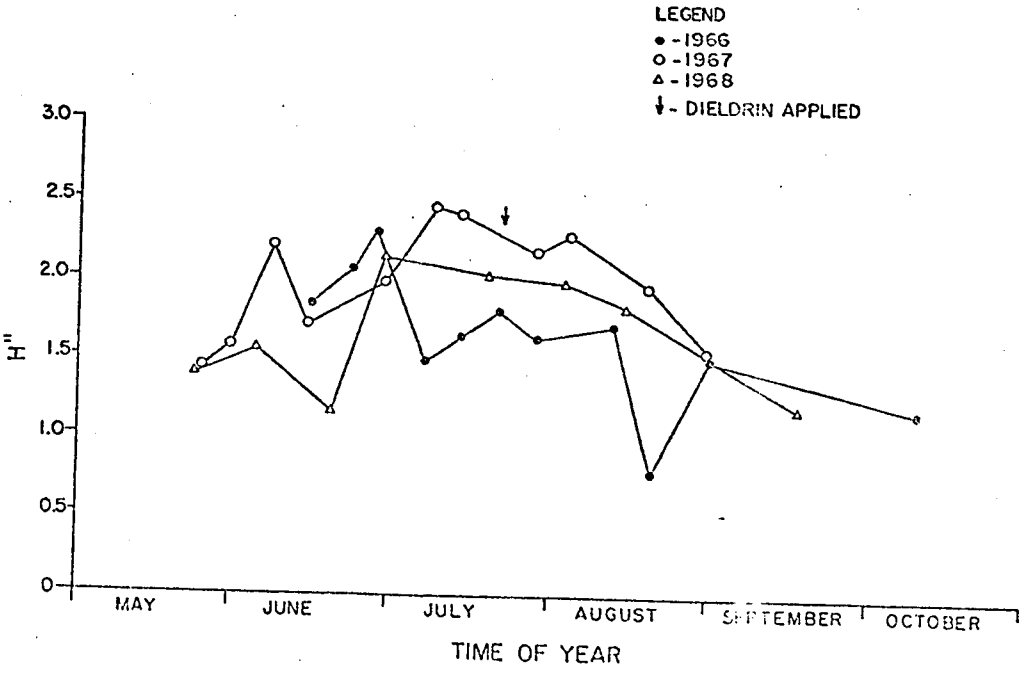


Figure 29

effects of decreased water volumes that coincided with tree removal. Whether these seemingly drastic faunal fluctuations are a normal part of the life of some sloughs or whether they are occasioned by changes in climatic factors cannot be answered within the context of this study.

Comparing C and D, total H'' for dip net samples was just barely significantly different at the 5% level ($t = 2.073$ for 55 DF). This difference was not reflected in the garbage can samples. Pre-treatment total H'' for D dip net and garbage can samples was not significantly different from pre-treatment total H'' for C dip net and garbage can samples. However, post-treatment total H'' for D dip net samples was significantly different at the 5% level from those of C. Garbage can samples did not reflect that difference.

Considering the within-slough comparisons (Table 3), for D, there was no difference in total H'' between pre- and post-treatment periods for both types of sample. The results of three studies which have used chlorinated hydrocarbons in lentic water and have monitored effects on the diversity of invertebrates in some way are shown in Table 27. Direct comparisons are difficult because of the different measures of diversity used. Each of these studies have shown that diversity changed as a result of application of the pesticide. However, each of these studies used a concentration of pesticide far greater than that of this study.

Comparisons of total H'' between pre- and post-treatment periods for both types of samples in C yielded a significant difference at the 1% level. This change in H'' 's in C has already been discussed. It is this change in total H'' in C between pre- and post-treatment

Table 27. The effects of chlorinated hydrocarbon pesticides on the diversity of invertebrates in lentic waters

| Reference | Pesticide | Application | Effects on Diversity |
|---|---|---|---|
| Jones and Moyle (1963) | DDT | 1 lb/acre in spring & ½ lb/acre in fall | Depression of microcrustacean populations immediately after each application. (All taxa of microcrustaceans lumped for tests for significance). |
| Edwards *et al* (1964) | DDD | 1 lb/acre (0.05 to 0.10 ppm in water) | Chironominae, Tanypodinae, Culicidae, and Ephemeroptera reduced in numbers or species. |
| Kennedy, Eller, and Walsh (1970) | methoxychlor | 0.01 and 0.04 ppm | Higher numbers of insects in the two treated ponds but lower number of taxa. |

periods that is the source of the difference in the dip net samples between C and D.

Chironomid H'' was not significantly different for either dip net or garbage can samples in pre- and post-treatment periods in either C or D. With regard to the possibility of using the Chironomidae as an indicator group, correlation coefficients were high for D garbage can samples ($r = 0.77$) and C dip net samples ($r = 0.74$) and low for D dip net samples ($r = 0.43$) and C garbage can samples ($r = 0.25$). (See Figs. 30 to 33). Because of the inconsistency of the results, the possibility of using Chironomidae as an indicator group must be discarded.

There was no significant difference between primary consumer H'' pre- and post-treatment in D for either dip net or garbage can samples. The same was true of secondary consumer H''. However, primary consumer H'' was significantly different at the 1% level from secondary consumer H'' for both dip net and garbage can samples. This would suggest either an unfortunate choice of taxa or a real difference in the diversity of the two groups in D slough, or both. The difference was again reflected in comparisons between primary and secondary consumer H'' 's in the pre-treatment period in both dip net and garbage can samples (significance at the 5% level; $t = 2.382$ for 32 DF and $t = 2.331$ for 34 DF for dip net and garbage can samples respectively). However, the difference between primary and secondary consumer H'' for the post-treatment dip net samples was not quite significant at the 5% level ($t = 1.976$ for 22 DF) but was significant at the 5% level for the garbage can samples ($t = 2.507$ for 22 DF). These results left unanswered the question of whether the dieldrin affected the

Figure 30. Correlation of total H'' with Chironomidae H'' for garbage can samples from C slough

Figure 31. Correlation of total H'' with Chironomidae H'' for dip net samples from C slough

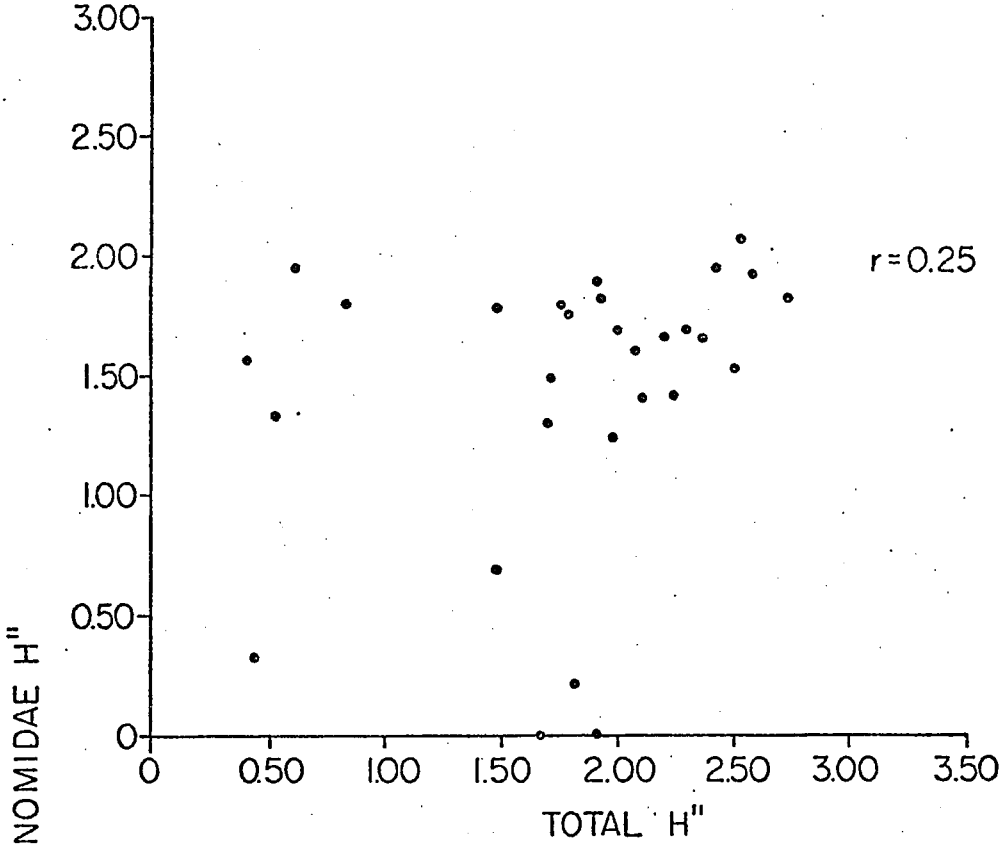


Figure 30

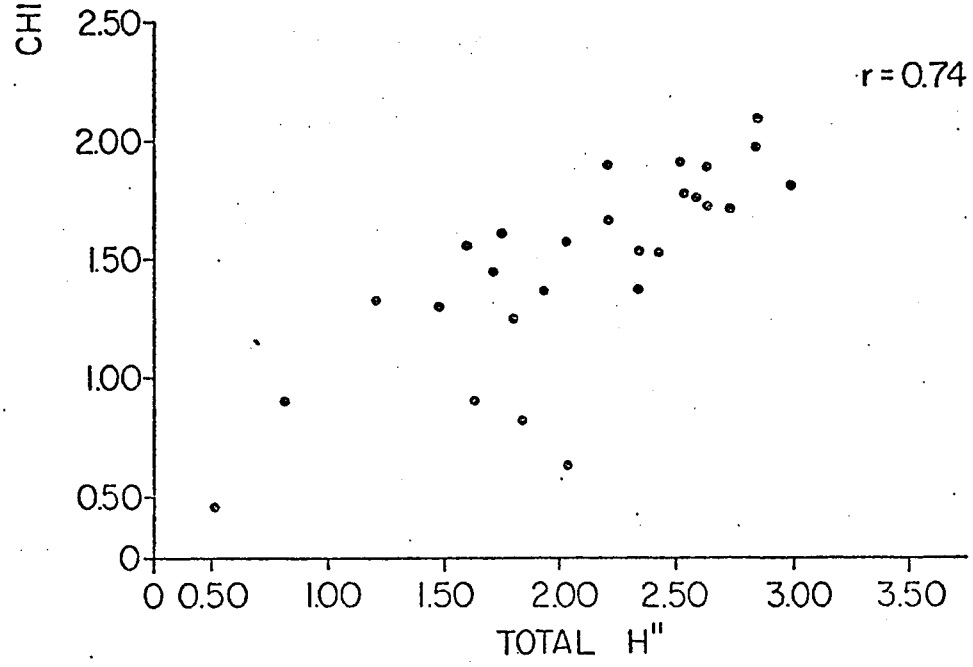


Figure 31

Figure 32. Correlation of total H'' with Chironomidae H'' for garbage can samples from D slough

Figure 33. Correlation of total H'' with Chironomidae H'' for dip net samples from D slough

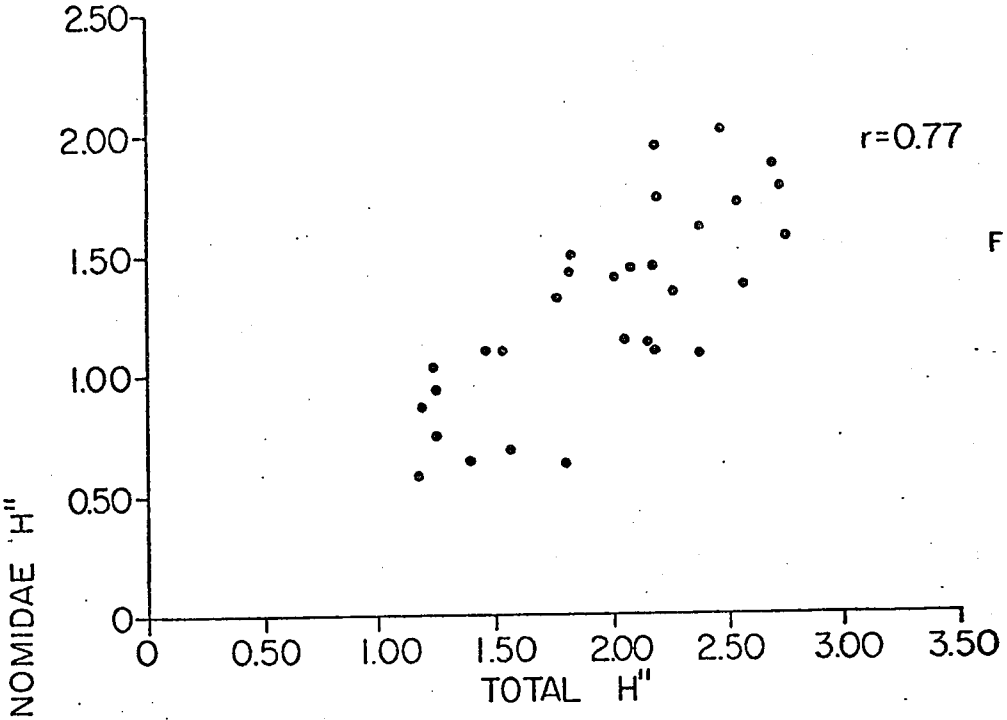


Figure 32

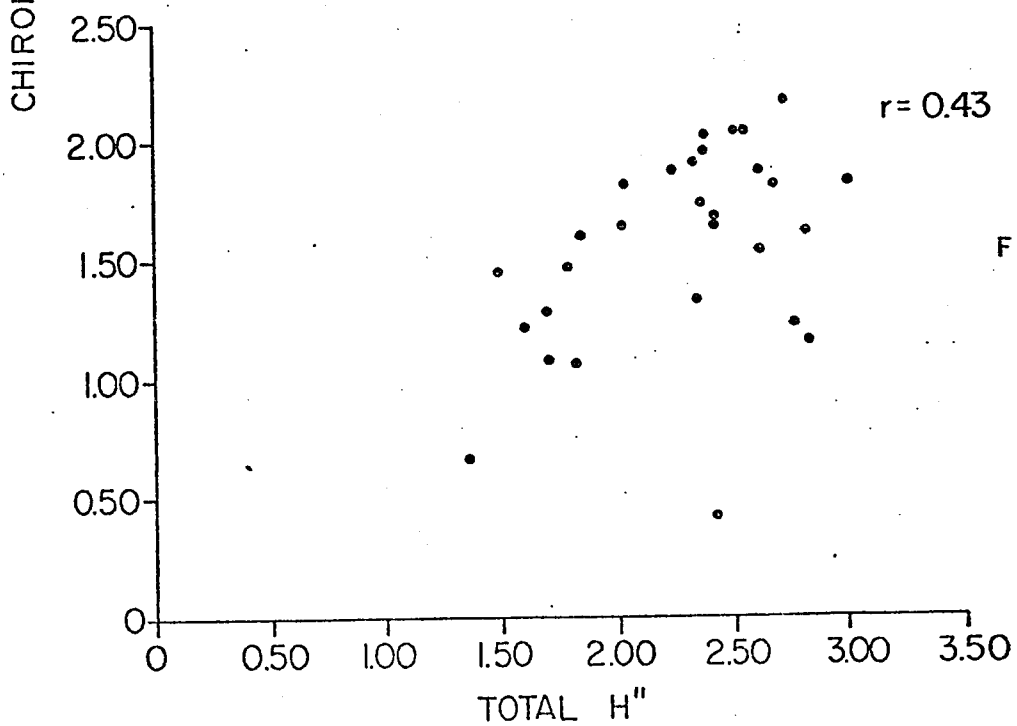


Figure 33

difference in H'' between primary and secondary consumers and so a two-way analysis of variance was done on a two by two factorial experiment using unpaired data: primary and secondary consumer H'' 's versus pre- and post-treatment H'' 's. For both dip net and garbage can samples there was a group effect (that is, a significant difference between primary and secondary consumer H'' 's); but there was no treatment effect (that is, there was no difference between pre- and post-dieldrin application in primary and secondary consumer H'' 's); and no interaction (that is, no diversity change caused by the pesticide). The p values were as follows:

| | dip net | garbage can |
|---|---|---|
| group | 0.004 | 0.001 |
| treatment | 0.387 | 0.795 |
| interaction | 0.785 | 0.732 |

Primary consumer H'' was not significantly different from secondary consumer H'' for both dip net and garbage can samples in C slough. However, when the primary and secondary consumer H'' 's are separated into pre- and post-treatment periods there is a significant difference at the 1% level for primary consumers for the dip net samples but this is not reflected in the garbage can samples although the "t" value for the latter is close to being significant at the 5% level (t = 1.860 for 28 DF). For secondary consumers both dip net and garbage can samples are significantly different at the 1% level.

The relatively close fit of the yearly graphs of H'' for dip net samples in D slough (Figs. 22 to 25) suggest that the part of the littoral from which the dip net samples were taken was relatively more stable than that of the garbage can samples. This is reasonable

because the shallow, near-shore area from which the garbage can samples were taken is more subject to environmental influences (for example, desiccation). Daborn (1969) concluded the same about the samples he took in the near-shore area of his slough. On the other hand, the wide range of H" values in both types of samples in C suggests that the littoral area of C was generally unstable (and/or perhaps that there was more overlap in the position in the littoral from which both samples were taken in C than in D). The drop in H" 's in C slough in 1967, as shown by Figs. 14 to 18, 20, and 21 would support the idea of the general instability of the littoral area.

The dip net and garbage can samples gave different results within the same comparison in only four out of the 19 "t"-tests and three of these four were nearly the same. This indicates that despite the fact that the two types of samples were generally taken in different areas of the littoral and despite suggestions that the littoral of C and the near-shore littoral of D were generally unstable the dip net and garbage can samples both reflected similar occurrences with respect to aspects of the diversities of the macroinvertebrates studied in these littoral areas.

Values of total H" generally ranged from 1.5 to 2.5 in the two sloughs. Ransom and Dorris (1972, Fig. 2) showed diversities that were generally between 1.0 and 3.0 for reservoir macroinvertebrates. Wilhm (1970c) reported an average value of 1.55 from the marginal area of a spring basin. Based on stream data, Wilhm (1972, p. 237) stated: "Thus it appears that diversity values exceeding three characterize clean water conditions, values less than one indicate heavy pollution, and values from one to three represent intermediate

conditions".

In summary, tree removal was not likely the cause of the diversity decline in C slough in 1968. Whether or not this change was caused by climatic factors cannot be answered by this study. The Chironomidae could not be used as an indicator group for diversity levels in the other macroinvertebrate groups studied. The dieldrin applied to D slough had no effect on any aspect of the diversities of the littoral macroinvertebrates studied.

# V. SUMMARY AND CONCLUSIONS

1. The advantages and disadvantages of using diversity indices derived from information theory for community studies are discussed. It is pointed out that the use of such indices in community studies dealing with the effects of pesticides on aquatic invertebrate fauna has been neglected.

2. Physical and chemical parameters of the two sloughs studied were similar throughout the study. Tree removal had no discernible effects on water level, maximum summer water temperature, turbidity, or nutrient concentrations in C slough.

3. Zooplankton had the highest initial concentration of dieldrin of any ecosystem constituent. Primary and secondary macroinvertebrate consumers carried similar levels of dieldrin in their tissues. The literature reveals this same lack of trophic level effect. Uptake of chlorinated hydrocarbon pesticides in aquatic invertebrates is probably more a function of exchange equilibria than food uptake. Pharmacokinetics and various extrinsic factors are also involved.

Dieldrin residues in mud, water, vegetation, and invertebrates of D slough declined according to a first order kinetics equation, following descriptions by other authors. These declines were influenced by the hydrophobic nature of chlorinated hydrocarbons and the interaction of physical and biological processes.

4. In general, H'' varied from 1.5 to 2.5 in C and D sloughs.

Tree removal was not likely the cause of the diversity decline in C slough in 1968. Chironomidae, the single most diverse group in both sloughs, could not be used as an indicator group to reflect total diversity.

5. The need to determine the levels of pesticide in fauna that will cause diversity changes is pointed out. At the parts per billion concentrations of dieldrin in the tissues of slough macroinvertebrates of this study no change could be detected in total, primary and secondary consumer, and Chironomidae diversities.

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# APPENDICES

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# APPENDIX I

## METHODS FOR THE GAS CHROMATOGRAPHIC ANALYSIS OF MUD, WATER, VEGETATION, AND INVERTEBRATES

### A. Mud, water, and vegetation

1. Apparatus

a) blendors

(i) Omni-Mixer--Ivan Sorvall Inc.; Norwalk, Conn.

(ii) Virtis 23 Homogenizer--The Virtis Co., Inc.; Gardiner, N. Y.

(iii) Waring Blendor--Waring Products Co.; Winsted, Conn.

b) International Centrifuge--International Equipment Co.; Needham Hts., Mass.

c) Chromatographic columns--28 mm o.d. x 580 mm with teflon stopcock and coarse fritted plate (available from Macalaster Scientific Corp.; Nashua, N. H.).

d) Exhaust cabinet.

e) Gas chromatograph--Varian Aerograph Model 1200 (Varian Aerograph; Walnut Creek, Calif.) with electron capture detector containing a 250 mc tritium ionization source and a 300 V potential across the detector. The recorder was a Leeds and Northrup Speedomax W (Leeds and Northrup Co.; Philadelphia, Pa.) with a 27 cm chart operated in the 1 mV span; and with a Disc Model 224 Integrator (Disc Instruments, Inc.; Santa Ana, Calif.). The analytical column was a 3 mm o.d. x 152.4 cm

Pyrex glass packed with 6% QF-1 and 4% SE-30 on 60/80 Chromosorb W (Varian Aerograph; Walnut Creek, Calif.). The column was conditioned for 24 hours at a temperature approximately 40°C above normal operating column temperature and with an increased nitrogen flow. The carrier gas was nitrogen (99.993% purity; Canadian Liquid Air Co. Ltd.). Flow rate during normal operation was 40-60 ml/minute. Column, injector, and detector temperatures were 200°C, 220°C, and 230°C respectively.

2. Reagents

a) Florisil (Fisher Scientific Co., Cat. No. F-100)--60-100 mesh activated at 1200°C. Satisfactory recoveries were obtained without standardization.

b) Petroleum ether--B.P. 30°-60°C; re-distilled.

c) Ethyl ether--reagent grade.

d) Acetonitrile--reagent grade (nanograde).

e) Acetone--reagent grade (nanograde).

f) N-hexane--spectro-grade.

g) Benzene--spectro-grade.

h) Extraction mixtures:

(i) for water analysis--ethyl ether 50% in petroleum ether (v/v).

(ii) for mud analysis--acetone 10% in acetonitrile (v/v).

i) Cleanup mixtures (mud and vegetation)--ethyl ether 6% and 15% in petroleum ether (both v/v).

j) Sodium sulphate--anhydrous, granular, reagent grade.

k) Sodium chloride--granular, reagent grade.

l) Dieldrin standard--85% dieldrin; Nutritional Biochemicals

Corp., Cleveland, Ohio; and City Chemical Corp., New York, N. Y.; prepared in n-hexane and stored at approximately 0°C.

3. Procedures

a) Water from each depth class was thoroughly mixed in each pail and a one liter subsample removed and passed through Whatman filter paper to remove larger organic particles (for example, plankton). The sample was then extracted according to Breidenbach *et al.* (1966, p. 22-25) with the following modifications: 950 ml of slough water and 50 ml distilled water containing 20 g $Na_2SO_4$ were added to a two liter separatory funnel and successively extracted with 100, 50, 50, 50, and 50 ml of 50% ethyl ether in petroleum ether (v/v). For each extraction the separatory funnel was shaken moderately for 4, 3, 2, 1, and 1 minutes respectively. The ethyl ether-petroleum ether fractions were poured through 5 cm of anhydrous $Na_2SO_4$ in a powder funnel plugged with a pledget of glass wool and the separatory funnel and $Na_2SO_4$ rinsed with small amounts of petroleum ether which were added to the combined extracts. Extracted samples were placed in the exhaust cabinet overnight to allow the solvents to evaporate. These samples generally did not require clean-up on Florisil columns and were made up in 10 ml n-hexane and injected. Recovery studies using dieldrin-free slough water to which sufficient dieldrin had been added to yield a concentration of 1 ppb, gave recovery percents of 87.5, 81.0 and 91.0 ($\bar{x}$ = 87.0).

b) Mud from the cores taken in each quarter was pooled according to quarter and a 100 g subsample removed. Extraction and cleanup was done according to Tyo (unpublished) as follows: 175 ml of 10% acetone in acetonitrile was added to the 100 g of mud which was then blended, using the Virtis Homogenizer or the Waring Blendor, at high

speed for five minutes. The slurry was poured into centrifuge bottles, and the homogenizer or blendor cup and blades washed three times with small amounts of the acetone-acetonitrile mixture, and the washes added to the centrifuge bottles. The slurry was centrifuged at 1500 RPM and the resulting supernatent decanted through a powder funnel plugged with a pledget of glass wool into a two liter separatory funnel containing 1000 ml of a 2% aqueous $Na_2SO_4$ solution and 100 to 125 ml of petroleum ether. This procedure was repeated substituting 100 ml of 100% acetonitrile for the 175 ml of 10% acetone-acetonitrile and, using a small amount of petroleum ether, the glass wool was rinsed. The separatory funnel was shaken vigorously for one minute, venting as necessary, and another 450 ml of the 2% aqueous $Na_2SO_4$ solution added. The separatory funnel was then shaken vigorously for five minutes, venting as necessary, and allowed to stand for five minutes until phase separation was complete. The water-acetonitrile-$Na_2SO_4$ solution was drained and discarded and the petroleum ether fraction was re-washed with 400 to 500 ml of the 2% aqueous $Na_2SO_4$ solution and the lower fraction was again drained and discarded. The petroleum ether was then slowly drained through 5 cm of anhydrous $Na_2SO_4$ in a powder funnel plugged with a pledget of glass wool and into a beaker. The separatory funnel and the $Na_2SO_4$ were rinsed several times with small amounts of petroleum ether and the rinsings were added to the beaker which was then placed in the exhaust cabinet overnight. Cleanup was basically as described in Barry *et al.* (1968, section 211.15). The chromatographic column was filled with approximately 11.3 cm of Florisil tamped down to 10 cm. 1.3 cm of anhydrous $Na_2SO_4$ was added to the top and the column was prewashed with 35 ml

of petroleum ether which was discarded. The evaporated, extracted sample was dissolved in as small a volume of petroleum ether as possible and added to the column. The beaker containing the extracted sample was washed several times with small amounts of petroleum ether and the rinsings were added to the column, followed by 200 ml of 6% ethyl ether in petroleum ether and 400 ml of 15% ethyl ether in petroleum ether. Flow rate was adjusted to about 5 ml/minute. The eluant was collected in a beaker and left in the exhaust cabinet overnight to dry. The sample was then made up in 10 ml n-hexane and injected. Recovery studies using a 10 ppb spike in dieldrin-free mud yielded percent recoveries of 78.0, 82.0, 82.0, and 82.0 ($\bar{x}$ = 81.0).

c) A 40 g subsample was taken from the pooled emergent, floating and/or submergent vegetation, and algae samples collected in each quarter. In essence, the method outlined in Barry *et al.* (1968, section 212.13b and 212.15) was followed. Surface moisture was removed from wet vegetation by blotting with a paper towel. The sample was transferred to an Omni-Mixer cup, 150 ml of 100% acetonitrile was added, and the sample blended at medium speed for two to three minutes. The resultant mash was added to centrifuge bottles, the Omni-Mixer cup and blades were rinsed with 100% acetonitrile which was added to the bottles, and the sample was centrifuged at 1750 RPM for ten minutes. The supernatant was poured through a pledget of glass wool in a powder funnel into a two liter separatory funnel. This procedure was repeated substituting 100 ml of 100% acetonitrile for the 150 ml used the first time. One hundred ml of petroleum ether was then poured into the separatory funnel through

the glass wool and the separatory funnel was shaken for one minute, venting as required. Seventy-five ml of an approximately 30% NaCl solution and 1500 ml of distilled water were added to the separatory funnel which was shaken for one more minute, venting as required. The separatory funnel was let stand for five minutes to allow phase separation and the acetonitrile-water-NaCl fraction (bottom) was drained off and discarded. The petroleum ether fraction was washed with two 100 ml portions of distilled water and the separatory funnel shaken gently, let stand, and the lower portion drained off and discarded. (If an emulsion formed, 5 ml of the 30% NaCl solution were added). Five to 7.5 cm of anhydrous $Na_2SO_4$ were added to a powder funnel plugged with a piece of glass wool, the $Na_2SO_4$ was pre-wet with a small volume of petroleum ether and the separatory funnel was drained through the $Na_2SO_4$ into a beaker. The separatory funnel was rinsed three times with small amounts of petroleum ether which was also drained through the $Na_2SO_4$. The collecting beakers were placed in the exhaust cabinet overnight to dry. Clean-up and injection was as described for the mud samples. Recovery studies using 100 ppb added to dieldrin-free vegetation gave percent recoveries of 80.5, 83.5, and 85.0 ($\bar{x}$ = 83.0).

To analyze the dieldrin content of the emulsifiable concentrate being used to treat D slough, two samples were diluted to $10^{-5}$ in distilled water and extracted as per Breidenbach *et al.* (1966, p.22-25) and two samples were diluted to $10^{-3}$ in n-hexane and extracted with n-hexane. The extract was allowed to evaporate, made up in 10 ml n-hexane and injected. The results were $0.185 \times 10^6$, $0.188 \times 10^6$, $0.162 \times 10^6$, and $0.173 \times 10^6$ ($\bar{x} = 0.177 \times 10^6$) ppm for a 20

E.C. mixture.

Standards were injected frequently (usually every four to eight sample injections) and, although the linear range of the machine was not plotted, most peaks were kept within 30% of the standing current. Also, height of the standard and unknown peaks were kept within one-third of each other as much as possible. Dieldrin concentration was calculated by the method of peak area according to the following formulae:

1. peak area = peak height x width at half height.

2. $$\text{ppm dieldrin} = \frac{\frac{\text{area of unknown peak}}{\text{area of standard peak}} \times \text{vol. of standard injected (ml)} \times \text{standard conc. (g/ml)}}{\frac{\text{weight of sample (g)}}{\text{dilution (ml)}} \times \text{volume injected (ml)}} .$$

However, peak height was sometimes substituted for peak area and the disc integrator was also used. Peak heights of less than 3 mm were considered to be below experimental limits of detection.

The confirmatory procedure used involved chemical conversion of dieldrin to a ketone by boron trifluoride etherate (Skerrett and Baker, 1959; J. Singh, personal communication). The following method (J. Singh, personal communication) was used:

1. The sample to be treated contained 50 ng to 2 µg of dieldrin.

2. If the final extract was in any solvent other than benzene, the solvent was evaporated completely and the remaining residue dissolved in 1 ml of benzene.

3. One to three drops of boron trifluoride etherate were added and the sample shaken vigorously for at least one minute.

4. The sample was placed in a waterbath for one-half hour at 78°C.

5. After cooling to room temperature, the reaction mixture was washed with two ml distilled water, let stand and then injected.

6. The retention time of the ketone was established by running a parallel conversion with dieldrin standard.

Approximately one sample in four was confirmed. All samples were not confirmed because the retention time of the ketone was approximately three times that of unconverted dieldrin; because the boron trifluoride etherate corrodes the moving parts of the syringe and causes them to freeze together; because the detector is dirtied; and because the process is irreversible so the sample, once converted, is lost.

B. Invertebrates

1. Apparatus and reagents--See Kadis, Jonasson, and Breitkreitz (1968); and add: a Varian Aerograph Model 2100 fitted with two five foot by one quarter inch o.d. stainless steel columns, one packed with 3% SE-30 on 100/120 mesh Aeropak 30 and one packed as in Kadis *et al.* (1968); and magnesium oxide-celite mixture (Kensington Sci. Co.; Oakland, Calif.; Cat. No. K-3239)--chromatographic grade.

2. Procedure--Invertebrates were divided into two types for purposes of maceration: those with hard exoskeletons (for example, Corixidae, Notonectidae, and adult Dytiscidae) and those with soft exoskeletons (for example, Hirudinea, Gastropoda removed from their

shells, zooplankton, and Chironomidae and Odonata immatures). After surface moisture was removed from each sample by blotting with paper toweling, the former were combined with sand and anhydrous $Na_2SO_4$ (for 2 g invertebrate tissue, approximately 5 g sand and 10 g $Na_2SO_4$) and ground with the Omni-Mixer at medium speed for about five minutes or until a visually homogeneous mixture resulted (Jonasson and Rosenberg, 1969). The mixture was then added to 50 g deactivated florisil in a mortar and pestle, the Omni-Mixer cup and blades were rinsed with petroleum ether, and the rinsings were added to the mortar and pestle. The invertebrates with soft exoskeletons were ground directly in 50 g of deactivated florisil in the mortar and pestle. For soft and hard types, the mixture from the pestle was then added to a chromatographic column containing 50 g deactivated florisil prewashed with 150 ml of 1:1 methylene chloride-petroleum ether, the mortar and pestle were rinsed with petroleum ether and the rinsings were added to the column, and the column was eluted with 800 ml 20:80 methylene chloride-petroleum ether. The eluant was flashed down to near dryness, made up in a suitable volume, and injected (Kadis *et al.*, 1968). Some samples which were still dirty were further cleaned up on a magnesium oxide-celite column as described in Barry *et al.* (1968, section 211.16c) and/or by the following method: 10 g deactivated florisil sandwiched between two 2.5 cm portions of anhydrous $Na_2SO_4$ prewashed three times with 25 ml petroleum ether. The sample was added to the column and the column was then eluted with 150 ml 5% benzene in petroleum ether and then 200 ml of 25% benzene in petroleum ether, the second fraction containing the dieldrin.

Recovery studies were done using *Hyallela azteca* from C slough. Samples spiked with 0.003 µg dieldrin ($0.12 \times 10^{-8}$ ppm in 2.42 g tissue) gave recovery percents of 93.3, 94.1, and 98.1 ($\bar{x} = 96.2$).

Most of the samples were injected into the 6% QF-1 column and most of these were done on the Varian 1520. Injections of the boron trifluoride etherate conversion were made on either the 6% QF-1 column or into the microcoulometric system. Standards were injected every two to three samples. Although the linear ranges of the gas chromatographs were calibrated, peaks were kept within 30% of the standing current and 30% of each other. Peak height was used to determine dieldrin concentrations (see formula above). Multiple injections of the same sample were averaged. The SE-30 column in the Varian 2100 was used as a confirmatory procedure additional to the microcoulometric system and the boron trifluoride conversion. Thin-layer chromatography proved to be unsatisfactory because of the low concentrations of dieldrin involved.

## APPENDIX II

## WINTER OBSERVATIONS

Although the major emphasis of this study was placed on the open-water period, and visits to the sloughs in winter were mainly to take water samples for oxygen analysis, still, the winter visits provided a number of interesting observations.

Table 1 gives ice thicknesses and depths to the slough bottom. Daborn (1969) reported that the water of his study slough was totally frozen by the end of December so it is possible that with some free water still present in my sloughs past the end of December in 1966 and 1967 (see Table 1) my sloughs did not freeze to the bottom in the first (1966/1967) or second (1967/1968) winters. Almost certainly, however, D slough totally froze in the third winter (1968/1969) probably because of the much reduced water level. The peripheral areas of D froze in the second and third winters but, surprisingly, the peripheral area of C did not in the second winter. The reduction of water level over the period of the study can be seen by the progressive lowering of the depths to the bottom for holes chopped into the deepest depth contour of each slough and for similar times of year:

| Date | D | C |
|---|---|---|
| April 28, 1967 | 147.3 cm | 147.3 cm |
| February 9, 1968 | 71.1 cm | 99.1 cm |
| March 6, 1969 | 61.0 cm | |

Table 1. Winter observations on C and D sloughs

| Sampling Date | Slough | Location | Ice Thickness (cm) | Distance to Bottom of Slough (cm) | Distance Between Bottom of Ice & Top of Mud (cm) | Additional Observations |
|---|---|---|---|---|---|---|
| Nov. 23/66 | D | midway on 100 m N to S* | | | | *Chaoborus*, Ephemeroptera, & Gammaridae in water. |
| Dec. 19/66 | D | midway on 60 m N to S | 41.9 | 116.8 | 75.0 | Strong smell $H_2S$; *Chaoborus* & Gammaridae in water. |
| Dec. 19/66 | C | intersect: 50 m N to S by 60 m E to W* | 45.7 | 127.0 | 106.7 | Mud smelled of $H_2S$; *Chaoborus*, *Diaptomus*, Ephemeroptera, and Corixidae in water; *L. trisulca* pulled up. |
| April 28/67 | D | midway on 60 m N to S | 66.0 | 147.3 | 81.3 | Dead corixid in water. |
| April 28/67 | C | intersect: 50 m N to S by 60 m E to W | 71.1 | 147.3 | 76.2 | Some *Chaoborus* in water. |
| Feb. 9/68 | D | 1. 55 m N to S by 40 m E to W | 61.0 | 71.1 | 10.2 | 1. Strong smell $H_2S$ from hole in ice and from water taken for dissolved oxygen analyses; bubbles in ice; |

Table 1. (Continued)

| Sampling Date | Slough | Location | Ice Thickness (cm) | Distance to Bottom of Slough (cm) | Distance Between Bottom of Ice & Top of Mud (cm) | Additional Observations |
|---|---|---|---|---|---|---|
| | | | | | | chironomid, *C. demersum*, & algae frozen into ice. |
| Feb. 9/68 | D | 2. 100 to 105 m N to S by 30 to 35 m E to W | 45.7 (to top of frozen mud) | 96.5 (to top of unfrozen mud) | none | 2. Strong smell $H_2S$ from hole. |
| Feb. 9/68 | C | 1. 45 m N to S by 60 m E to W | 88.9 | 99.1 | 10.2 | 1. Strong smell $H_2S$ from water taken for dissolved oxygen analyses; *C. demersum* frozen into ice; Gammaridae too, at 76.2 cm from surface. |
| | | 2. 10 to 15 m N to S by 30 to 35 m E to W | 76.2 | 81.3 | 5.1 | 2. Smell of $H_2S$ from hole in ice; mud still frozen 45.7 cm deeper; *L. trisulca*, Corixidae, Zygoptera, & Trichoptera frozen into ice. |

Table 1. (Continued)

| Sampling Date | Slough | Location | Ice Thickness (cm) | Distance to Bottom of Slough (cm) | Distance Between Bottom of Ice & Top of Mud (cm) | Additional Observations |
|---|---|---|---|---|---|---|
| Mar. 6/69 | D | 1. midway on 60 m N to S | 61.0 | 61.0 | | |
| | | 2. 100 m, N shore | 15.2 | 15.2 | | |

* N = north, S = south, E = east, W = west.

...and from the differences in distances from the bottom of the ice to the top of the mud, also for similar areas and times:

| Date | D | C |
|---|---|---|
| April 28, 1967 | 81.3 cm | 76.2 cm |
| February 9, 1968 | 10.2 cm | 10.2 cm |
| March 6, 1969 | 0 | |

Temperatures and oxygen concentrations for the winter sampling periods are given in Tables 6 and 7 and Figs. 7 and 9. No oxygen was detected in D in the December 19, 1966 and February 9, 1968 sampling dates or in the February 19, 1968 C slough sampling. Dead slough vegetation as well as allochthonous organic matter (for example, leaf fall) accumulate in the slough all through the open water period and, during the period of ice cover, decomposition of this organic matter depletes the oxygen in the water. Under anaerobic conditions, sulfate is used in the chemosynthetic processes of sulfur bacteria and is reduced to $H_2S$ (Reid, 1961). This accounts for the many times during winter sampling that I smelled $H_2S$ (see Table 1). It is significant in this regard that the levels of sulfate measured during the open water period are about ten times those reported by Daborn (1969).

The bubbles in the ice that I observed result from the release of dissolved oxygen from the water during ice formation and its subsequent trapping in the ice (Daborn, 1969).

Although my study did not take a life history approach it is apparent that many invertebrates survive the winter in the water remaining below the ice (when sufficient oxygen is present) or are frozen into the ice, usually in a small pocket or bubble of air (see Table 1). Hynes (1970a, b) documented the survival and thriving

of invertebrates beneath the ice of streams. Of course, oxygen is not usually a limiting factor in the stream environment (Hynes, 1970a). Many invertebrates of northern latitudes reach their maximum biomass under the ice of streams and emerge in the early spring (Hynes, 1970a, b). Judging from the large size of the Ephemeroptera, *Chaoborus* sp., and Gammaridae that come up with the water, these animals were in their last instars or, considering the Gammaridae, may have been adult.

The ability of invertebrates (and plants) to survive being frozen into the ice of sloughs must be an important adaptation to life in these habitats. References to this phenomenon among invertebrates are scattered through the literature. Scholander *et al.* (1953) and Thienemann (1954) make references to Chironomidae larvae being frozen into ice. Daborn (1970, p. 571) reported finding a variety of invertebrates "in apparently viable condition". Paterson (1971) reported on the overwintering success of the pitcher plant chironomid (*Metriocnemus knabi* Coq.) and mosquito (*Wyeomyia smithii* [Coq.]) in the essentially freshwater habitat in the axils of the plant. Daborn (1970) found that the percentage of Zygoptera nymphs surviving in the ice decreased progressively through the winter and suggested that the high mortality was due to lower than normal ice temperatures. Conversely, Paterson (1971) reported overwintering success to be greater than 95% for *M. knabi* and *W. smithii*. Like terrestrial insects, freshwater ones prepare for overwintering by ceasing to feed and voiding their gut contents (Salt, 1961; and Paterson, 1971). Nobody has examined freshwater invertebrates for the presence of glycerol. However, Salt (1961, p. 70) suggested the likelihood that "all freezing-tolerant insects, and

perhaps other invertebrates as well, contain glycerol, or some equivalent, as a protective substance".

## APPENDIX III

### PHYSICAL AND CHEMICAL MEASUREMENTS OF C AND D SLOUGHS[1]

1. Water level--Seasonal and long-term fluctuations in water level are common for bodies of water of this kind (Hartland-Rowe, 1966; and Daborn, 1969). The below average precipitation during the course of this study contributed to the overall decline of water levels. The total precipitation from May to October in 1966, 1967, and 1968 was 29.24 cm, 25.12 cm, and 26.72 cm respectively compared to the long-term average total precipitation for this period of 33.33 cm. Total precipitation for 1966, 1967, and 1968 was 39.27 cm, 39.09 cm, and 35.46 cm respectively compared to the long-term average total precipitation of 47.35 cm. Figs. 1 and 2 (in text of thesis) show size, shape, and depth contours for D slough at the start of the study and just prior to dieldrin application respectively. Fig. 1 (this Appendix) shows the difference in the size of C slough at the start of the study and near the end.

2. Temperatures--Vertical water temperature profiles for C and D sloughs appear in Tables 2 and 3. Maximum and minimum and mean

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[1] All weather data are for Edmonton City and are taken from the Annual Meteorological Summary for Edmonton City and Edmonton International Airport, 1966-1969; Canada Department of the Environment, Atmospheric Environment Service; Weather Office, International Airport; Edmonton, Alberta.

Figure 1. Size of C slough at the start of the study (end of May, 1966) compared to its size near the end of the study (June and August, 1968)

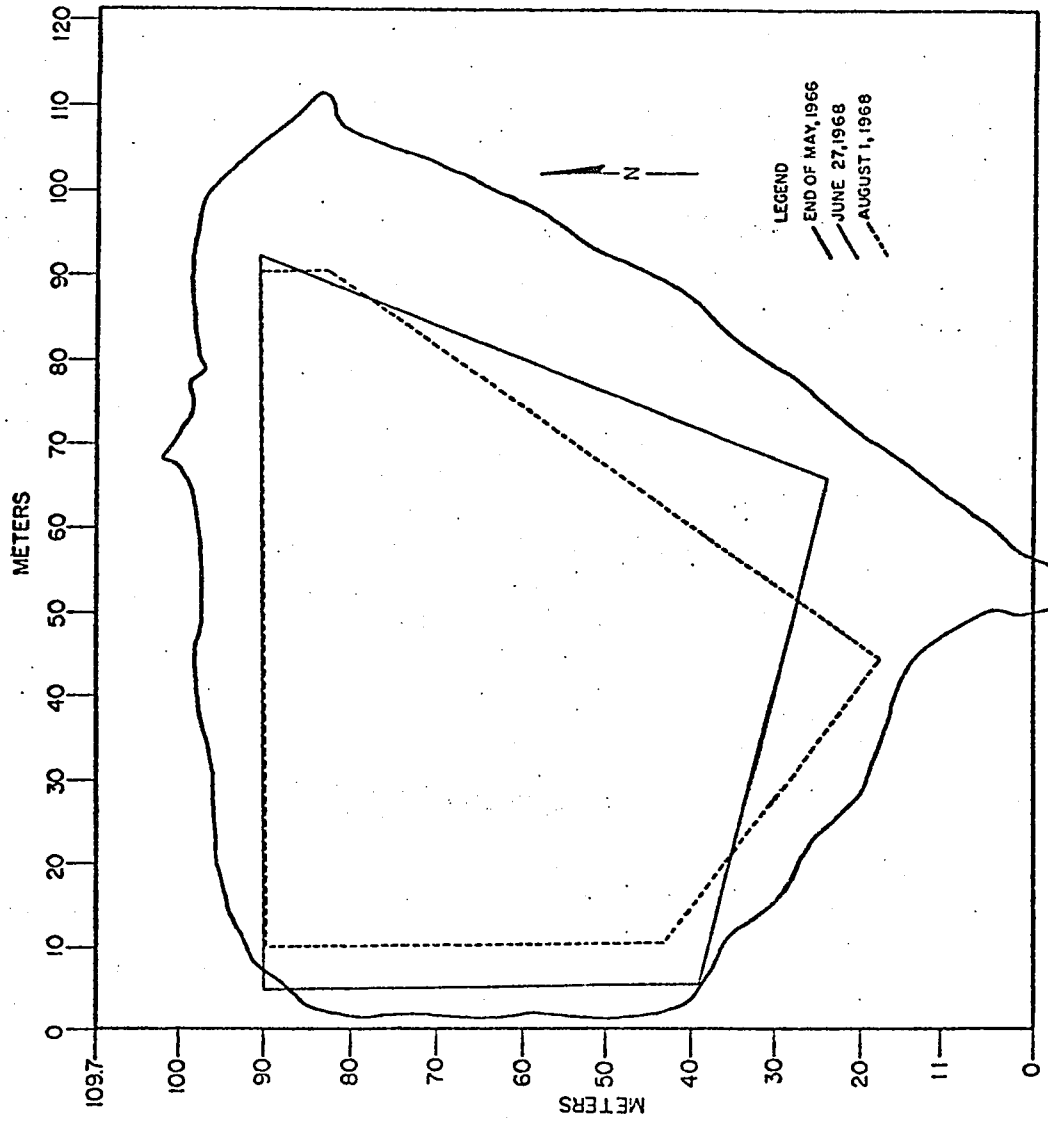
METERS
0
10
20
30
40
50
60
70
80
90
100
110
120
109.7
100
90
80
70
60
50
40
30
20
11
0
METERS
N
LEGEND
END OF MAY, 1966
JUNE 27, 1968
AUGUST 1, 1968

Figure 1

Table 2. Vertical water temperature profiles for C slough

| Date and Time | Depth (cm) | Temperature (°C) |
|---|---|---|
| June 13/66; | 53.3 | 19.0 |
| 1445 hrs | 55.9 | 19.2 |
| | 61.0 | 18.9 |
| | 76.2 | 18.6 |
| | 86.4 | 18.1 |
| | 106.7 | 17.8 |
| | 121.9 | 17.5 |
| | 147.3 | 16.4 |
| | 148.6 | 17.2 |
| | 149.9 | 17.1 |
| | 152.4 | 17.0 |
| | 156.2 | 17.0 |
| September 1/66 | surface | 17.8 |
| | 15.2 | 17.2 |
| | 30.5 | 17.2 |
| | 45.7 | 16.7 |
| | 61.0 | 16.1 |
| | 76.2 | 15.6 |
| | 91.4 | 15.6 |
| | 106.7 | 15.6 |
| | 121.9 | 15.6 |
| | 137.2 | 15.6 |

Table 3. Vertical water temperature profiles for D slough

| Date and Time | Depth (cm) | Temperature (°C) |
|---|---|---|
| June 13/66; | 66.0 | 17.2 |
| 1330 hrs | 68.6 | 16.7 |
| | 83.8 | 16.7 |
| | 99.1 | 16.8 |
| | 111.8 | 17.0 |
| | 119.4 | 16.7 |
| | 127.0 | 15.0 |
| | 129.5 | 15.8 |
| | 132.1 | 15.0 |
| | 139.7 | 15.0 |
| | 147.3 | 15.6 |
| August 31/66; | surface | 17.8 |
| 1440 hrs | 15.2 | 17.8 |
| | 30.5 | 16.1 |
| | 45.7 | 15.8 |
| | 61.0 | 15.6 |
| | 76.2 | 15.3 |
| | 91.4 | 15.0 |
| | 106.7 | 15.0 |
| | 121.9 | 14.4 |
| | 137.2 | 15.0 |

surface water temperatures for C and D sloughs over the study period are shown in Figs. 2 to 5.

Mean surface water temperatures from May to October of each year of the study appear in Table 4. Mean air temperature data for the study period is given in Table 5. The increase in mean surface water temperatures in 1967 was caused by above average air temperatures in August, 1967. The disparity between mean surface water temperatures of both sloughs in 1968 is unexplained.

3. Turbidity (Fig. 6)--Low turbidity was usually coincident with algal blooms. The overall seasonal decreases in turbidity may be due to a reduction in allochthonous matter being washed into the slough as a result of the low precipitation during the three seasons of the study. The relatively high early June, 1968 values may be a reflection of the last part of the winter melt.

4. Water chemistry

a) Dissolved oxygen--Tables 6 and 7 list the oxygen concentrations, water temperatures, and percent saturations of oxygen for the different depth classes in each slough over the study period. Curves of oxygen concentrations are similar for both sloughs within each year (Figs. 7 to 9). Among years, 1967 and 1968 are similar. However, 1966 differs probably because water samples were not analyzed in the July to August period. Peaks in oxygen concentration in 1967 and 1968 are coincident with the algal blooms for those years (July to August for 1967; June to July for 1968). Lower oxygen concentrations in C slough for these periods may reflect the fact that blooms were never as extensive in C as they were in D. Unfortunately, no water samples were analyzed during the 1966 bloom period (July to August).

Figure 2. Maximum and minimum water temperatures in C slough for May to October 1966, 1967, and 1968

Figure 3. Maximum and minimum water temperatures in D slough for May to October 1966, 1967, and 1968

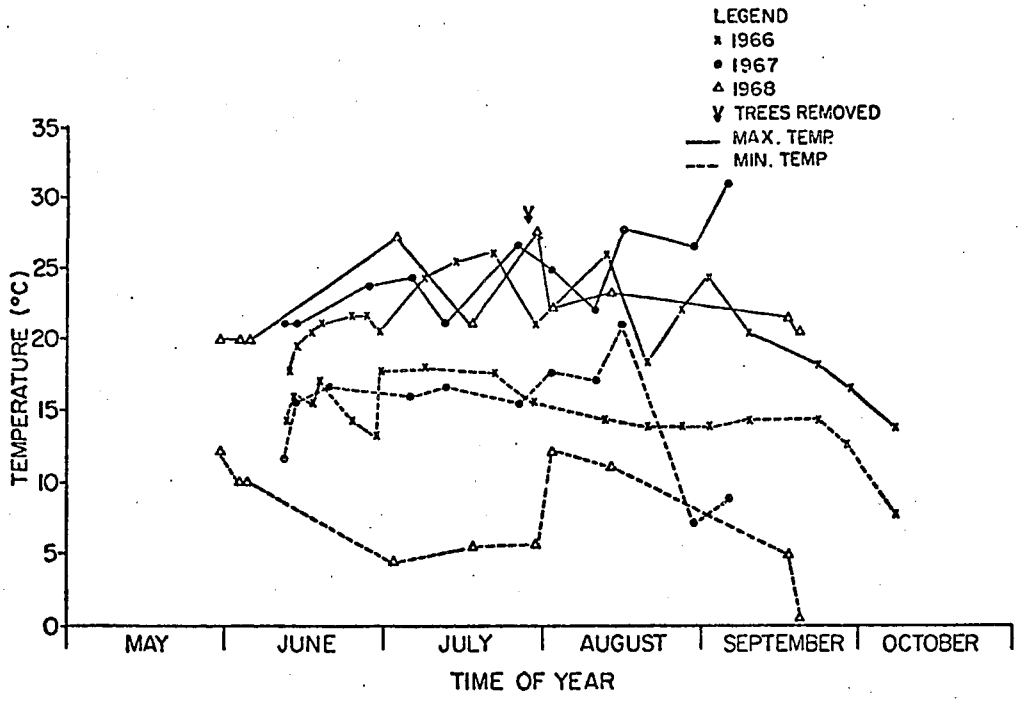


Figure 2

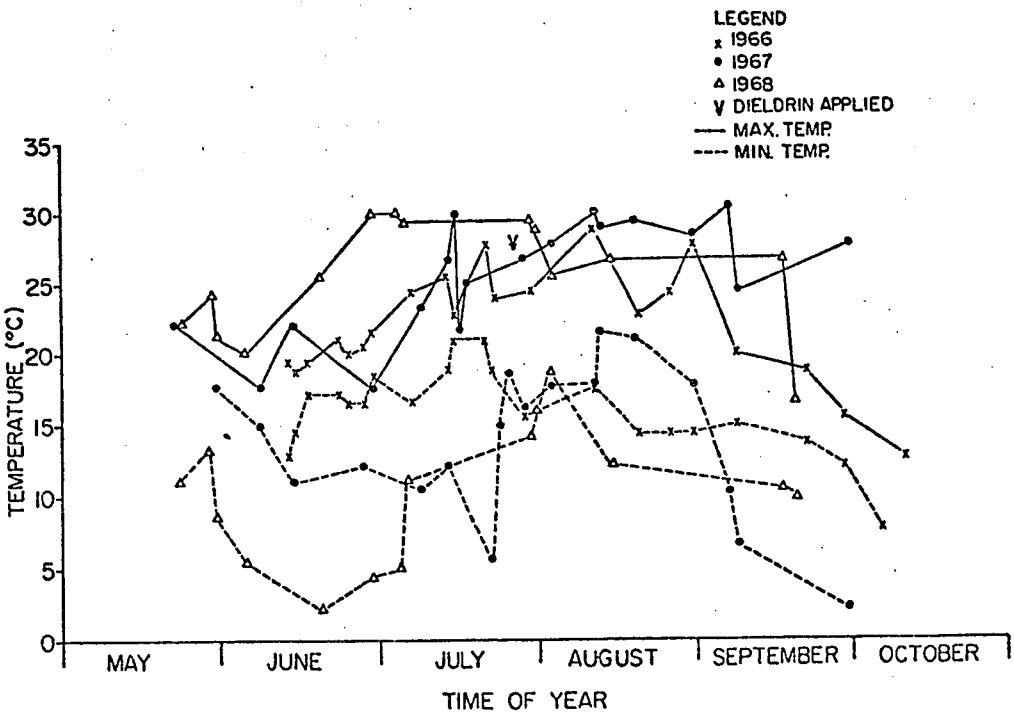


Figure 3

Figure 4. Mean surface water temperatures in C slough for May to October 1966, 1967, and 1968

Figure 5. Mean surface water temperatures in D slough for May to October 1966, 1967, and 1968

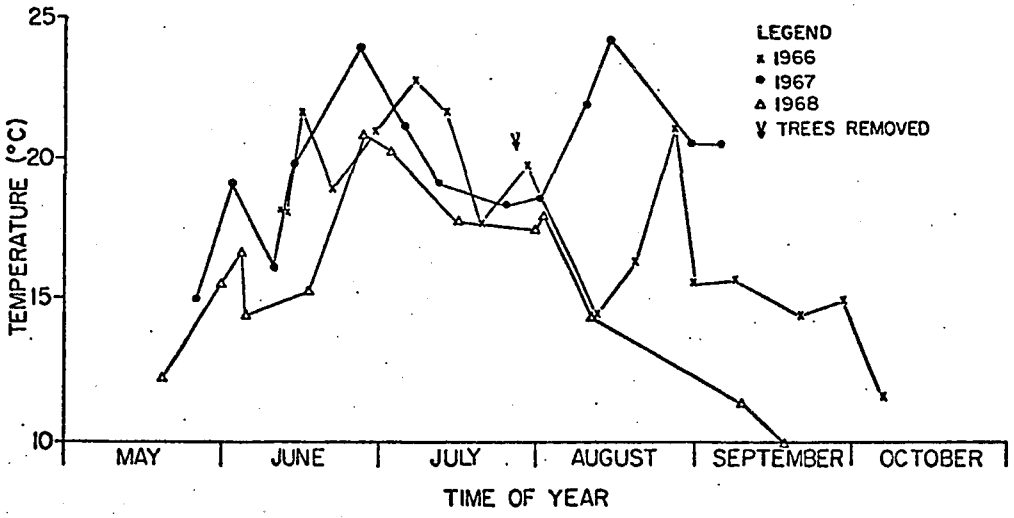


Figure 4

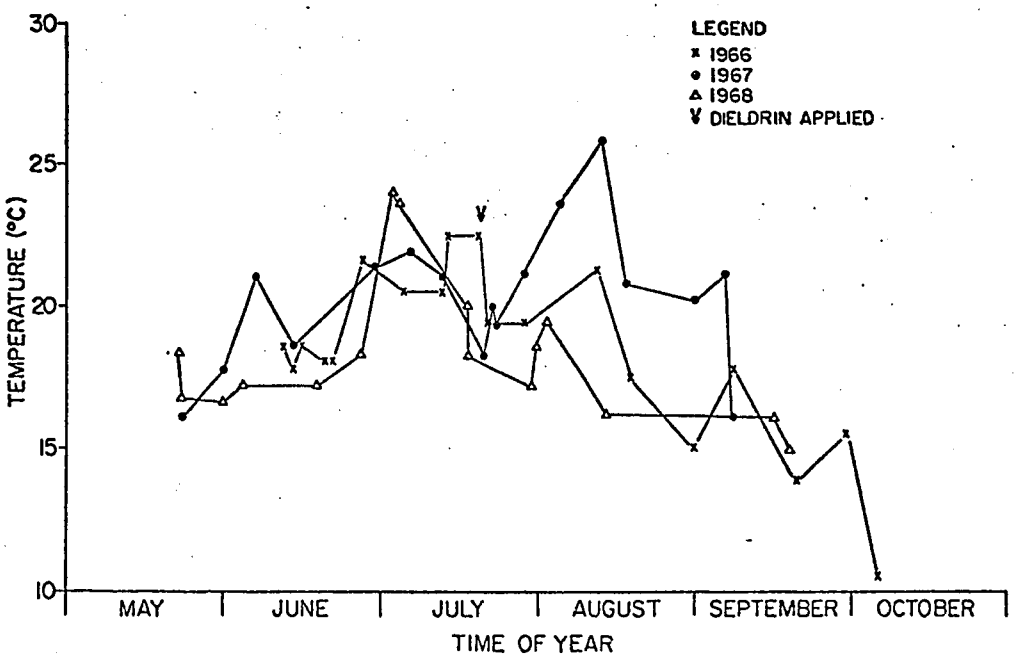


Figure 5

Table 4. Mean surface water temperatures from May to October of each year of the study for each slough

| Slough | Year | Mean Surface Temperature (°C) | |
|---|---|---|---|
| D | | West Level Pole | South Level Pole |
| | 1966 | 18.3 | 18.6 |
| | 1967 | 20.2 | 20.2 |
| | 1968 | 18.2 | 18.4 |
| C | | | North Level Pole |
| | 1966 | 18.1 | 18.2 |
| | 1967 | 20.2 | 19.9 |
| | 1968 | 16.0 | 15.6 |

Table 5. Mean air temperatures monthly from May to October, the period May to October, and yearly for 1966, 1967, and 1968 for Edmonton City

| Period of Time | Mean Air Temperature (°C) 1966 | 1967 | 1968 | Long Term |
|---|---|---|---|---|
| May | 12.4 | 10.6 | 11.2 | 11.2 |
| June | 13.8 | 14.3 | 14.5 | 14.3 |
| July | 17.2 | 17.8 | 17.3 | 17.3 |
| August | 15.4 | 19.0 | 14.6 | 15.6 |
| September | 13.5 | 16.0 | 10.9 | 10.8 |
| October | 5.0 | 5.9 | 5.3 | 5.1 |
| May to October | 12.9 | 14.3 | 12.4 | 12.3 |
| Yearly | 1.8 | 3.1 | 3.3 | 2.7 |

Figure 6. Turbidity in C and D sloughs for the study period

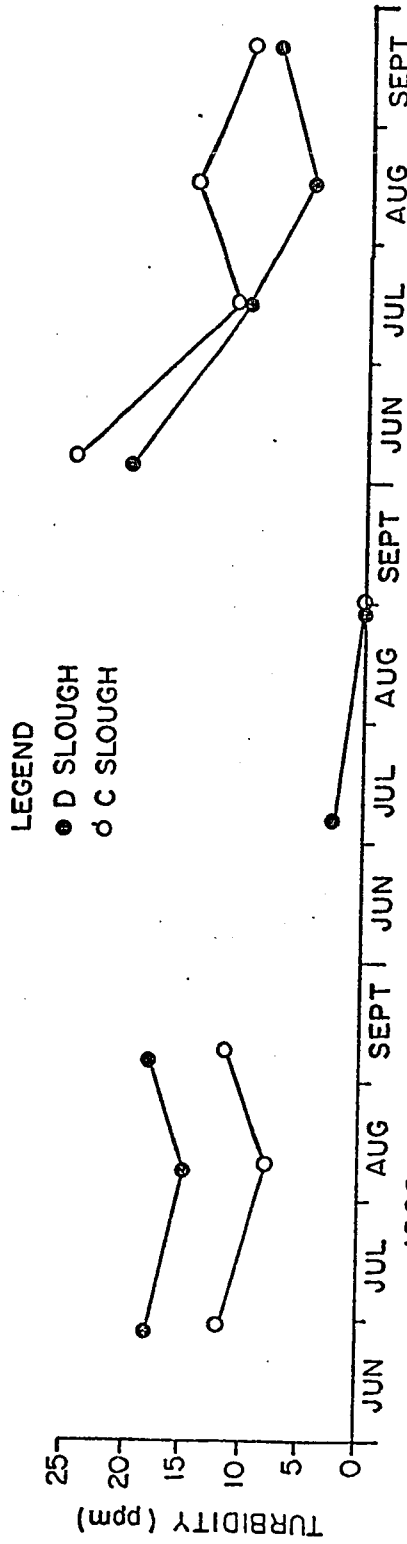
TURBIDITY (ppm)
25
20
15
10
5
0
JUN
JUL
AUG
SEPT
1966
JUN
JUL
AUG
SEPT
1967
JUN
JUL
AUG
SEPT
1968
TIME OF YEAR
LEGEND
D SLOUGH
C SLOUGH

Figure 6

Table 6. Dissolved oxygen data for C slough*

| Date and Time** Sample Taken | Depth Class† | Oxygen Concentration (mg/l) | Oxygen Concentration Corrected for Altitude (mg/l)†† | Temperature (°C) | Oxygen Percent Saturation‡ |
|---|---|---|---|---|---|
| June 14/66; | 1 | | | 18.9 | |
| 1600 hrs | 2 | 5.24 | 5.76 | 18.9 | 60.0 to 65.0 |
| | 3 | 6.12 | 6.73 | 18.6 | 70.0 |
| | 4 | 4.25 | 4.68 | 18.3 | 49.5 |
| | 5 | 4.45 | 4.90 | 18.1 | 50.0 to 55.0 |
| September 1/66 | 2 | 3.28 | 3.61 | 17.2 | 36.5 |
| | 3 | 1.49 | 1.64 | 16.1 | 15.5 |
| | 4 | 1.95 | 2.15 | 15.6 | 21.0 |
| | 5 | 1.83 | 2.01 | 15.6 | 19.5 |
| December 19/66; | 1 | | | 2.0 | |
| 1200 hrs | 2 | 4.20 | 4.62 | 2.0 | 33.0 |
| | 3 | 1.80 | 1.98 | 2.5 | 14.5 |

Table 6. (Continued)

| Date and Time** Sample Taken | Depth Class† | Oxygen Concentration (mg/l) | Oxygen Concentration Corrected for Altitude (mg/l)†† | Temperature (°C) | Oxygen Percent Saturation‡ |
|---|---|---|---|---|---|
| | 4 | 1.25 | 1.38 | 2.5 | 9.5 |
| | 5 | | | 3.0 | |
| April 28/67 | 1 (surface) | | | 1.3 | |
| | 1 (25.4 cm) | 8.40 | 9.24 | 1.3 | 65.0 |
| | 2 | 7.45 | 8.20 | 1.0 | 55.0 to 60.0 |
| | 3 | 7.35 | 8.09 | 1.3 | 55.0 to 60.0 |
| | 4 | 4.00 | 4.40 | 1.3 | 31.0 |
| | 5 | | | 1.3 | |
| June 2/67 | 1 (surface) | | | 19.3 | |
| | 1 (15.2 cm) | | | 19.2 | |
| | 2 (30.5 cm) | 8.30 | 9.13 | 18.8 | 97.5 |
| | 2 (45.7 cm) | | | 18.2 | |

Table 6. (Continued)

| Date and Time** Sample Taken | Depth Class† | Oxygen Concentration (mg/l) | Oxygen Concentration Corrected for Altitude (mg/l)†† | Temperature (°C) | Oxygen Percent Saturation‡ |
|---|---|---|---|---|---|
| | 3 (61.0 cm) | 8.50 | 9.35 | 17.6 | 95.0 to 100.0 |
| | 3 (76.2 cm) | | | 16.8 | |
| | 4 (91.4 cm) | 8.80 | 9.68 | 16.3 | 95.0 to 100.0 |
| | 4 (106.7 cm) | | | 16.2 | |
| | 5 (121.9 cm) | 9.45 | 10.40 | 15.9 | 100 to 105 |
| | 5 (137.2 cm) | | | 16.2 | |
| | 5 (152.4 cm) | | | 15.8 | |
| | 5 (167.6 cm) | | | 15.5 | |
| August 9/67 | 2 | 11.00 | 12.10 | 23.0 | 140 |
| | 3 | 11.00 | 12.10 | 22.0 | 135 to 140 |
| | 4 | 11.00 | 12.10 | 19.7 | 130 to 135 |
| | 5 | 11.10 | 12.21 | 19.2 | 130 to 135 |

Table 6. (Continued)

| Date and Time** Sample Taken | Depth Class† | Oxygen Concentration (mg/l) | Oxygen Concentration Corrected for Altitude (mg/l)†† | Temperature (°C) | Oxygen Percent Saturation‡ |
|---|---|---|---|---|---|
| September 5/67 | 2 | 8.70 | 9.57 | 20.2 | 105 |
| | 3 (61.0 cm) | 8.70 | 9.57 | 20.3 | 105 |
| | 3 (76.2 cm) | 8.20 | 9.02 | 20.0 | 95.0 to 100.0 |
| | 3 (83.8 cm) | 7.80 | 8.58 | 19.0 | 90.0 to 95.0 |
| | 4 | | | 18.2 | |
| February 9/68 | 1 | | | -0.4 | |
| | 2 | 0 | 0 | -0.4 | 0 |
| | 3 (61.0 cm) | | | -0.5 | |
| | 3 (83.8 cm) | | | -0.5 | |
| May 30/68 | 2 | 9.73 | 10.70 | 15.6 | 105 to 110 |
| | 3 | 2.29 | 2.52 | 15.6 | 19.5 |
| July 2/68 | 2 (30.5 cm) | 12.65 | 13.92 | 21.1 | >150 |
| | 2 (30.5 cm) | 11.29 | 12.42 | 20.6 | 135 |

Table 6. (Continued)

| Date and Time** Sample Taken | Depth Class† | Oxygen Concentration (mg/l) | Oxygen Concentration Corrected for Altitude (mg/l)†† | Temperature (°C) | Oxygen Percent Saturation‡ |
|---|---|---|---|---|---|
| | 2 (30.5 cm) | 11.83 | 13.01 | 19.6 | 140 |
| | 3 | 10.66 | 11.73 | 17.8 | 120 to 125 |
| July 29/68 | 2 (30.5 cm) | 3.98 | 4.38 | 18.7 | 47.0 |
| | 2 (30.5 cm) | 6.07 | 6.68 | 19.0 | 70.0 to 75.0 |
| | 3 (61.0 cm) | 5.64 | 6.20 | 18.6 | 65.0 |
| | 3 (61.0 cm) | 5.02 | 5.52 | 18.8 | 55.0 to 60.0 |
| September 16/68 | 2 (30.5 cm) | 6.36 | 7.00 | 12.3 | 60.0 to 65.0 |
| | 2 (30.5 cm) | 6.45 | 7.10 | 11.9 | 65.0 |
| | 2 (30.5 cm) | 6.36 | 7.00 | 12.2 | 60.0 to 65.0 |

Table 6. (Footnotes)

* Additional temperature readings are included.

** When available.

† 1 = up to 29.5 cm
2 = 30.5 to 58.4 cm
3 = 59.4 to 88.9 cm
4 = 89.9 to 119.4 cm
5 = 120.4 plus cm

} Depths are given when depth classes are used more than once.

†† } From Welch (1948, p. 366).
Ψ

Table 7. Dissolved oxygen data for D slough*

| Date and Time** Sample Taken | Depth Class† | Oxygen Concentration (mg/l) | Oxygen Concentration Corrected for Altitude (mg/l)†† | Temperature (°C) | Oxygen Percent Saturation‡ |
|---|---|---|---|---|---|
| June 14/66; | 1 | 4.07 | 4.48 | 18.3 | 47.0 |
| 1410 hrs | 2 | 4.15 | 4.57 | 17.8 | 48.0 |
| | 3 | 3.17 | 3.49 | 17.0 | 35.5 |
| | 4 | 3.28 | 3.61 | 16.7 | 36.0 |
| | 5 | | | 15.6 | |
| September 1/66; | 1 | | | 17.2 | |
| 1100 hrs | 2 (30.5 cm) | 1.35 | 1.49 | 15.0 | 15.0 |
| | 2 (45.7 cm) | 0.43 | 0.47 | 15.0 | 5.0 |
| | 3 | 0.74 | 0.81 | 15.0 | 7.5 |
| | 4 | 0.17 | 0.19 | 15.6 | 1.5 |
| | 5 | | | 15.0 | |
| November 23/66; | 1 | 1.26 | 1.39 | 1.0 | 9.5 |
| 1530 hrs | 2 | 0 | 0 | 2.0 | 0 |
| | 3 | | | 3.0 | |

Table 7. (Continued)

| Date and Time** Sample Taken | Depth Class† | Oxygen Concentration (mg/l) | Oxygen Concentration Corrected for Altitude (mg/l)†† | Temperature (°C) | Oxygen Percent Saturation‡ |
|---|---|---|---|---|---|
| December 19/66; | 1 | | | 1.0 | |
| Approx. 1400 hrs | 2 | 0 | 0 | 2.0 | 0 |
| | 3 | 0 | 0 | 3.0 | 0 |
| | 4 (91.4 cm) | 0 | 0 | 3.5 | 0 |
| | 4 (116.8 cm) | | | 4.0 | |
| April 28/67; | 1 (surface) | | | 0.5 | |
| 1200 hrs | 1 (25.4 cm) | 9.30 | 10.23 | 0.5 | 70.0 |
| | 2 | 7.80 | 8.58 | 0.8 | 60.0 |
| | 3 | 5.70 | 6.27 | 0.8 | 44.0 |
| | 4 | 5.40 | 5.94 | 0.8 | 41.0 |
| | 5 | | | 0.8 | |
| May 31/67; | 1 | | | 17.8 | |
| 1700 hrs | 2 (30.5 cm) | 4.30 | 4.73 | 16.4 | 48.0 |
| | 2 (45.7 cm) | 4.30 | 4.73 | 16.4 | 48.0 |

Table 7. (Continued)

| Date and Time** Sample Taken | Depth Class† | Oxygen Concentration (mg/l) | Oxygen Concentration Corrected for Altitude (mg/l)†† | Temperature (°C) | Oxygen Percent Saturation‡ |
|---|---|---|---|---|---|
| | 3 (61.0 cm) | | | 16.0 | |
| | 3 (76.2 cm) | 4.20 | 4.62 | 15.5 | 45.5 |
| | 4 (91.4 cm) | | | 14.8 | |
| | 4 (106.7 cm) | 3.90 | 4.29 | 14.0 | 41.0 |
| | 5 (121.9 cm) | | | 12.8 | |
| | 5 (137.2 cm) | | | 12.4 | |
| August 10/67 | 2 | 15.20 | 16.72 | 21.8 | >150 |
| | 3 | 12.40 | 13.64 | 20.0 | 145 to 150 |
| | 4 (91.4 cm)Φ | 0.50 | 0.55 | 16.7 | 5.0 |
| | 4 (91.4 cm) | 3.70 | 4.07 | 16.7 | 41.0 |
| | 4 (116.8 cm) | | | 15.6 | |
| September 5/67 | 2ϕ | 6.60 | 7.26 | 20.2 | 80.0 |
| | 3 (61.0 cm)ΦΦ | 4.85 | 5.34 | 18.3 | 55.0 |

Table 7. (Continued)

| Date and Time** Sample Taken | Depth Class† | Oxygen Concentration (mg/l) | Oxygen Concentration Corrected for Altitude (mg/l)†† | Temperature (°C) | Oxygen Percent Saturation‡ |
|---|---|---|---|---|---|
| | 3 (78.7 cm) | 0.70 | 0.77 | 18.7 | 8.0 |
| | 3 (86.4 cm)Φ | 0 | 0 | 17.1 | 0 |
| | 4Φ | 0.70 | 0.77 | 16.3 | 7.5 |
| February 9/68 | 1 (5.1 cm) | | | -0.4 | |
| | 1 (15.2 cm) | | | -0.4 | |
| | 2 (30.5 cm) | 0 | 0 | -0.4 | 0 |
| | 2 (45.7 cm) | | | -0.4 | |
| | 3 | | | -0.4 | |
| May 31/68 | 2 | 4.24 | 4.66 | 16.7 | 48.0 |
| | 3 | 4.21 | 4.63 | 15.6 | 45.5 |
| | 4 | 4.38 | 4.82 | 15.6 | 47.5 |
| July 3/68 | 2 (30.5 cm) | 15.60 | 17.16 | 24.2 | >150 |
| | 2 (30.5 cm) | 16.28 | 17.91 | 20.9 | >150 |

Table 7. (Continued)

| Date and Time** Sample Taken | Depth Class† | Oxygen Concentration (mg/l) | Oxygen Concentration Corrected for Altitude (mg/l)†† | Temperature (°C) | Oxygen Percent Saturation‡ |
|---|---|---|---|---|---|
| | 2 (30.5 cm) | 18.61 | 20.47 | 22.0 | >150 |
| | 3 | 15.31 | 16.84 | 17.8 | >150 |
| July 30/68 | 2 (30.5 cm) | 7.21 | 7.93 | 18.9 | 85.0 |
| | 2 (30.5 cm) | 8.82 | 9.70 | 17.6 | 100.0 |
| | 2 (30.5 cm) | 10.14 | 11.15 | 18.2 | 115 to 120 |
| | 2 (45.7 cm) | 3.98 | 4.38 | 17.3 | 45.0 |
| September 16/68 | 2 (30.5 cm) | 8.06 | 8.87 | 15.7 | 85.0 to 90.0 |
| | 2 (30.5 cm) | 8.06 | 8.87 | 15.5 | 85.0 to 90.0 |
| | 2 (30.5 cm) | 8.06 | 8.87 | 15.6 | 85.0 to 90.0 |

Table 7. (Continued)

| Date and Time** Sample Taken | Depth Class† | Oxygen Concentration (mg/l) | Oxygen Concentration Corrected for Altitude (mg/l)†† | Temperature (°C) | Oxygen Percent Saturation‡ |
|---|---|---|---|---|---|
| | 2 (30.5 cm) | 18.61 | 20.47 | 22.0 | >150 |
| | 3 | 15.31 | 16.84 | 17.8 | >150 |
| July 30/68 | 2 (30.5 cm) | 7.21 | 7.93 | 18.9 | 85.0 |
| | 2 (30.5 cm) | 8.82 | 9.70 | 17.6 | 100.0 |
| | 2 (30.5 cm) | 10.14 | 11.15 | 18.2 | 115 to 120 |
| | 2 (45.7 cm) | 3.98 | 4.38 | 17.3 | 45.0 |
| September 16/68 | 2 (30.5 cm) | 8.06 | 8.87 | 15.7 | 85.0 to 90.0 |
| | 2 (30.5 cm) | 8.06 | 8.87 | 15.5 | 85.0 to 90.0 |
| | 2 (30.5 cm) | 8.06 | 8.87 | 15.6 | 85.0 to 90.0 |

Table 7. (Footnotes)

* Additional temperature readings are included.

** When available.

† 1 = up to 29.5 cm
2 = 30.5 to 58.4 cm
3 = 59.4 to 88.9 cm
4 = 89.9 to 119.4 cm
5 = 120.4 plus cm

} Depths are given when depth classes are used more than once.

†† } From Welch (1948, p. 366).

Ψ

Φ Taken in area of colourless sulfur bacteria.

ΦΦ Taken in interface area between colourless sulfur bacteria and clear water.

ϕ Taken in clear area above colourless sulfur bacteria.

Figure 7. Oxygen concentrations (corrected for altitude) for the different depth classes in C and D sloughs for 1966

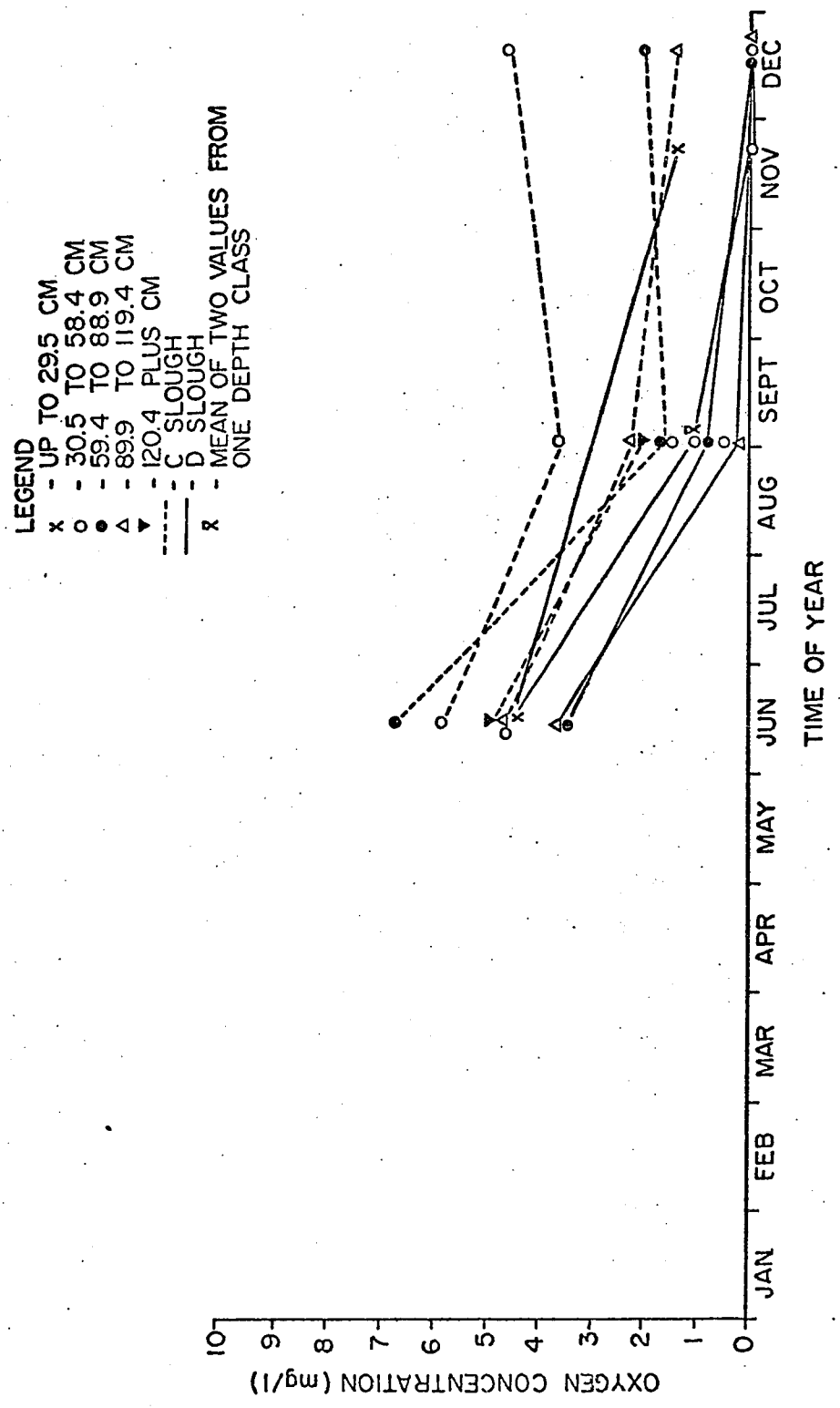
LEGEND
x - UP TO 29.5 CM
o - 30.5 TO 58.4 CM
● - 59.4 TO 88.9 CM
Δ - 89.9 TO 119.4 CM
▼ - 120.4 PLUS CM
---- - C SLOUGH
—— - D SLOUGH
x̄ - MEAN OF TWO VALUES FROM ONE DEPTH CLASS
OXYGEN CONCENTRATION (mg/l)
0
1
2
3
4
5
6
7
8
9
10
JAN
FEB
MAR
APR
MAY
JUN
JUL
AUG
SEPT
OCT
NOV
DEC
TIME OF YEAR

Figure 7

Figure 8. Oxygen concentrations (corrected for altitude) for the different depth classes in C and D sloughs for 1967

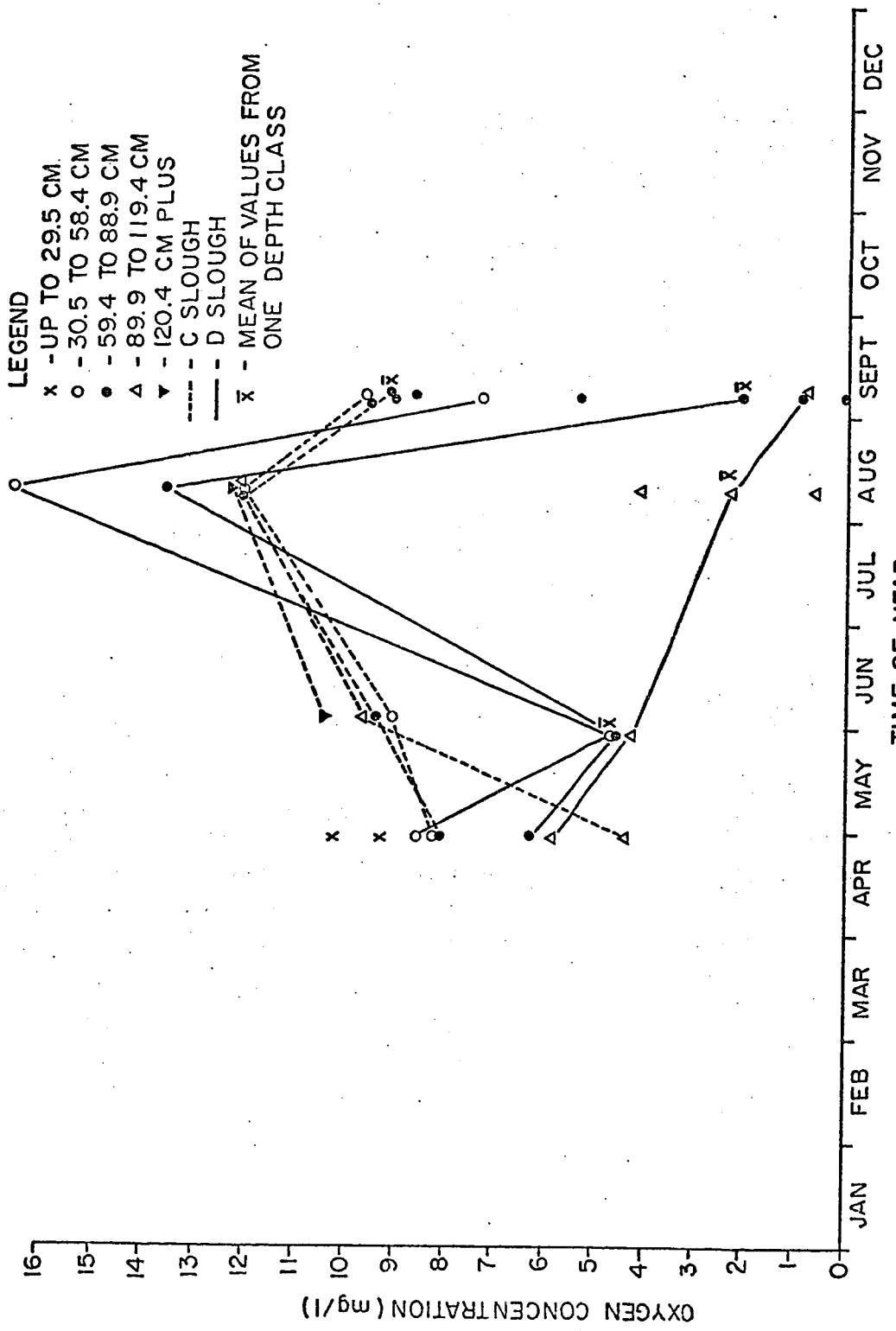
LEGEND
x - UP TO 29.5 CM.
o - 30.5 TO 58.4 CM
• - 59.4 TO 88.9 CM
Δ - 89.9 TO 119.4 CM
▼ - 120.4 CM PLUS
---- - C SLOUGH
—— - D SLOUGH
x̄ - MEAN OF VALUES FROM ONE DEPTH CLASS
OXYGEN CONCENTRATION (mg/l)
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
JAN
FEB
MAR
APR
MAY
JUN
JUL
AUG
SEPT
OCT
NOV
DEC
TIME OF YEAR

Figure 8

Figure 9. Oxygen concentrations (corrected for altitude) for the different depth classes in C and D sloughs for 1968

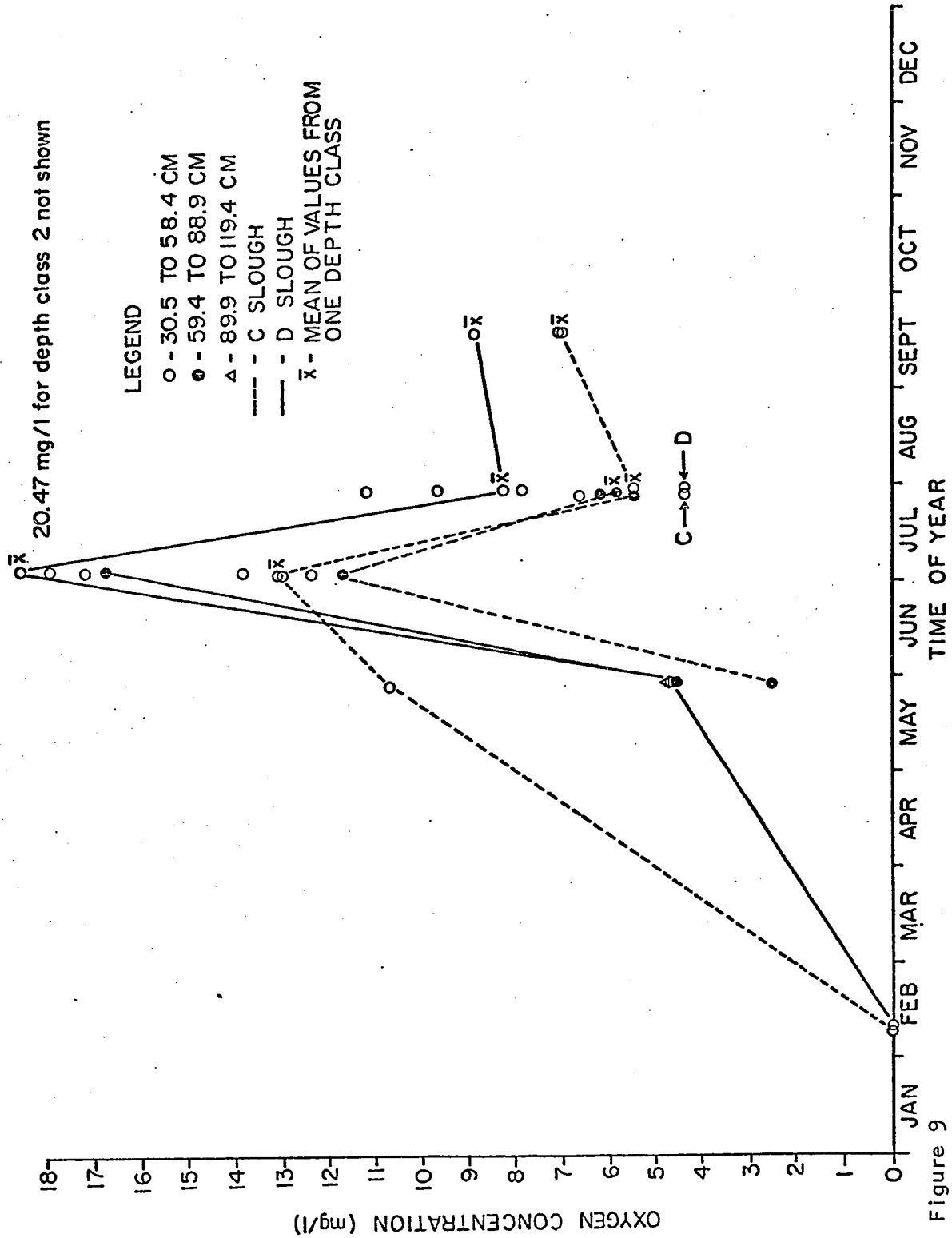
20.47 mg/l for depth class 2 not shown
LEGEND
o - 30.5 TO 58.4 CM
● - 59.4 TO 88.9 CM
Δ - 89.9 TO 119.4 CM
- - - C SLOUGH
—— D SLOUGH
x̄ - MEAN OF VALUES FROM ONE DEPTH CLASS
C → ← D
OXYGEN CONCENTRATION (mg/l)
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18
JAN FEB MAR APR MAY JUN JUL AUG SEPT OCT NOV DEC
TIME OF YEAR

Figure 9

b) Dissolved solids and other dissolved gases

(i) Hardness (see Figs. 10 and 11). After three successive seasons of below-average precipitation perhaps the general increase in total hardness in 1968 was due to a concentration effect of the low water levels. D had slightly higher concentrations in 1966. In 1967 the single date sampled in C had a similar value to the same date in D. In 1968, however, total hardness was higher in C.

Calcium to magnesium hardness ratios show that within C in 1966 calcium reached up to four times the level of magnesium. The ratios for D were closer to one over the season indicating that the concentrations were more equitable. In average hard waters the proportion of magnesium to calcium can increase (Reid, 1961). However, in 1967 the difference in concentrations between calcium and magnesium for the first sampling date in D is quite high. For the second sampling date in 1967 the ratio returned to the 1966 levels. Ratios for C and D for the second sampling date in 1967 are close. Ratios are similar in C and D by the end of the 1968 season. Mean values for the calcium to magnesium hardness ratios for the 1966, 1967, and 1968 seasons were 2.40, 1.25 (single reading), and 2.87 (overall mean: 2.17) for C; and 1.24, 3.60, and 1.41 (overall mean: 1.84) for D.

(ii) Alkalinity (see Fig. 12). Throughout the three seasons D showed higher total and bicarbonate alkalinities than C while the phenolphthalein and carbonate alkalinities were approximately equal. Phenolphthalein alkalinity readings were always obtained at pH's above 8.4, the pH at which appreciable carbonate is present (Daborn, 1969) with one exception: C slough, July 11, 1968 which gave a phenolphthalein alkalinity reading of 17 ppm at a pH of 7.4

Photosynthetic activity removes $CO_2$ from the water and could result in an increase of $CaCO_3$ (Reid, 1961). Since the Hach test measures total alkalinity as parts per million $CaCO_3$, I would have expected an upward trend in total alkalinity coincident with the periods of algal blooming. However, $CO_2$ content in water is dependent on a variety of other factors (Reid, 1961) and the complex interrelationships involving the carbon dioxide-bicarbonate-carbonate equilibrium, water, and pH could have altered the photosynthesis-$CaCO_3$ relationship.

Because the dominant cations of both sloughs were calcium and magnesium the curves for total alkalinity should follow those for total hardness. The two curves for C for 1966 were a different shape but there was an overall decrease in both. In 1968 the curves were again different and while total hardness showed an overall increase, total alkalinity showed an overall decrease. For D in 1966 and 1967 the curves were similar and both showed an overall decrease. In 1968 the curves were similar in shape but total alkalinity showed an overall decrease while total hardness stayed much the same. C showed a general upward trend in total hardness and a general downward one in total alkalinity throughout the three seasons of the study. In D total hardness stayed much the same while total alkalinity showed a general downward trend.

(iii) pH (see Fig. 13). Seasonal means of 8.20, 9.10 (single reading), and 8.42 (overall mean: 8.57); and 7.90, 8.93, and 8.82 (overall mean: 8.55) were obtained for C and D respectively. Daborn (1969) reported a seasonal mean of 8.95 with a range of 8.50 to 9.60 which shows a more efficient bicarbonate buffering system.

The highest pH's were in the middle of the season and pH generally increased throughout the study. The midseason pH pulses in D could have been related to algal blooms occurring at that time. It is significant in this regard that the 1966 peak was in August and the 1968 peak was in July, the maximum bloom period for each year. (The two analyses done in 1967 are too few to give an indication of when the peak was reached). C did not have as extensive blooms and it is possible that the buffering system was able to cover up the influence of the blooms on pH. I cannot explain the wide fluctuations of pH in C in 1968.

(iv) $CO_2$ (see Fig. 14). Since the presence of $CO_2$ lowers pH it is not surprising that the graphs of $CO_2$ are generally opposite to those of pH for each of the seasons for each slough.

Photosynthetic activity lowers $CO_2$ concentration so, all other things being equal, the reductions in $CO_2$ concentration should parallel peak periods of photosynthesis. In D in 1966 the lowest $CO_2$ concentrations were in August, the period of maximum blooming. However, peak $CO_2$ concentration is reached in C at the same time. There is insufficient data to make conclusions for 1967; and in 1968, D showed a minimum slightly after the main bloom period of that season. C reached a minimum $CO_2$ concentration at the time of the bloom (but the pH for this date dropped. See Fig. 13).

(v) Orthophosphate (see Fig. 15). Values for orthophosphate remained below 1.0 ppm throughout the study except for D, June 3, 1968 which had a value of 1.3 ppm; and C, July 15, 1968 which had a value of 20.0 ppm. This latter value is questionable because it is high relative to the other values and because phosphorus normally occurs in very

small amounts (Reid, 1961). It is likely that most of the temperatures at which the tests were done were below the recommended 24°C and so the accuracy of the results may have been affected. 1968 in D was the only season with a curve that could resemble a pattern of orthophosphate use by plants.

(vi) Sulphate (see Fig. 16). The fate of sulphate was similar in C and D throughout the study. I would have expected a decrease in sulphate during the growing period due to uptake by green plants (especially algae) and by reduction to $H_2S$, especially in D. ($H_2S$ was not detected during the study but this was probably due to a faulty reagent in the Hach test; and because the test should be done on freshly pumped water, not aerated surface water from which $H_2S$ is easily lost).

(vii) Nitrite and nitrate nitrogen (see Fig. 17). Reid (1961) states that nitrite in natural water is probably formed mainly by reduction of nitrate (for example, by diatoms and certain other algae). However, nitrite can be oxidized by nitrifying bacteria to form nitrate which is the form of nitrogen most easily taken up by green plants. Further, he states that, in general, seasonal variations of nitrite concentrations follow those of nitrate. Since all green plants require nitrate its level may decrease toward the end of the growing season so nitrate reduction to nitrite should decline as well. This scheme unfortunately ignores the results of oxidation of nitrite to nitrate.

Curves for nitrate for 1966 and 1967 for both sloughs and nitrite in C for 1967 could not be drawn because of the lack of analyses. The curves for nitrite concentration in 1966 reached a maximum in August

in C and a minimum in D for the same time. July to August was the period of the main algal bloom which was more extensive in D than in C. I cannot further explain the maximum in C in August other than to postulate that more nitrate was being reduced to nitrite than was being used by algae and other green plants. However, this hypothesis runs into problems if I try to use it for the other two seasons. For example, in D in 1967 nitrite concentration increased during the period of the main bloom. However, in 1968 in C, minima for nitrite and nitrate were reached in July which corresponds to the period of the main bloom; and although the curve for nitrate shows an overall increase while that of nitrite shows an overall decrease, the shapes of the two curves are similar. In D, nitrite was at its minimum in June to July as expected but nitrate peaked in July which is not expected.

(viii) Iron (see Fig. 18). Sometimes with the depletion of oxygen the ferric form of iron is reduced to the ferrous which goes into solution. As a result of the breakdown of the ferric complex the concentrations of silicate, phosphate, bicarbonate, or iron are often increased. However, such changes depend on the original chemical nature of the waters and the mere depletion of oxygen will not bring about transformation from ferric to ferrous forms. Organic decomposition causes oxygen depletion and also forms organic compounds that reduce the ferric ion (Reid, 1961).

Even if the situation in the sloughs is simplified to consider the possibility that the reduction of the ferric ion is enabling silicate, phosphate, bicarbonate, or iron to increase, the results are not clear. Sampling began too late in 1966 and there was

insufficient data in 1967 from which conclusions could be drawn. Iron levels in 1968, however, are highest in the first sampling following a winter in which oxygen concentrations went below detectable levels. The silica curves for 1968 (Fig. 20) agree only with the curves of iron in C. Those for D are opposite. Orthophosphate curves (Fig. 15) are similar to the iron curves in D but not in C. Bicarbonate curves (Fig. 12) are at their maxima at the same time as the iron curves for both C and D, the curves being similar.

(ix) Manganese (see Fig. 19). Since the role of manganese is similar to that of iron (Reid, 1961), I would expect that the shape of the curves of these two elements should be similar. In fact, they are for D in 1966. However, for C in 1966 there is an overall increase through the season in manganese and an overall decrease in iron but only the late June to early August portion differs. In 1968 the curves are similar in that iron and manganese have an overall decline in C and an overall increase in D. Manganese is usually less abundant than iron (Reid, 1961) but the reverse was true in my sloughs.

(x) Silica (see Fig. 20). Quantities of silica may be removed from the water during periods of diatom blooms (Reid, 1961). Hence it is strange that silica maxima appear during the periods of algal bloom in D in 1966 and 1968. A silica minimum is reached in August of 1968 in D just after the bloom period. The curves in C are more expected, especially the one in 1968, as is the overall decrease in D through the 1967 season. The three values (1.46, 0.78, and 0.56 ppm) reported by Daborn (1969) are in the same range as those of this study.

(xi) Chlorine and chloride (see Fig. 21). Since chlorine is not essential for plant life, differences in chlorine concentrations appear probably only when they are caused by hydrographic and physical factors (Ruttner, 1963). Thus, the overall increase in chlorine and chloride for each slough in each season (except for chloride in C in 1968) would probably be due to the concentrating effects of evaporating water over the course of the season. Chloride in C in 1968 had a slight overall increase. The single value (0.03 ppm) reported by Daborn (1969) is in the same range as those of my study.

(xii) Chromate (see Fig. 22). Hutchinson (1957), reporting on analyses of chromium in natural waters, gave a range of 0 to 40 mg $m^{-3}$ with a mean of 5 mg $m^{-3}$. Lake Michigan water contained 2 mg $m^{-3}$. On this basis the values obtained (0.11 to 0.34 ppm) are on the order of 100 times greater. I cannot explain why this is so. Daborn (1969) did not detect chromate in the single determination he did.

(xiii) Other dissolved solids.

1. Copper--C slough: June 30, 1966, 0.1 ppm; August 9, 1966, 0.1 ppm; and September 18, 1968, 0.3 ppm.

--D slough: June 29, 1966, 0.035 ppm; and September 18, 1968, 0.3 ppm.

Daborn (1969) reported that he did not detect copper in the single determination he did.

2. Fluoride--C slough: June 30, 1966, 1.29 ppm.

--D slough: June 29, 1966, 0.68 ppm.

Figure 10. Total, magnesium, and calcium hardness in C and D sloughs for the study period

Figure 11. Calcium to magnesium ratios in C and D sloughs for the study period

Figure 12. Alkalinity in C and D sloughs for the study period

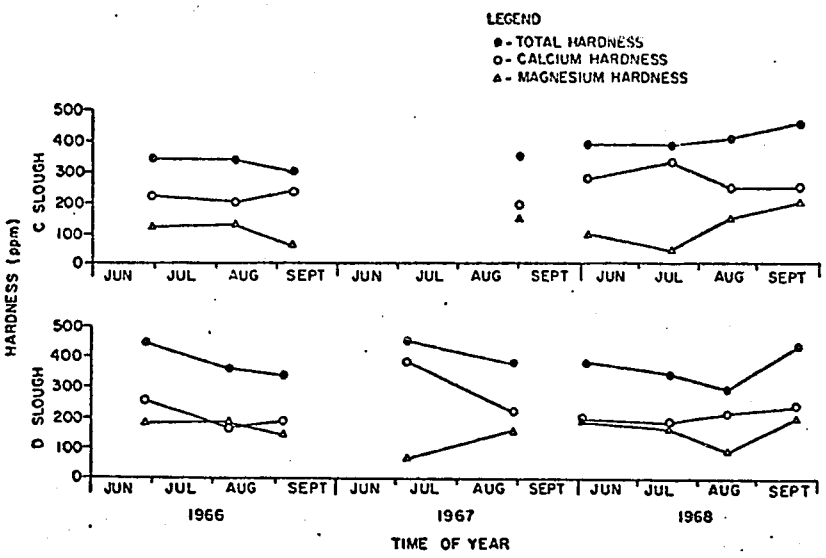


Figure 10

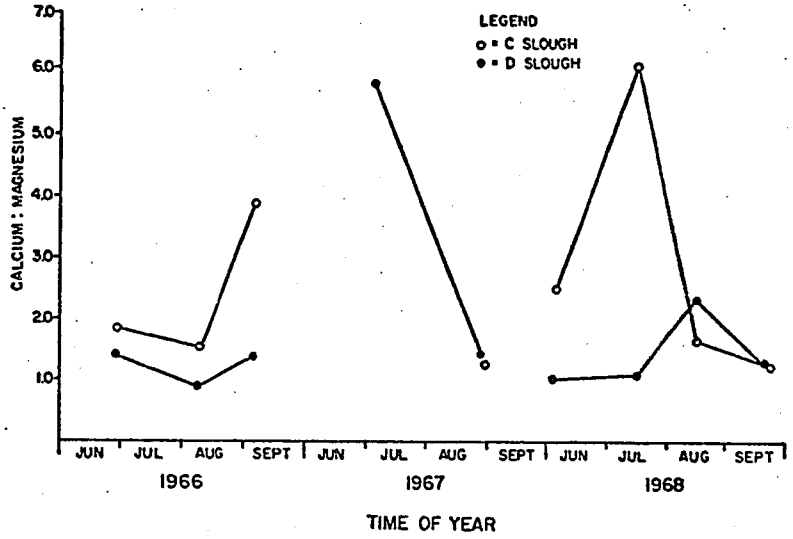


Figure 11

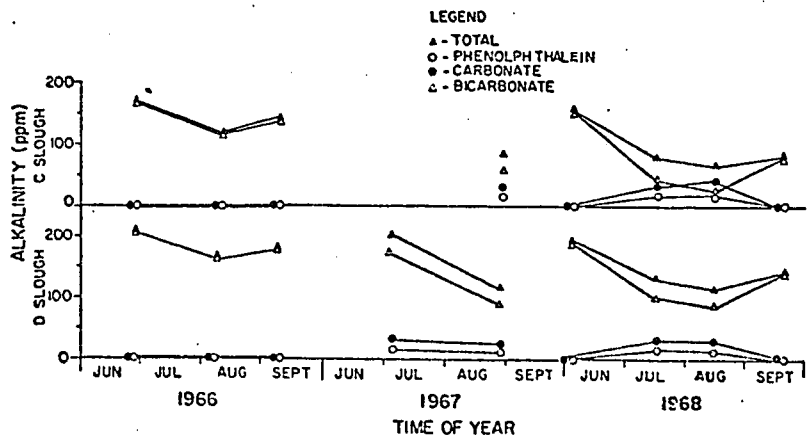


Figure 12

Figure 13. pH in C and D sloughs for the study period

Figure 14. Free carbon dioxide in C and D sloughs for the study period

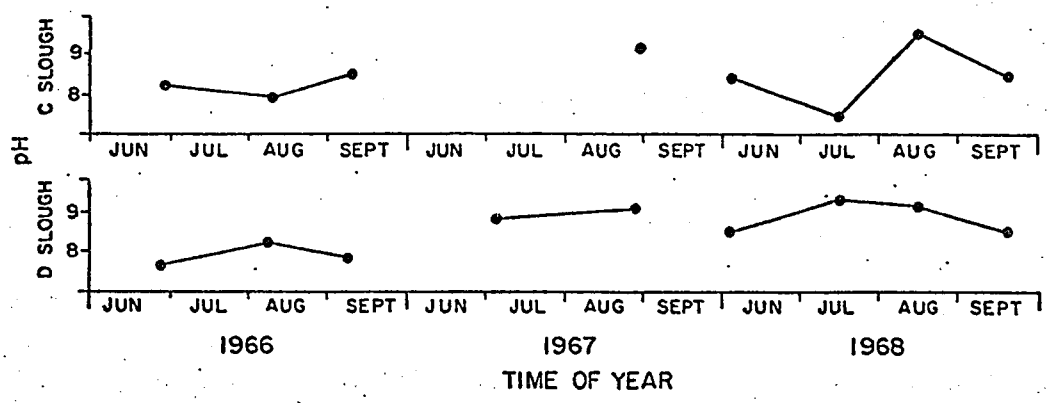


Figure 13

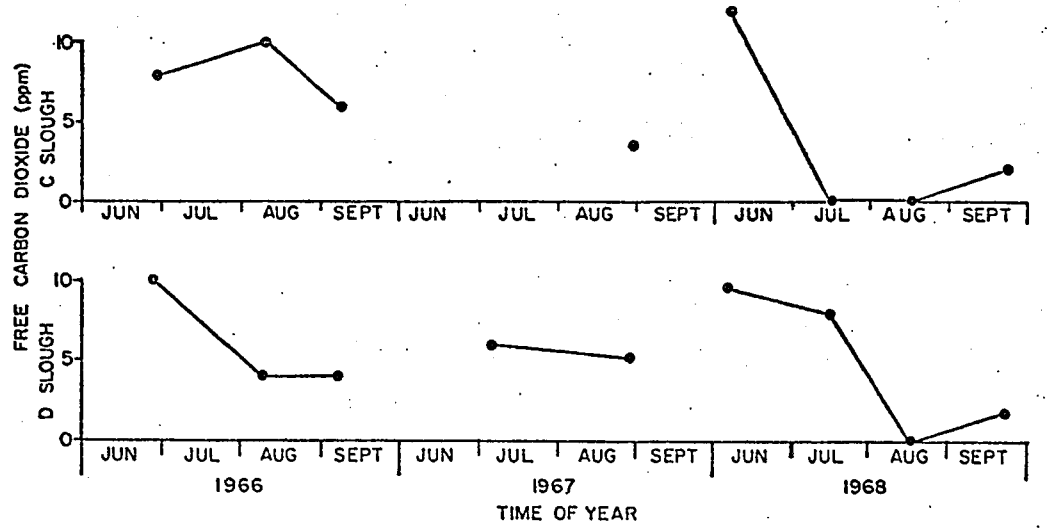


Figure 14

Figure 15. Orthophosphate in C and D sloughs for the study period

Figure 16. Sulphate in C and D sloughs for the study period

Figure 17. Nitrite and nitrate nitrogen in C and D sloughs for the study period

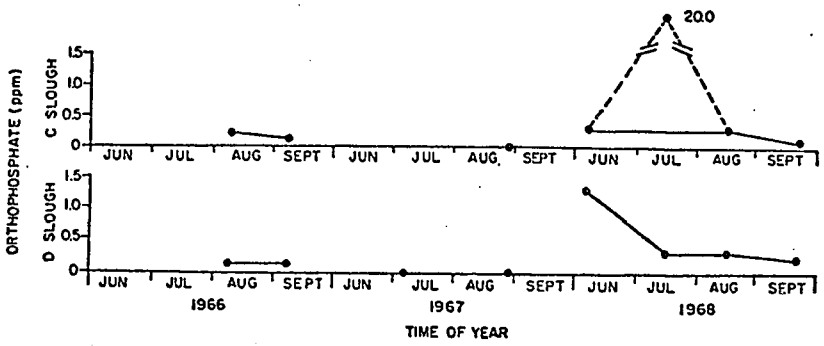


Figure 15

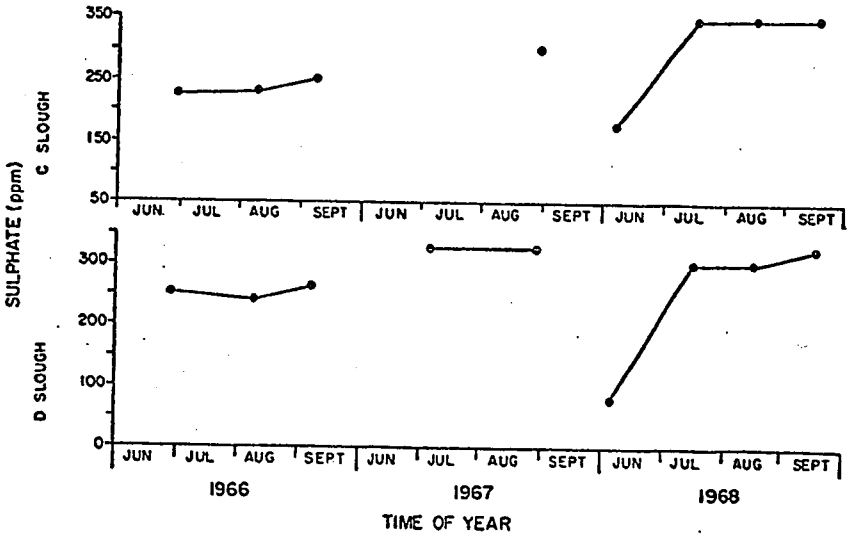


Figure 16

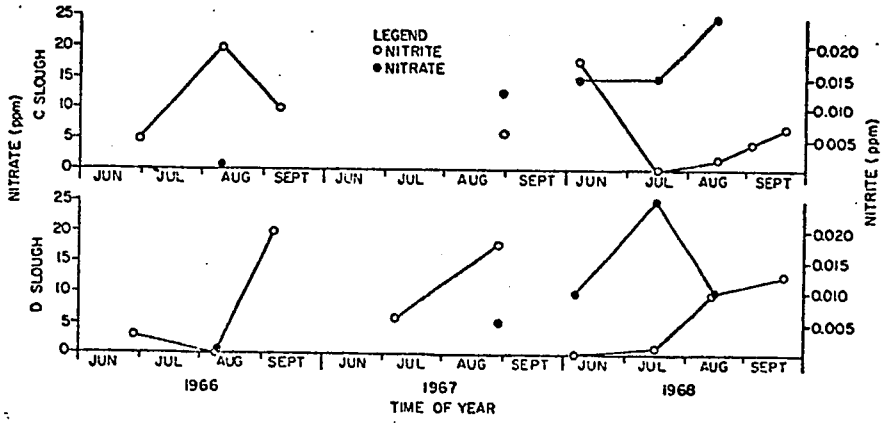


Figure 17

Figure 18. Iron in C and D sloughs for the study period

Figure 19. Manganese in C and D sloughs for the study period

Figure 20. Silica in C and D sloughs for the study period

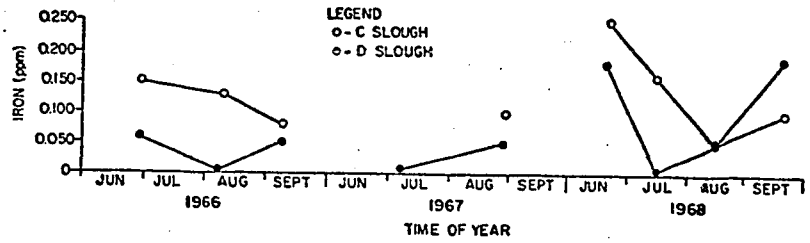


Figure 18

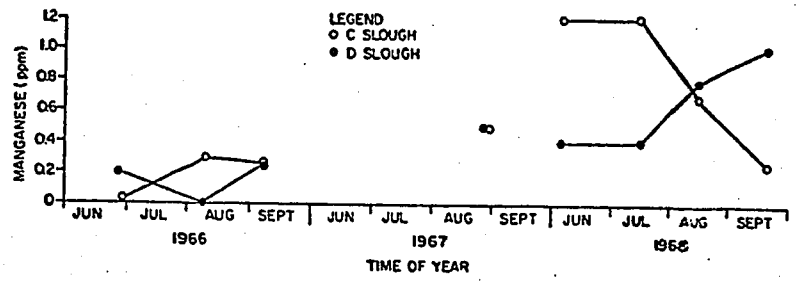


Figure 19

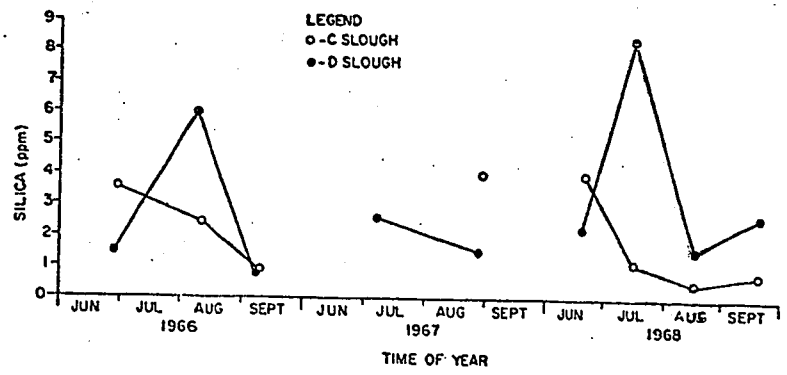


Figure 20

Figure 21. Chlorine and chloride in C and D sloughs for the study period

Figure 22. Chromate in C and D sloughs for the study period

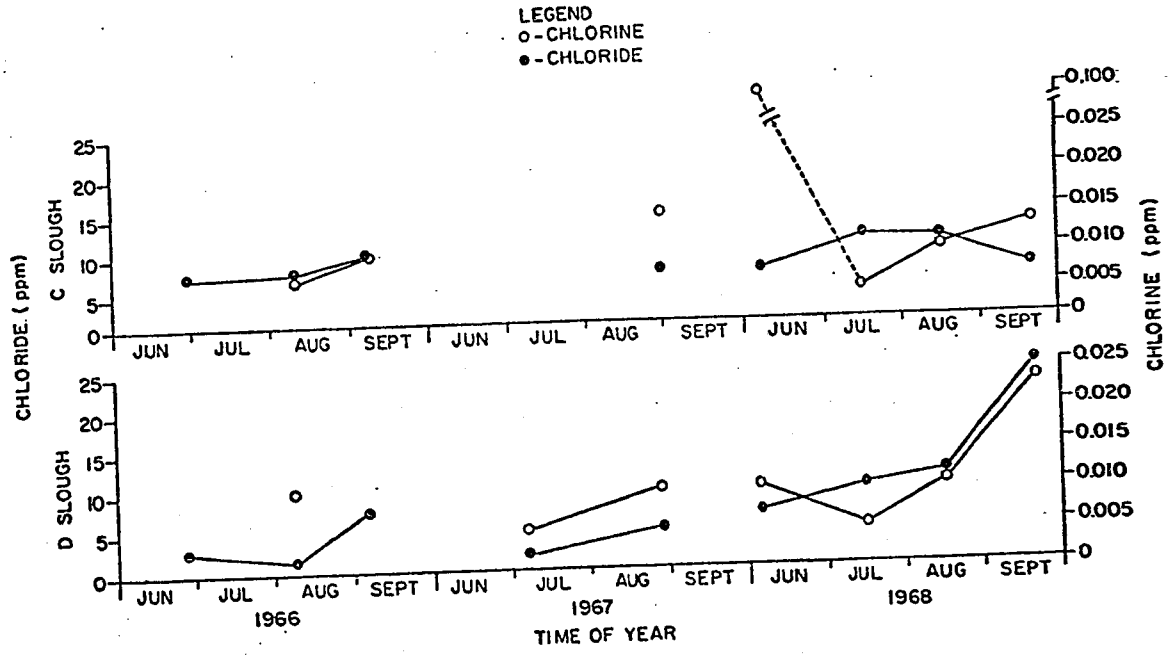


Figure 21

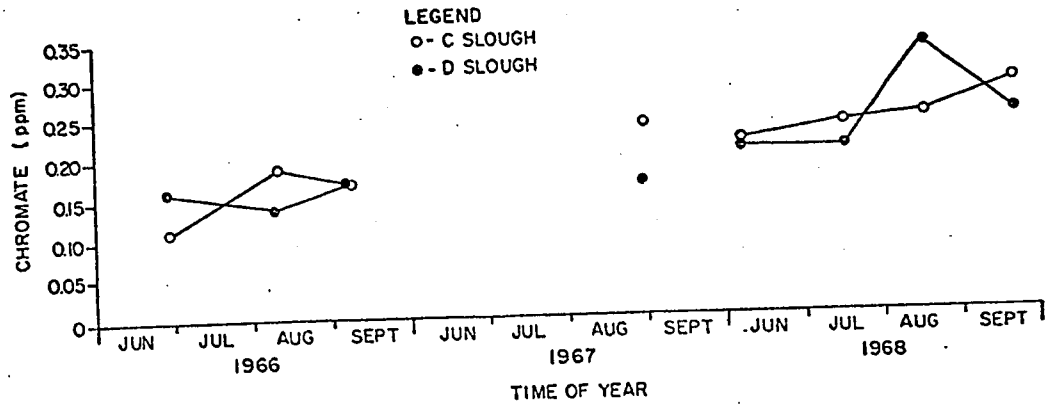


Figure 22

# APPENDIX IV

## IDENTIFICATIONS OF MACROINVERTEBRATES FROM C AND D SLOUGHS

### A. Taxa used in analyses of diversity

The actual list of taxa used in the analyses of diversity has been presented in Section IV, Part C. This part of Appendix IV discusses any special methods and lists references used in the identification of, and/or presents taxonomic information pertinent to certain taxa. Tables 8 to 16 show presence or absence of each of the taxa in C and D sloughs over the study period.

1. Hirudinea--Gastric and crop caeca of whole specimens preserved in alcohol or formalin can be seen, for taxonomic purposes, if the animal is compressed between two pieces of clear glass and viewed under a binocular microscope using light shined through the specimen from below.

[Reference: Smith, A. R. Unpublished. An illustrated key to the leeches (Hirudinea) of Alberta].

2. Amphipoda

[References: Pennak, 1953; and Bousfield, 1958].

3. Insecta

a) Odonata--Lestidae and Aeshnidae larval and adult material agreed. The only species of Coenagrionidae not present in the adult collections was *Enallagma civile*. I am not fully satisfied with the identification of these specimens not only because of their absence from the adult material but especially because Walker (1953) does not

report it extending this far west (although it does occur in Saskatchewan). However, based on caudal lamella characters, it is distinct from the four other species and it has been retained because it represents another "kind" for the analyses of diversity.

Adult Libellulidae collected were of two and possibly three species: *Sympetrum costiferum*, *S. vicinum* (Hagen), and *S. obtrusum?* (Hagen). Only one specimen (♀) of *S. obtrusum* was collected and its determination is uncertain. *Sympetrum* overwinters as an egg or partially grown larva and emerges in the summer whereas *Leucorrhinia* overwinters in the last instar and emerges early in the spring (P. S. Corbet, personal communication). All the Libellulidae adults examined came from late July to late August which is probably why no *Leucorrhinia* were found. I cannot explain the absence of *S. vicinum* as larvae or *S. internum* as adults. The mature *S. costiferum* and *S. internum* larvae of my sloughs are different from the mature *S. vicinum* and *S. obtrusum* larvae, all as described by Walker (1917). Furthermore, P. S. Corbet verified and/or corrected my adult identifications and some of my larval ones. With regard to the larvae, Walker (1917, p. 409) states: "Variation within the limits of the species is generally so great that it is seemingly impossible in most cases to find any constant character by which a particular species may be recognized with certainty".

[Other references: Lestidae--Walker, 1958.
Aeshnidae--Walker, 1958.
Libellulidae--Walker, 1916; Needham and Heywood, 1929; Needham and Westfall, 1955; Musser, 1962; and Miller, Hamrum, and Anderson, 1964].

b) Hemiptera

[References: Hungerford, 1948; and Brooks and Kelton, 1967].

c) Ephemeroptera--No adults were identified so no information is available on the species present. Daborn (1969) reports the *Caenis* of his slough was *C. simulans* McD.

[Reference: Edmunds, 1959].

d) Coleoptera

[References: Carr, 1920; Leech and Chandler, 1956; Galewski, 1963; and Zimmerman, 1970].

e) Chironomidae--Most specimens could be identified to genus without mounting them. However, those of which I was uncertain were slide-mounted using the method outlined by Hamilton (1965):

1. Let stand in 8% KOH until head capsule and body appear to be cleared. (Usually this takes more than 24 hours even for small specimens).

2. Transfer from KOH to glacial acetic acid; to absolute ethanol; to absolute ethanol layered over cedarwood oil; and then to cedarwood oil. Let stand for at least 15 minutes at each step.

3. Mount in Canada balsam.

4. Let the balsam set over a few days. Ensure the body part is positioned correctly. Put another drop of balsam on; place coverslip over specimen; and put slide in oven at about 30°C until dry. (This will be about six weeks).

The head capsule of the larva was separated from the rest of the body in cedarwood oil or, immediately after mounting, on the slide in the Canada balsam and the head placed ventral side up. The rest of the body was placed on its side. Pupae were left whole and placed dorsal

side up. For a very quick look at some specimens (for example, the Lauterborn organs of Tanytarsini) the larvae were merely placed in a cavity slide containing a drop of glycerine, checked under a compound microscope, and then returned to the vial from which they came. As a preparatory step to this procedure, the specimens were sometimes cleared in 8% KOH.

The following is a qualitative discussion of the immature Chironomidae of C and D sloughs with information provided by adults added whenever available. Taxa are according to Hamilton, Saether, and Oliver (1969) and Hamilton and Saether (personal communication).

Subfamily Tanypodinae

Tribe Pentaneurini

*Ablabesmyia* spp.--This was the commonest of the tanypodines. The larvae all seemed to represent one species but according to the adult fauna there may be two: *A. denticulatus* Sublette and one unidentified.

*Guttipelopia?* sp.--A single specimen was collected from D slough in 1967. Its determination is unsure. It could be *Ablabesmyia*. It was considered to be *Ablabesmyia* in the analyses of diversity.

*Thienemannimyia* grp.--A single specimen was collected from D slough in 1967.

Tribe Macropelopiini

*Procladius* spp.--The larvae represented two species: *Procladius* (s.s.) sp. and *Procladius* (*Psilotanypus*) sp. The adults represented more than one species as well.

*Psectrotanypus* spp.--Two species represented, based on the difference in the number of teeth in and the overall appearance of

the paralabial combs. Based on the adult identifications one of these species may be *P. varius* (Fabricius) and one may be a new species.

Tribe Tanypodini

*Tanypus* sp.--Unmounted specimens are difficult to differentiate from one of the species of *Psectrotanypus*. Only 10 specimens of *Tanypus* were found--probably all of one species.

Subfamily Chironominae

Tribe Chironomini

*Chironomus* spp.--The two species of greatest abundance were *C.* nr. *tentans* Fabr. and *C.* nr. *attenuatus* Walker. Adults of *C. tentans* and *C. attenuatus* were present as well as up to three unidentified species. All reared specimens are currently in the possession of Dr. D. R. Oliver, Entomological Research Institute, Ottawa, Canada.

*Cryptochironomus* sp.--All larvae seemed to be of one species.

*Cryptocladopelma* sp.--(= *Harnischia* in Hamilton *et al.* [1969]. They have since changed this to *Cryptocladopelma*). Larvae seemed to be of one species.

*Dicrotendipes* spp.--Early instars have to be mounted to separate them from those of *Glyptotendipes* (*Phytotendipes*). The adults revealed the possibility of two species: *D. modestus* (Say) and one unidentified.

*Einfeldia* spp.--The larvae represented two species: *E. pagana* (Meig.) grp. and *E. pectoralis* Kieff. grp. although the only adults examined were *E. pagana*.

*Endochironomus* sp.--All the larvae appeared to be the same species. The adults were possibly *E. nigricans* (Joh.).

*Glyptotendipes* (*Phytotendipes*) spp.--The larvae were of two species, differing in the size of the first lateral teeth on the labial (hypostomial) plate relative to the central tooth and the presence or absence of small crenulations on the paralabial plates. The adults represented one species. This is not surprising because only four larval specimens of one of the species were collected. This genus was the second commonest Chironomini (next to *Chironomus*) in the sloughs. All my reared material is currently in the possession of Dr. D. R. Oliver, Entomological Research Institute, Ottawa, Canada.

*Microtendipes* sp.--The larvae of this genus appeared only in 1968 in C and D sloughs and appeared to be of one species.

*Parachironomus* spp.--The larvae represented two species based on the difference in the number of teeth in the labial plate (5 lateral versus 7). There was only one specimen of one of the species. The adults also were of two species, the basistyles and dististyles of the two being markedly different.

*Phaenopsectra* spp.--The larvae represented two and possibly three species: *P.* (*Tribelos*) sp., *P.* (*Tribelos*) *jucundus* (Walker), and *P.* (*Phaenopsectra*) sp.

*Polypedilum* spp.--The larvae represented two species: *P.* (*Polypedilum*) "Nubeculosium" grp. and *P.* (*Polypedilum*) "Tripodura" grp.

*Pseudochironomus* sp. and *Xenochironomus* sp.--Only one larva of each was found, both from C slough in 1967.

Tribe Tanytarsini

*Cladotanytarsus* sp.--The larvae and pupae were seemingly of

one species.

*Micropsectra* spp.--The larvae and pupae represented one species but the adults represented two.

*Paratanytarsus* spp.--The larvae represented a complex of up to four species judging from preliminary measurements of the length to width ratio of the basal antennal segment, length of the Lauterborn organ, and length of the head capsule; and from the appearance of the central tooth of the labial plate (notched or not). Also, four different forms of pupae were present as determined by the arrangement of spines on the third to fourth or fifth abdominal segments: "*Ditanytarsus*", "A", "B", and "C" types. "B" was represented by one specimen from D slough in 1967 and "C" type was represented by two specimens from C slough in 1967. However, the adults examined represented only one species.

*Tanytarsus* spp.--The larvae represented one and perhaps a second species based on a comparison of antennal segment lengths. The pupae were of two forms: long and short spined, the latter being difficult to distinguish from *Cladotanytarsus* pupae. The adults were of two species.

No attempt was made to affix specific names to the adults pending publication of Sublette's revision of the Tanytarsini.

Subfamily Orthocladiinae

This subfamily has not been subdivided into tribes (Hamilton *et al.*, 1969). The following genera were present in my sloughs:

*Acricotopus* spp.--The larvae represented perhaps two species. The labial plate of early instar larvae of this genus is sometimes difficult to differentiate from that of a *Cricotopus*, "*Paratrichocladius*"

type, which has been worn down.

*Corynoneura* sp.--Most specimens of immatures were less than 2 mm long and thus could not be included in the analyses of diversity. Adults of this genus were present in the collections examined. A single adult male may be a new species (O. A. Saether, personal communication).

*Cricotopus* spp.--This genus is perhaps the most complex and unsettled one of all the Chironomidae of my study. Larvae of three types within this genus were collected: "*Eucricotopus*", "*Paratrichocladius*" and "*Trichocladius*". (On the basis of Dr. Saether's examinations of larvae the sloughs may have up to five species of the "*Eucricotopus*" type.) However, only two types of pupae were represented: "*Eucricotopus*" and "*Trichocladius*". The larvae and pupae of these types are very distinct. The genus is likely to be split up in the near future and separate genera erected at least partially on the basis of these types (O. A. Saether, personal communication). Some of the "*Trichocladius*" type larvae were difficult to distinguish from those of the genus *Orthocladius* sp. These problem larvae were considered to be of the "*Trichocladius*" type because larvae which were clearly *Orthocladius* were never collected. However, this decision was complicated by the presence of adults which were either *Cricotopus* or *Orthocladius*. Determinations of these adults have not been completed by the Winnipeg laboratory. Additionally, there were two species of adults which were clearly *Cricotopus*. One of these was of the *C. sylvestris* group which corresponds to *C.* "*Eucricotopus*" type. The other is unidentified.

*Metriocnemus* sp.--Only two larvae were collected, one from

each of the sloughs in 1967.

*Psectrocladius* spp.--The larvae represented two species: *P.* (*Psectrocladius*) sp. and *P.* (*Allopsectrocladius*) *flavus* Joh. The pupae of the two species could not be differentiated. The adults examined were of a single species.

gen. nr. *Chaetocladius* sp.--Only one larva was collected from D slough in 1966.

gen. nr. *Krenosmittia* sp.--Only two larvae were collected, one from D slough in 1966 and one from C slough in 1967.

[Other references: Lenz, 1936 to 1962; Johannsen, 1937a, b; Townes, 1945; Brundin, 1956; Roback, 1957; Fittkau, 1962; Beck and Beck, 1966; Hamilton, A. L., O. A. Saether, and D. R. Oliver. Unpublished. Handbook of Canadian Chironomidae].

4. Water mites--Six genera were represented in the sloughs. Individuals of *Arrenurus* were consistently less than 2 mm long and so they were considered not to be sampled quantitatively and this taxon was not used in the analyses of diversity.

[Reference: Newell, 1959].

B. Taxa not used in analyses of diversity

These identifications are presented merely to complete the qualitative characterization of the sloughs of the study.

1. Oligochaeta--With the exception of the identification of the genus *Chaetogaster* sp., I did no other identifications of specimens of this group. A large oligochaete recurred in the samples. Daborn (1969) reported the presence of *Lumbriculus variegatus* (Müller), a very common and large oligochaete, in his slough and it is not

Table 8. Presence or absence of Hirudinea in C and D sloughs for each year of the study*

| Species | C 1966 | C 1967 | C 1968 | D 1966 | D 1967 | D 1968 |
|---|---|---|---|---|---|---|
| *Glossiphonia complanata* | + | + | x | + | + | + |
| *Glossiphonia heteroclita* | x | +(2) | x | x | +(1) | +(4) |
| *Helobdella fusca* | + | + | x | + | + | + |
| *Helobdella stagnalis* | + | + | + | + | + | + |
| *Oculobdella lucida* | + | + | + | + | + | + |
| *Placobdella ornata* | x | x | x | x | +(1) | x |
| *Theromyzon meyeri* | x | + | + | x | x | + |
| *Theromyzon rude* | + | + | + | + | + | + |
| *Dina parva* | x | +(2) | x | x | x | x |
| *Erpobdella punctata* | + | + | x | + | + | x |
| *Mooreobdella fervida* | + | + | + | + | + | + |
| *Nephelopsis obscura* | + | + | + | + | + | + |

* + = present, x = absent; for species with fewer than five specimens the number of specimens is given in brackets.

Table 9. Presence or absence of Amphipoda in C and D sloughs for each year of the study*

| Species | C | | | D | | |
|---|---|---|---|---|---|---|
| | 1966 | 1967 | 1968 | 1966 | 1967 | 1968 |
| *Gammarus lacustris* | x | + | +(1) | + | + | +(3) |
| *Hyallela azteca* | + | + | + | + | + | + |

* + = present, x = absent; for species with fewer than five specimens the number of specimens is given in brackets.

Table 10. Presence or absence of Ostracoda in C and D sloughs for each year of the study*

| Species | C | | | D | | |
|---|---|---|---|---|---|---|
| | 1966 | 1967 | 1968 | 1966 | 1967 | 1968 |
| *Cypris pubera* | + | + | x | +(1) | x | + |
| *Megalocypris alba* | + | + | +(2) | + | + | + |

* + = present, x = absent; for species with fewer than five specimens the number of specimens is given in brackets.

Table 11. Presence or absence of larval Odonata in C and D sloughs for each year of the study*

| Species | C 1966 | C 1967 | C 1968 | D 1966 | D 1967 | D 1968 |
|---|---|---|---|---|---|---|
| *Aeshna interrupta* | + | + | x | + | + | +(4) |
| *Coenagrion angulatum* | + | + | +(3) | + | + | + |
| *Coenagrion resolutum* | + | + | +(1) | + | + | + |
| *Enallagma civile* | + | +(4) | x | + | + | + |
| *Enallagma cyathigerum* | + | + | +(2) | + | + | + |
| *Enallagma ebrium* | +(1) | + | x | + | + | +(2) |
| *Lestes congener* | + | + | x | + | + | +(2) |
| *Lestes disjunctus* | + | + | x | + | + | + |
| *Leucorrhinia borealis* | x | +(1) | x | +(2) | + | +(4) |
| *Leucorrhinia intacta* | x | x | x | + | +(2) | +(2) |
| *Sympetrum costiferum* | + | + | x | +(2) | + | + |
| *Sympetrum internum* | + | + | x | + | + | + |

* + = present, x = absent; for species with fewer than five specimens the number of specimens is given in brackets.

Table 12. Presence or absence of larval Hemiptera in C and D sloughs for each year of the study*

| Taxon | C | | | D | | |
|---|---|---|---|---|---|---|
| | 1966 | 1967 | 1968 | 1966 | 1967 | 1968 |
| *Cymatia americana* | + | + | + | + | + | + |
| other immature Corixidae | + | + | + | + | + | + |
| *Gerris* | x | +(2) | x | + | +(3) | x |
| *Notonecta* | +(1) | +(1) | x | +(1) | +(1) | x |
| *Notonecta kirbyi* | +(1) | +(5) | x | x | x | +(3) |
| *Notonecta undulata* | + | + | +(1) | + | + | + |

* + = present, x = absent; for taxa with fewer than five specimens the number of specimens is given in brackets.

Table 13. Presence or absence of larval Ephemeroptera in C and D sloughs for each year of the study*

| Genus | C | | | D | | |
|---|---|---|---|---|---|---|
| | 1966 | 1967 | 1968 | 1966 | 1967 | 1968 |
| *Caenis* | + | + | + | + | + | + |
| *Callibaetis* | + | + | + | + | + | + |
| *Cloeon* | + | + | + | x | +(1) | +(1) |

* + = present, x = absent; for genera with fewer than five specimens the number of specimens is given in brackets.

Table 14. Presence or absence of larval Coleoptera in C and D sloughs for each year of the study*

| Genus | C | | | D | | |
|---|---|---|---|---|---|---|
| | 1966 | 1967 | 1968 | 1966 | 1967 | 1968 |
| *Agabus* | + | + | +(2) | + | + | + |
| *Dytiscus* | + | + | x | + | +(4) | x |
| *Graphoderus* | + | +(2) | x | + | + | + |
| *Hydroporus-Hygrotus* | + | + | + | + | +(4) | + |
| *Illybius* | +(1) | x | x | x | x | x |
| *Laccophilus* | + | + | + | + | + | + |
| *Oreodytes-Deronectes* | x | + | +(3) | x | x | x |
| *Rhantus-Colymbetes* | + | + | + | + | + | + |
| *Thermomectus* | x | +(1) | x | x | x | x |
| *Gyrinus* | x | +(4) | x | +(1) | +(2) | x |
| *Gyretes* | x | x | x | x | +(1) | x |
| *Haliplus* | +(4) | + | + | +(4) | + | + |
| *Berosus* | x | +(1) | +(1) | x | x | x |

Table 14. (Continued)

| Genus | C 1966 | C 1967 | C 1968 | D 1966 | D 1967 | D 1968 |
|---|---|---|---|---|---|---|
| *Enochrus* | x | x | x | + | x | + |
| *Hydrobius* | x | x | x | +(1) | x | x |

* + = present, x = absent; for genera with fewer than five specimens the number of specimens is given in brackets.

Table 15. Presence or absence of immature Chironomidae in C and D sloughs for each year of the study*

| Genus | C | | | D | | |
|---|---|---|---|---|---|---|
| | 1966 | 1967 | 1968 | 1966 | 1967 | 1968 |
| *Ablabesmyia* | + | + | + | + | + | + |
| *Guttipelopia?* | x | x | x | x | +(1) | x |
| *Thienemannimyia* | x | x | x | x | +(1) | x |
| *Procladius* | +(2) | + | + | x | + | + |
| *Psectrotanypus* | + | x | + | +(4) | + | + |
| *Tanypus* | x | +(1) | + | x | x | +(3) |
| *Chironomus* | + | + | + | + | + | + |
| *Cryptochironomus* | +(2) | +(1) | + | x | x | + |
| *Cryptocladopelma* | +(1) | + | + | x | +(2) | + |
| *Dicrotendipes* | + | + | + | + | + | + |
| *Einfeldia* | + | + | + | + | + | + |
| *Endochironomus* | + | + | +(1) | + | + | + |
| *Glyptotendipes* | + | + | + | + | + | + |
| *Microtendipes* | x | x | + | x | x | + |

Table 15. (Continued)

| Genus | C 1966 | C 1967 | C 1968 | D 1966 | D 1967 | D 1968 |
|---|---|---|---|---|---|---|
| *Parachironomus* | + | + | + | + | + | + |
| *Phaenopsectra* | x | x | x | + | + | x |
| *Polypedilum* | x | + | + | + | + | +(3) |
| *Pseudochironomus* | x | +(1) | x | x | x | +(1) |
| *Xenochironomus* | x | +(1) | x | x | x | x |
| *Cladotanytarsus* | +(3) | + | + | x | x | +(4) |
| *Micropsectra-Tanytarsus* | + | + | + | + | + | + |
| *Paratanytarsus* | + | + | + | + | + | + |
| *Acricotopus* | + | + | x | + | + | + |
| *Corynoneura* | +(1) | + | + | +(1) | +(2) | x |
| *Eucricotopus* type | + | + | + | + | + | + |
| *Paratrichocladius* type | + | + | x | +(1) | + | +(2) |
| *Trichocladius* type | x | +(2) | +(3) | x | +(3) | + |
| *Metriocnemus* | x | +(1) | x | x | +(1) | x |

Table 15. (Continued)

| Genus | C 1966 | C 1967 | C 1968 | D 1966 | D 1967 | D 1968 |
|---|---|---|---|---|---|---|
| *Psectrocladius* | + | + | + | + | + | + |
| nr. *Chaetocladius* | x | x | x | +(1) | x | x |
| nr. *Krenosmittia* | x | +(1) | x | +(1) | x | x |

* + = present, x = absent; for genera with fewer than five specimens the numbers of specimens is given in brackets.

Table 16. Presence or absence of water mites in C and D sloughs for each year of the study*

| Genus | C | | | D | | |
|---|---|---|---|---|---|---|
| | 1966 | 1967 | 1968 | 1966 | 1967 | 1968 |
| *Eylias* | + | + | +(2) | + | +(2) | +(4) |
| *Hydrachna* | + | + | +(2) | + | +(3) | + |
| *Hydrodroma* | + | +(3) | x | +(2) | +(2) | x |
| *Limnesia* | + | + | +(3) | + | + | + |
| *Piona* | x | + | x | +(2) | +(4) | + |

* + = present, x = absent; for genera with fewer than five specimens the number of specimens is given in brackets.

unlikely that this species was the one present in my sloughs as well.

[Reference: Goodnight, 1959].

2. Crustacea

a) Eubranchiopoda

(i) Anostraca--Two specimens of *Eubranchipus bundyi* (Forbes) were collected from C slough on separate occasions in the early part of the 1967 sampling season (late May and early June). Daborn (1969) reported large numbers of the same fairy shrimp in his ponds in early April so it is likely that I missed their period of abundance.

(ii) Conchostraca--A total of 11 specimens of *Lynceus brachyurus* O. F. Müller were collected, all from D slough, all in 1968.

[References: Dexter, 1959; and Mattox, 1959].

b) Zooplankton--I made no attempt to determine all the species of zooplankton in my sloughs because the limnetic samples were not used. However, I made the following determinations from two samples taken early in the study: *Daphnia rosea* Sars 1862 emend. Richard 1896, *Diaptomus leptopus* S. A. Forbes, *Cyclops vernalis* Fischer, and *Cyclops navus* Herrick. *Daphnia* and *Diaptomus* were the most common of the larger zooplankters. Additionally, I noticed the presence of Chydoridae.

[References: Pennak, 1953, 1963; Brooks, 1957, 1959; and Wilson and Yeatman, 1959].

c) Ostracoda--Of the at least six species in the sloughs only two could be used in the analyses of diversity because they were the only specimens large enough to be considered quantitatively collected. These two species were *Megalocypris alba* (Dobbin) and *Cypris pubera* Müller. The remaining four species were *Candona compressa* (Koch), *C. renoensis* Gutentag and Benson or *Cypridopsis hartwigi* Mueller,

*Cyclocypris serena* (Koch), and *Cypridopsis vidua* (Mueller).

[References: Delorme, 1964, 1967a, b, 1969, 1970a, b].

3. Insecta

a) Trichoptera--The immature fauna of my sloughs represented four families. In order of abundance:

(i) Limnephilidae

1. *Limnephilus infernalis* (Banks)

2. *L. janus* Ross

3. Limnephilus species A to G--separated on the basis of head capsule colour patterns; maybe too finely split.

4. *Philarctus quaeris* (Milne)

5. *Anabolia bimaculata* (Walker)

6. *Glyphotaelius?* sp. (= *Nemotaulius?* sp. of which there is one species in Alberta: *N. hostilis* [Hagen]. See Nimmo, 1971).

(ii) Phryganeidae

1. *Phryganea cinerea?* Walker

2. *Agrypnia straminea?* Hagen

3. *Agrypnia improba?* (Hagen)

(iii) Leptoceridae

1. *Triaenodes* nr. *marginata* Sibley--one pupa.

2. *Triaenodes injusta?* (Hagen)

3. *Mystacides longicornis?* Linnaeus

4. *Oecetis?*

(iv) Hydroptilidae

*Agraylea* sp.

Adults collected in the emergence traps represented only the

Limnephilidae and Phryganeidae. The incomplete taxonomic representation by the adults is probably due to the relatively low numbers of adults captured by the traps.

Limnephilidae: *Limnephilus hyalinus* Hagen
*Limnephilus infernalis* (Banks)
*Limnephilus labus* Ross
*Philarctus quaeris* (Milne)
*Anabolia bimaculata* (Walker)
*Nemotaulius hostilis* (Hagen)

Phryganeidae: *Agrypnia straminea* Hagen
*Agrypnia vestita* (Walker)

The correspondence between immature and adult identifications is not complete for those families represented. This not unexpected result is probably due not only to the possibly incomplete adult collections mentioned above but also because the task of identifying the larvae--especially the early instars--is a difficult one.

[Other references: Ross, 1944; Wiggins, 1960, 1963; Hicken, 1968].

b) Lepidoptera--Larval and pupal Pyralidae of the genus *Acentropus* sp. were collected.

[Reference: Welch, 1959].

c) Diptera

(i) Tipulidae--All the specimens collected belonged to the genus *Prionocera* sp.

[Reference: Johannsen, 1934].

(ii) Culicidae--Representatives of three genera were collected:

*Anopheles earlyei?* Vargas, *Culiseta* sp., and *Aedes flavescens?* (Müller). Only specimens of *Aedes* came from both sloughs.

[References: Johannsen, 1934; and Wirth and Stone, 1956].

(iii) Chaoboridae--*Chaoborus americanus* (Johannsen) and *C. crystallinus* (De Geer) were the only two species present. Specimens of *Chaoborus* were present throughout the study in very large numbers.

[References: Cook, 1956; Saether, O. A. Unpublished. Keys to Palaearctic and Nearctic Species of *Chaoborus*].

(iv) Ceratopogonidae--Larvae and/or pupae of the genera *Dasyhelea* sp., *Bezzia* sp., and *Palpomyia* sp. or *Sphaeromias* sp. were collected.

[Reference: Thomsen, 1937].

(v) A few Sciomyzidae and Stratiomyidae larvae as well as unidentified Brachycera pupae were collected.

d) Adult Hemiptera (Species represented by fewer than five specimens are noted).

(i) Corixidae

*Callicorixa alaskensis* Hungerford

*Callicorixa audeni* Hungerford

*Cenocorixa bifida* (Hungerford)

*Cenocorixa dakotensis* (Hungerford)

*Cymatia americana* Hussey

*Dasycorixa* prob. *hybrida* (Hungerford)--1 specimen, ♂, C, 1967

*Hesperocorixa atopodonta* (Hungerford)

*Hesperocorixa laevigata* (Uhler)

*Hesperocorixa michiganensis* (Hungerford)

*Sigara bicoloripennis* (Walley)

*Sigara decoratella* (Hungerford)

[References: Hungerford, 1948; and Brooks and Kelton, 1967].

(ii) Gerridae

*Gerris bueoni* Kirkaldy

*Gerris pingreensis* Drake and Hottes--2 specimens, ♂, C, 1966

[Reference: Brooks and Kelton, 1967].

(iii) Notonectidae

*Bueona confusa* Truxal--1 specimen, ♂, C, 1967

*Notonecta kirbyi* Hungerford

*Notonecta undulata* Say

[Reference: Brooks and Kelton, 1967].

(iv) Saldidae

*Saldula* sp.--generic determination uncertain; 1 specimen, ♂, D, 1968

[Reference: Brooks and Kelton, 1967].

e) Adult Coleoptera (Species represented by fewer than five specimens are noted).

(i) Dytiscidae

*Acilius semisulcatus* Aubé--1 specimen, C, 1967

*Agabus ajax* Fall

*Agabus antennatus* Leech

*Agabus anthracinus* Mann.--2 specimens, D, 1968

*Agabus erichsoni* G. and H. (= *A. nigroaeneus* Er.; Fall, 1922a)

*Bidessus affinis* Say--2 specimens, D and C, 1968

*Colymbetes exaratus* Le Conte

*Colymbetes paykulli* Er.

*Colymbetes sculptilis* Harr.

*Colymbetes seminiger* Le Conte

*Dytiscus oologbucki* Kby.--1 specimen, D, 1967

*Graphoderus occidentalis* Horn

*Graphoderus perplexus* Shp.

*Hydroporus griseostriatus* De Geer

*Hydroporus notabilis* Lec.

*Hydroporus superioris* Balf.-Br.

*Hygrotus canadensis* Fall

*Hygrotus compar* Fall

*Hygrotus dispar* Lec.

*Hygrotus impressopunctatus* Schall

*Hygrotus patruelis* Lec.

*Hygrotus punctilineatus* Fall--1 specimen, C, 1968

*Hygrotus sayi* Balf.-Br.

*Hygrotus sellatus* Lec.

*Hygrotus turbidus* Lec.

*Hygrotus unguicularis* Crotch

*Illybius quadrimaculatus* Aubé--2 specimens, D, 1967; C, 1968

*Illybius subaeneus* Er.

*Laccophilus biguttatus* Kby.

*Rhantus consimilis* Mots.

*Rhantus frontalis* Marsh

*Rhantus wallisi* Hatch

Represented as larvae only: *Oreodytes* sp. or *Deronectes* sp.; and *Thermonectus* sp. (1 specimen, C, 1967)

[Other references: Fall, 1919, 1923; Carr, 1920; Hatch, 1928; Wallis, 1939a, b, c, 1950; Leech and Chandler, 1956; Arnett, 1961; and Zimmerman, 1970].

(ii) Gyrinidae

*Gyrinus wallisi* Fall--1 specimen, C, 1966

Represented as larvae only: *Gyretes* sp.--1 specimen, D, 1967

[References: Fall, 1922b; and Leech and Chandler, 1956].

(iii) Haliplidae

*Haliplus immaculicolis* Harris

*Haliplus leechi* Wallis--1 specimen, C, 1967

*Haliplus stagninus* Leech--4 specimens: 3, C, 1967; 1, C, 1968

*Haliplus strigatus* Robts.

*Haliplus subguttatus* Robts.--1 specimen, C, 1967

[References: Wallis, 1933; and Leech, 1964].

(iv) Helodidae

*Cyphon variablis* (Thunb.)--1 specimen, D, 1967

(v) Hydrophilidae

*Berosus styliferus?* Horn--1 specimen, C, 1966

*Enochrus diffusus* (Le Conte)

*Enochrus hamiltoni* Leech

*Helophorus minutus?* Fabricius--1 specimen, C, 1966

*Hydrobius fuscipes* (L.)--2 specimens, D, 1966 and 1968

*Laccobius agilis* Randall--1 specimen, C, 1966

[References: Leech and Chandler, 1956; and Arnett, 1961].

(vi) Other Coleoptera

Chrysomelidae: *Galerucella nymphaeae* L.

*Orsodacna atra* Ahr.

Scarabaeidae: *Aphodius* sp.

Staphylinidae: *Stenus* sp.

4. Mollusca

a) Pelecypoda--The depauperate clam fauna consisted of a few specimens of *Pisidium* sp.

b) Gastropoda--Most of the snail fauna consisted of the following taxa:

(i) Lymnaeidae: *Lymnaea stagnalis* (Linnaeus)

*Lymnaea elodes* Say

(ii) Planorbidae: *Helisoma trivolvis* (Say)

*Promenetus* sp.

*Gyraulis* sp.

*Gyraulis crista* Linnaeus

(iii) Physidae: *Physa* sp.

*Physa jennessi* Dall

[References: Baker, 1928; La Roque, 1953; Pennak, 1953; and Needham and Needham, 1962].

5. Miscellaneous

a) Coelenterata--During the course of the study a few specimens of *Hydra* probably *carnea* Agassiz were collected.

[Reference: Paetkau, 1964].

b) Turbellaria--Specimens of *Mesostoma* sp. were collected. They were more common in D slough than in C.

[Reference: Jones, 1959].

c) Bryozoa--Although no colonies were found, a few spinoblast statoblasts (of *Cristatella mucedo* Cuvier) appeared in the samples. Hui (1963) reports the presence of *Plumatella fungosa* (Pallas), *P. repens* L., and *C. mucedo* in the area of my sloughs. The statoblasts found were similar to those he figured for *C. mucedo*. However, it is also possible that the statoblasts were brought from elsewhere. The powers of dispersal of statoblasts have been well documented (Pennak, 1953).

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