STUDIES ON AQUATIC OLIGOCHAETA IN INLAND WATERS OF WISCONSIN

Richard P. Howmiller
*University California—
Santa Barbara*

INTRODUCTION

Aquatic oligochaete worms, especially the Tubificidae, are common in the benthos of many lakes and rivers. In some aquatic environments, for example in polluted stretches of rivers and the profundal zone of many lakes, these organisms are often the most abundant of benthic macroinvertebrates.

Many of the aquatic oligochaetes occupy a niche similar to that of their terrestrial counterparts, ingesting and burrowing in the bottom sediments. Through these activities they may have profound effects upon the functioning of aquatic ecosystems. Under experimental conditions tubificids have been shown to promote the release of plant nutrients (Howmiller, unpublished) and pollutants (Jernelov 1970) from sediments, and to increase the rate of biochemical oxidation of sediments (Zvetlova 1972).

The worms are preyed upon by numerous invertebrate predators and by bottom-feeding fishes. Their importance as a food item of fishes is often underestimated because the worms are so rapidly digested that only unrecognizable fragments remain in stomach samples handled in the usual fashion. However, the fact that some tubificids serve as intermediate hosts of fish parasites (Calentine and Delong 1966, Calentine and Mackiewicz 1966) attests to their use as food by several fish species. The value of the worms as fish food is recognized by tropical fish fanciers who support a small industry supplying them with "tubifex worms"—the only direct economic importance of aquatic oligochaetes.

Pollution biologists have long associated an abundance of oligochaetes, coupled with a scarcity of other benthic invertebrates, with severe organic pollution. Thus one often sees the worms collectively referred to as "sludgeworms". In fact, only a few species of tubificids are tolerant of gross pollution. Thus, in recent years, attention has been focused on the possibility of a more sensitive index of environmental quality based on the relative abundance of species found to be intolerant, moderately tolerant, and very tolerant of organic enrichment. This interest has been a primary consideration in several studies of oligochaete species' distributions in waters of the Great Lakes. The worm fauna of the Great Lakes is now quite well known and it has become clear that polluted bays and harbors, and moderately enriched areas such as southern Lake Michigan, have characteristic species assemblages which are distinct from those of the open unpolluted areas of the lakes. The worm fauna of Great Lakes' waters bordering on Wisconsin has been studied by Hiltunen (1969a) in the Apostle Islands region of Lake Superior, Howmiller and Beeton (1970) in Green Bay, and Hiltunen (1967) and Howmiller (1972) in Lake Michigan proper. The fauna of these areas includes forty-one species of Oligochaeta (Howmiller and Beeton 1970).

Despite the importance of aquatic oligochaetes, and the frequency with which they are encountered by aquatic biologists, the fauna of most regions is poorly known. Though the aquatic biota of Wisconsin has probably been recorded more thoroughly than that of any other state, the literature contains only occasional records of oligochaetes at the species level. For many years, the records of *Sparganophilus eiseni* (= *S. tamesis*), *Lumbriculus limosa* (= *L. varigatus*), *Chaetogaster, Nais, Pristina, Limnodrilus claparedeianus,* and *Tubifex tubifex* from Lake Mendota (Muttkowski 1918) have constituted the most complete account of the aquatic Oligochaeta of Wisconsin. The purpose of the present communication is to record additional species from Wisconsin and to give an account of some ecological observations.

RECENT WISCONSIN RECORDS

Oligochaete species identified from my recent collections are listed in Table 1, in which localities are given as code letters. Explanation of the code letters, and locations of these lakes and rivers, are as follows:

Code	Lake or River	County
YL	Yellow Lake	Burnett
LK	Lake Kegonsa	Dane
LM	Lake Mendota	Dane
SP	Salmo Pond	Dane
TM	Theresa Marsh	Dodge
GL	Green Lake	Green Lake
LGL	Little Green Lake	Green Lake
GP	Grand Portage (Tank) Lake	Iron
KR	Kinnickinnic River	Milwaukee
MR	Milwaukee River	Milwaukee
RR	Root River	Milwaukee
CL	Clear Lake	Oneida
WR	Wisconsin River	Oneida
LP	Lake Pepin	Pepin
LMa	Lake Mallalieu	St. Croix

Code	Lake or River	County
DL	Devils Lake	Sauk
CrL	Crystal Lake	Vilas
TL	Trout Lake	Vilas
LD	Lake Delavan	Walworth
LG	Lake Geneva	Walworth
PL	Pleasant Lake	Walworth
LN	Lake Nagawicka	Waukesha
IF	(Illinois) Fox River	Waukesha
LW	Lake Winnebago	Winnebago
FR	Fox River	Winnebago

Nomenclature used in Table 1 follows that in the recent monograph of Brinkhurst and Jamieson (1971) except that *Limnodrilus spiralis* (Eisen) is here retained as a distinct species. *Limnodrilus spiralis* is separated from *L. hoffmeisteri* and other *Limnodrilus* species on the basis of differences in penis sheath morphology. The sheath of *L. spiralis* is, on the average, longer than that of *L. hoffmeisteri* and has its opening at the tip, surrounded by a flat plate with one edge upturned (Fig. 1a). The shorter sheath of *L. hoffmeisteri* is usually somewhat curved and is hooded with the opening at 90° to the shaft (Fig. 1b). Brinkhurst (Brinkhurst and Jamieson 1971) considers *L. spiralis* a synonym of *L. hoffmeisteri* and feels that a separate species should not be erected on the basis of the differences mentioned above unless the worms can be shown to be different in some other way. However, these differences are pronounced and, in my experience, intergrades are rare or nonexistent. It is difficult to be very positive on this last point since penis sheathes are often somewhat deformed when the animal is placed under a coverslip, especially in specimens where the sheath is just forming. Thus it is possible that a specimen with a sheath deformed in slide preparation could be mistaken for an intergrade, or vice versa. Differences in distribution of mature specimens of the two forms, in a lake in which both occur (Table 2), suggest that they are ecologically different in addition to being morphologically distinct.

Hiltunen (1967) found *L. spiralis* in Lake Michigan, but considered it a variant of *L. hoffmeisteri*. He has since recorded elsewhere[1] that *L. spiralis* is discontinuously widespread in the Great Lakes region, in mesotrophic and eutrophic habitats, and that specimens intermediate between it and typical *L. hoffmeisteri* are infrequently observed.

The question may merit further taxonomic investigation, but at present it seems appropriate to retain *L. spiralis* as a distinct species.

---

[1] Hiltunen, J. K. 1973. A Laboratory Guide; keys to the tubificid and naidid Oligochaeta of the Great Lakes region. Unpubl. ms. 24 pp.

TABLE 1. AQUATIC OLIGOCHAETA IDENTIFIED FROM RECENT COLLECTIONS AND LOCALITIES AT WHICH THEY WERE FOUND (FOR EXPLANATION OF CODE LETTERS SEE TEXT). SPECIES REPORTED BY MUTTKOWSKI (1918) FROM LAKE MENDOTA ARE MARKED WITH A SINGLE ASTERISK. ALL OTHERS ARE NEW RECORDS FOR INLAND WATERS OF WISCONSIN

Species	*Localities*
Lumbriculidae	
Lumbriculus variegatus (Verrill)*	SP, CrL
Naididae	
Arcteonais lomondi (Martin)	LMa, DL
Aulophorus vagus Leidy	TM
Dero digitata (Muller)	TM, LMa, DL, LN, FR
Haemonais waldvogeli Bretscher	TM
Nais elinguis (Muller)	TM
Nais simplex Piguet	LN
Ophidonais serpentina (Muller)	TM, LMa, DL, IFR
Stylaria fossularis Leidy	LGL, DL
Stylaria lacustris (Linnaeus)	TM, CL, LMa
Tubificidae	
Aulodrilus americanus Brinkhurst & Cook	YL
Aulodrilus limnobius Bretscher	YL, LMa, DL
Aulodrilus pigueti Kowalewski	YL, LMa, DL, LW
Aulodrilus pluriseta (Piguet)	DL
Branchiura sowerbyi Beddard	LP, LG
Ilyodrilus templetoni (Southern)	YL, LM, TM, LGL, GP, LMa, DL, CrL, TL, FR
Limnodrilus cervix Brinkhurst	LD, FR
Limnodrilus claparedeianus Ratzel*	LGL
Limnodrilus hoffmeisteri Claparede	YL, LK, LM, TM, GL, LGL, GP, KR, MR, RR, WR, LP, LMa, DL, CrL, TL, LD, LG, PL, IFR, LW, FR
Limnodrilus profundicola (Verrill)	GL
Limnodrilus spiralis (Eisen)**	LG
Limnodrilus udekemianus Claparede	RR, LMa, LG, IFR, FR
Peloscolex multisetosus multisetosus (Smith)	LMa, LG, FR
Peloscolex multisetosus longidentus Brinkhurst & Cook	KR
Potamothrix hammoniensis (Michaelsen)	LG
Potamothrix moldaviensis (Vejdovsky & Mrazek)	GLY, LMa, DL
Tubifex kessleri americanus Brinkhurst & Cook	GL
Tubifex tubifex (Muller)*	GL, KR, MR, WR, LMa, LG, FR

** see text

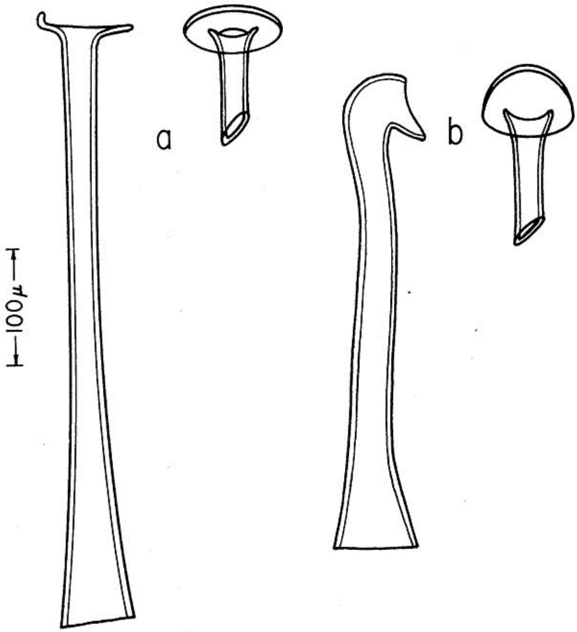

FIGURE 1. Illustrating differences in form of the penis sheath in (a) *Limnodrilus spiralis* and (b) *L. hoffmeisteri.* Drawn from Lake Geneva specimens.

The purpose of listing localities in Table 1 is not to suggest the existence of discrete species' distributions within the state but to indicate the degree of commonness or rarity of each of the species. In this regard it must be pointed out that there was some bias in sampling as most samples were taken in deeper waters free of macroscopic vegetation. The tubificids are thus more adequately represented than the naidids which prefer weedy littoral situations. However, many readers will recognize that the waters sampled represent a considerable variety of environmental conditions; from nearly oligotrophic Crystal Lake to the very eutrophic conditions of Lakes Winnebago and Delavan, and from the very shallow Theresa Marsh to Green Lake, the deepest lake in the state.

OLIGOCHAETA AND LAKE TYPES

Introduction

There is, of course, always an academic interest in defining the sorts of environments in which particular organisms are found. In recent decades there has been an increasing interest in asking

TABLE 2. ABUNDANCE OF TUBIFICID WORMS, AS INDIVIDUALS PER SQUARE METER, AT FIVE DEPTHS ALONG A TRANSECT IN LAKE GENEVA. ESTIMATES ARE BASED ON A SINGLE (15 X 15 CM) EKMAN GRAB SAMPLE AT EACH DEPTH EXCEPT FOR THE 27.5 M STATION WHERE FOUR SUCH SAMPLES WERE TAKEN. SEVERAL SAMPLES TAKEN FROM DEPTHS OF 36.5 AND 43.5 M CONTAINED NO MACROSCOPIC INVERTEBRATES

	Depth, meters				
	12.5	17.5	21.0	24.5	27.5
Branchiura sowerbyi	133				
Limnodrilus hoffmeisteri	222	174			
L. spiralis		290	1993	4098	22
L. udekemianus	44				
Potamothrix hammoniensis		58	87		11
Peloscolex multisetosus	178		87		
Tubifex tubifex		581			222
Undetermined immatures;					
with hair chaetae		2148	260	141	1566
without hair chaetae	133	3193	6240	2826	11
Total	710	6444	8667	7065	1832
Most probable no. species	5	4	4	2	3
Number Examined	16	111	100	100	165

this question in a slightly different way, viz; Which species of organisms are typically found in a particular type of environment? Adequate knowledge of this sort may allow us to use organisms as indicators of environmental quality. For example, changes in composition of the biota have provided useful indices for documenting the eutrophication of lakes (Brinkhurst 1969, Hooper 1969).

The bottom fauna of littoral areas has only limited value as an index of the trophic state of a lake, because littoral areas are strongly influenced by edaphic factors and often receive considerable inputs of allochthonous detritus. The profundal region, on the other hand, offers relative uniformity of environmental conditions. In many respects the conditions are related to the productivity of the overlying water. Chief among these are the quantity and quality of organic matter and the dissolved oxygen concentration (Jonasson 1972). Consequently, most attempts to correlate lake trophy and bottom fauna have been concerned with the profundal benthos.

Earlier work of this sort focused upon the larvae of chironomid midges (Thienemann 1922, Deevey 1941, Brundin 1958). Differences found, at the generic level, resulted in the formation of a "bottom faunistic lake type system" which seemed to have widespread applicability (Brundin 1958), although the relationship between productivity and bottom fauna was often complicated by morphometric influences (Brundin 1949).

Brinkhurst (1964) investigated the oligochaete fauna of a number of lakes in the English Lake District with this same question in mind. His results are a bit difficult for the reader to evaluate as species abundances are indicated merely as absent, present or abundant. Also, he presents no data to indicate how one might rank the lakes investigated using other criteria, saying only that they "have been held to represent a series according to the classical taxonomy of lakes". He concluded that his findings indicated several species to be common in a wide variety of lakes. Thus, while *Peloscolex ferox* seemed to be characteristic of less productive lakes and *Euilyodrilus (Potamothrix) hammoniensis* was increasingly common in more productive lakes, the data offered no more quantitative relationship between lake type and worm fauna composition.

In view of the previously mentioned studies on the Great Lakes, which have found species assemblages differing greatly under different environmental conditions, Brinkhurst's (1964) results seemed surprising. There seemed a possibility that relationships between worm faunal composition and lake type might be found elsewhere, where perhaps, there was a richer fauna to offer more ecologically specialized worm species. Thus the present study was undertaken.

Procedure

The twenty-six lakes chosen for investigation included all those studied by Lueschow and co-workers (1970). They measured a number of parameters indicative of trophic status of the lakes and calculated a "composite rating" which allowed a ranking of the lakes from most oligotrophic to most eutrophic. The other lakes included in the present investigation, with the exception of Devils Lake, were among those studied by Hilsenhoff and Narf (1968). Hilsenhoff and Narf measured various environmental factors thought to be important in regulating chironomid populations but did not rate the lakes as oligotrophic or eutrophic.

Environmental parameters measured during the investigations reported here included depth profiles of temperature and dissolved oxygen, transparency, color, conductivity, alkalinity, seston, and organic and carbonate content of sediments.[2] The data, particularly

[2] A detailed account of methods and limnological data comprises an August 1972 progress report to the Wisconsin Department of Natural Resources.

transparency, color, organic seston and total phosphorus values, were used to arrange the lakes in a trophic series (Fig. 2). Those lakes studied by Lueschow and co-workers (1970), are listed here in the same order as ranked by them on the basis of their "composite rating". Thus the data collected during the present investigation have essentially been used only to place the other lakes in their series. The order in Fig. 2 is thus meant to indicate trophic status, with the more oligotrophic lakes at the top of the list, and the most eutrophic at the bottom.

Samples for study of the oligochaete fauna were taken at some distance from shore, usually from a depth near maximum depth. In one instance (Lake Geneva, See Table 2) samples from a shallower depth, still well within the profundal zone, were substituted when deeper samples were found devoid of macroscopic organisms.

Four replicate samples were taken at the single sampling site in each lake using a 15 x 15 cm tall form Ekman grab. Samples were sieved immediately with a U.S. Std No. 30 screen (0.565 mm) and the residue from the screen preserved in 10% formalin. All organisms were picked from the preserved residue by hand, with the aid of low power magnification. Oligochaete worms were mounted whole on microscope slides with Turtox CMC or Amman's

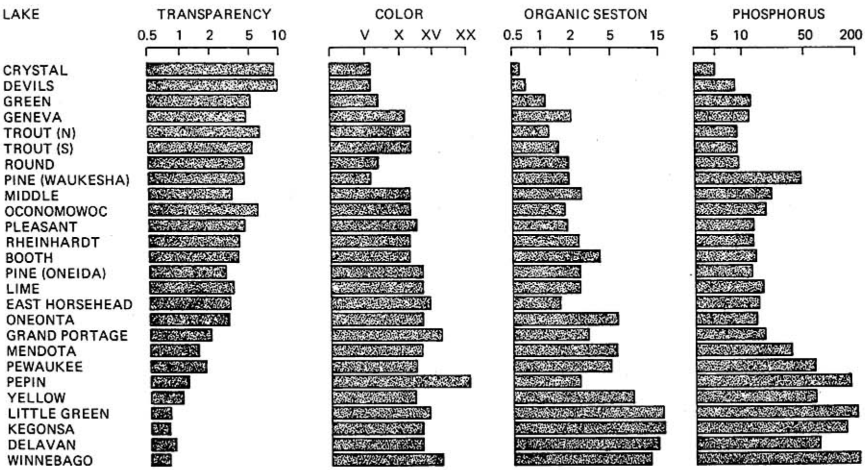

FIGURE 2. Illustrating values of some limnological parameters for twenty-six Wisconsin lakes. Transparency is in meters and was measured with a 20 cm all-white Secchi disc. Color was determined by comparison with a Forel–Ule scale. Organic seston data are given in mg/liter and were obtained by measuring loss on ignition of material on Whatman GF/C filters. Total phosphorus values are given in µg/liter; the samples were taken from a depth of 1.0 m and determinations made by the method of Schmid and Ambuhl (1965).

Lactophenol or a mixture of the two. They were examined after waiting several weeks for clearing of soft tissues.

Results and Discussion

Samples from the profundal of nine of the lakes (Round, Pine in Waukesha County, Middle, Oconomowoc, Booth, Lime, Oneonta, Pewaukee, and Delavan) contained no oligochaete worms. Note that while these lakes without worms fall in a range which may be described as mesotrophic to very eutrophic (Fig. 2), the six most oligotrophic lakes all contained oligochaetes in the profundal sediments.

All the oligochaetes found in these profundal samples belonged to the family Tubificidae. Table 3 lists the abundance of individual taxa for each of the seventeen lakes from which worms were collected. Absolute abundance is given as individuals per square meter, based on the mean of counts from the four Ekman grab samples. The standard error of the mean is also given in the table. Since in all cases the number of samples was four, the standard deviation is twice the standard error. The relative abundance of each taxon, as a percentage of the total number of tubificids, is also given in Table 3.

Before further reviewing Table 3, it should be pointed out that many common tubificids can be positively identified only when they are sexually mature and bearing sexual structures (e.g. genital chaetae or penis sheathes). Thus, in almost every case, it was impossible to identify many of the worms in the samples. These are listed as undetermined immatures and placed into two groups; those which possessed hair chaetae and those lacking hair chaetae. Knowing which species are present in the samples, from positive identifications of mature specimens, allows one to make a reasonable guess at the identity of immature specimens. Thus, in Table 3, I have listed probable abundance of *Limnodrilus hoffmeisteri;* this number including *L. hoffmeisteri* and a portion or all of the immature worms without hair chaetae. In cases where a portion of the immatures without hair chaetae could have belonged to another species (e.g. *L. profundicola* in Green Lake) the immatures were assigned to the two species on the basis of relative abundance of positively identified mature specimens. In the same manner, undetermined immature specimens without hair chaetae were included among probable numbers of *Ilyodrilus templetoni* or *Tubifex tubifex* depending on which was found as mature specimens in the particular lake. In one case (Lake Geneva) only a portion of the immatures with hairs was included among probable *Tubifex tubifex* because these could also have included immature *Potamothrix hammoniensis.*

This manipulation of data no doubt involves some error since it assumes that all species populations included some mature individuals. This is obviously not true, since many lakes contained immatures with or without hairs and no mature specimens which fit the category. Also, assignment of immatures to two species was done with the assumption that mature specimens constituted the same proportion of both populations. This assumption, too, is certainly in error to some extent. Unfortunately, there is no way to assess the magnitude of error introduced by these assumptions. As long as there is no way to reliably identify immature specimens and we lack life history information which might indicate the normal proportion of mature specimens under given environmental conditions, calculations of the sort described above will provide the only means of estimating the number of species in a lake and the relative abundance of each.

In these seventeen lakes, mean abundance of tubificids ranged from 11 individuals / m^2 in South Trout and Pine (Oneida County) to over 27000/m^2 in Green Lake (Table 3). The standard errors associated with these means are in many cases quite large, but small enough to leave no doubt that there are differences of several orders of magnitude in the abundance of tubificids in these lakes. It is clear that the four most oligotrophic lakes were the four in which oligochaetes were most abundant, but there was no consistent relationship between worm abundance and lake trophy when all seventeen lakes were considered (compare Fig. 2, Table 3).

It is apparent from Table 3 that *Limnodrilus hoffmeisteri* was, by far, the most common worm in the lakes. Of the seventeen lakes having worms in the profundal benthos, this species occurred in twelve (in thirteen if one includes *L. spiralis* in *L. hoffmeisteri*). It was clearly numerically dominant in most of these lakes (Table 3). This was not unexpected. *L. hoffmeisteri* is cosmopolitan and is generally the most common worm in any region (Brinkhurst and Jamieson 1971). It has been found to be the most abundant worm in studies of many types of environments, though in extreme cases this has often been associated with organic pollution (Brinkhurst 1969).

Ilyodrilus templetoni was the second most common and abundant species. It was represented by mature specimens in six lakes and probably occurred among the immature specimens of five other lakes (Table 3). In Crystal Lake and Lake Mendota, *I. templetoni* accounted for a considerable proportion of the worm fauna and this may have been true of several other lakes (South Trout, Rheinhardt, Pine in Oneida County, East Horsehead; Table 3).

TABLE 3. ABUNDANCE OF TUBIFICID WORMS IN THE PROFUNDAL SEDIMENTS OF SEVENTEEN WISCONSIN LAKES. THE UPPER PORTION OF THE TABLE GIVES ABUNDANCE IN INDIVIDUALS PER SQUARE METER, BASED ON THE MEAN OF COUNTS FROM FOUR 15 X 15 CM EKMAN GRAB SAMPLES, FOLLOWED BY THE STANDARD ERROR OF THE MEAN; AND, IN PARENTHESES, THE RELATIVE ABUNDANCE OF EACH TAXON, AS A PERCENTAGE OF TOTAL TUBIFICIDAE. THE LOWER PORTION OF THE TABLE LISTS PROBABLE NUMBERS OF *LIMNODRILUS HOFFMEISTERI*, *ILYODRILUS TEMPLETONI*, AND *TUBIFEX TUBIFEX* (SEE TEXT); THE MOST PROBABLE NUMBER OF SPECIES IN EACH COLLECTION, AND THE TOTAL NUMBER OF SPECIMENS EXAMINED

Taxon	Lake					
	Crystal	Devils	Green	Geneva	Trout (N)	Trout (S)
Aulodrilus pigueti						
Branchiura sowerbyi						
Ilyodrilus templetoni	478 ± 198 (21.3)				78 ± 21 (10.8)	11 ± 11 (100)
Limnodrilus claparedeianus						
L. hoffmeisteri	133 ± 41 (5.9)	44 ± 0 (3.6)	592 ± 318 (2.2)		178 ± 79 (24.6)	
L. profundicola			200 ± 139 (0.7)			
L. spiralis				22 ± 22 (1.2)		
Potamothrix hammoniensis				11 ± 11 (0.6)		
Tubifex tubifex			308 ± 133 (1.1)	222 ± 104 (12.2)		
Undetermined immatures; With hair chaetae	889 ± 107 (39.6)	111 ± 29 (9.2)	26092 ± 17168 (94.6)	1556 ± 294 (85.4)	11 ± 11 (1.5)	
Without hair chaetae	744 ± 250 (33.2)	1056 ± 100 (87.2)	369 ± 260 (1.3)	11 ± 11 (0.6)	456 ± 138 (63.0)	
Total Tubificidae	2244 ± 247	1211 ± 178	27564 ± 17645	1822 ± 424	722 ± 225	11 ± 11
"Probable *L. hoffmeisteri*"	39.1	90.8	3.5		87.6	
"Probable *I. templetoni*"	60.9	9.2			12.3	100
"Probable *T. tubifex*"			95.7	93.6		
Probable No. species	2	2	3	3	2	1
No. specimens examined	202	109	344	164	65	1

TABLE 3. (CONTINUED)

Taxon	Lake					
	Pleasant	Rheinhardt	Pine (Oneida)	E. Horsehead	Grand Portage	Mendota
Aulodrilus pigueti						
Branchiura sowerbyi						
Ilyodrilus templetoni					11 ± 11 (1.0)	133 ± 104 (27.2)
Limnodrilus claparedeianus						
L. hoffmeisteri	89 ± 48 (26.7)				367 ± 178 (34.4)	22 ± 22 (4.5)
L. profundicola						
L. spiralis						
Potamothrix hammoniensis						
Tubifex tubifex						
Undetermined immatures; With hair chaetae		67 ± 29 (100)	11 ± 11 (100)	22 ± 22 (100)		89 ± 36 (18.2)
Without hair chaetae	244 ± 38 (73.3)				689 ± 256 (64.6)	244 ± 82 (50.0)
Total Tubificidae	333 ± 56	67 ± 29	11 ± 11	22 ± 22	1067 ± 400	489 ± 180
"Probable *L. hoffmeisteri*"	100				99.0	54.5
"Probable *I. templetoni*"		100	100	100	1.0	45.4
"Probable *T. tubifex*"						
Probable No. species	1	1	1	1	2	2
No. specimens examined	30	6	1	1	96	44

TABLE 3. (CONTINUED)

Taxon	Lake				
	Pepin	Yellow	L. Green	Kegonsa	Winnebago
Aulodrilus pigueti					11 ± 11 (9.0)
Branchiura sowerbyi	122 ± 38 (14.8)				
Ilyodrilus templetoni			11 ± 11 (4.1)		
Limnodrilus claparedeianus			22 ± 13 (8.2)		
L. hoffmeisteri	89 ± 18 (10.8)	89 ± 18 (38.2)	100 ± 33 (37.4)	166 ± 21 (42.7)	67 ± 38 (54.9)
L. profundicola					
L. spiralis					
Potamothrix hammoniensis					
Tubifex tubifex					
Undetermined immatures; With hair chaetae					
Without hair chaetae	611 ± 93 (74.3)	144 ± 52 (61.8)	133 ± 18 (49.8)	222 ± 48 (57.1)	44 ± 18 (36.1)
Total Tubificidae	822 ± 116	233 ± 69	267 ± 31	389 ± 64	122 ± 64
"Probable *L. hoffmeisteri*"	85.1	100	78.3	100	91.0
"Probable *I. templetoni*"			4.1		
"Probable *T. tubifex*"					
Probable No. species	2	1	3	1	2
No. specimens examined	74	21	25	35	11

These findings contrast sharply with Brinkhurst's (1964) data from British Lakes which indicate that *I. templetoni* (as *Tubifex templetoni*) occurred in few lakes and was never abundant. Howmiller and Beeton (1970) found *I. templetoni* common in a portion of Green Bay but not so above the latitude of Sturgeon Bay or below Long Tail Point near the mouth of the Fox River. The species thus seems to be favored by moderate organic enrichment but intolerant of gross pollution.

Tubifex tubifex, third most common worm in these profundal samples, occurred in only two lakes but there comprised most of the worm fauna (Table 3). It may be of significance that the two lakes in which it occurred, Green and Geneva, are at the oligotrophic end of the series and are the deepest of these lakes. *Tubifex tubifex,* in puzzling contrast with its well-deserved reputation for tolerance of severe organic pollution in rivers and harbors, has frequently been reported as a relatively abundant species in the profundal of oligotrophic lakes. Brinkhurst (1964) reported that it alone occurred in material from high alpine lakes of Austria and this seems to be true as well of some oligotrophic sub-alpine lakes in the Sierra Nevada (Howmiller, unpublished). *Tubifex tubifex* occurs in the profundal benthos of the oligotrophic upper Great Lakes (Hiltunen 1967, Howmiller 1972) and in the less productive regions of the lower lakes (Brinkhurst and Jamieson 1971).

The three species just discussed, *L. hoffmeisteri, I. templetoni,* and *T. tubifex,* are the only common oligochaetes in the profundal region of these Wisconsin lakes. While six other species were found in the present series of samples, each occurred in only a single lake (Table 3). These lakes are thus at least as poor in species as those of the English Lake District investigated by Brinkhurst (1964). Of the twenty lakes which he sampled, four yielded no worms, seven contained only one species, six contained two species, and three had three species. Of the five species recorded from these English lakes; *Peloscolex ferox, Aulodrilus pluriseta, Tubifex tubifex, Ilyodrilus templetoni,* and *Limnodrilus hoffmeisteri,* only the latter occurred in more than half the lakes. *Aulodrilus pluriseta* and *T. tubifex* were found in only two lakes each.

The paucity of species in the profundal of inland lakes contrasts strongly with findings in bays, harbors, and littoral areas of the Great Lakes. For example, thirty species of Oligochaeta, including nineteen tubificids, have been reported from Green Bay. As pointed out by Dahl (1970), there are many possibilities for overland dispersal of oligochaetes. The occurrence of only a few species in the profundal of these Wisconsin lakes, considering their close proximity to the rich fauna of the Great Lakes, thus indicates that in terms of the requirements of oligochaete species, the profundal regions of inland lakes constitute a set of very similar environments. The corollary of this is that composition of the profundal oligochaete fauna has no index value for distinguishing between lakes within the range offered by the series investigated. There does seem some tendency for more oligotrophic lakes to be less likely to lack worms in profundal regions, and perhaps *T. tubifex* occurs in abundance in the profundal zone only in more oligotrophic lakes. However, it would seem to require an investigation of much wider scope to determine whether these are valid generalizations.

VERTICAL DISTRIBUTION OF OLIGOCHAETA IN LAKES

While the investigation just described was concerned primarily with worms of profundal regions, samples were taken at several shallower depths in two of the lakes. These samples were examined for evidence of depth differences in composition of the worm fauna, as has been reported for several British and European lakes (Brinkhurst 1964).

Benthic samples were taken from seven depths in Lake Geneva on a single date (Table 2). The samples from the two deepest stations (36.5 and 43.5 m) contained no macroscopic invertebrates. This is no doubt a result of prolonged anoxia in the deepest part of the basin. Vertical zonation of tubificid species was suggested by composition of the samples from the five lesser depths.

Two species, *Branchiura sowerbyi* and *Limnodrilus udekemianus* occurred only in the shallowest water, from 12.5 m in depth. Two others, *L. hoffmeisteri* and *Peloscolex multisetosus,* reached their maximum abundance in this sample. In addition to these four species, the sample contained immature specimens of at least one other. The most probable number of species was considered to be five, more than at any greater depth.

A sample from 17.5 m depth contained typical *L. hoffmeisteri* as well as *L. spiralis*. Of these, only *L. spiralis* was represented among mature specimens at greater depths. The 17.5 m sample also contained mature *Potamothrix hammoniensis* and *T. tubifex* and was dominated by unidentifiable immature specimens representing mostly or entirely *T. tubifex.*

At 21.0 meters the sample was dominated by immatures without hairs. The mature specimens in the sample can be assigned only to *L. spiralis*. *Potamothrix hammoniensis, Peloscolex multisetosus* and a relatively small number of immatures resembling *T. tubifex* were also found at this depth.

The sample from 24.5 m depth contained still fewer immatures with hairs and was dominated by mature *L. spiralis*.

Samples from 27.5 m indicated a fauna dominated by *T. tubifex;* the immatures with hairs are believed to represent mostly this species. Small numbers of *L. spiralis* and *P. hammoniensis* were also found (Table 2).

This series, while inadequate in that it represents only a single transect with single samples from most depths, provides evidence of vertical differences in composition of the worm fauna in a single lake. It is also clear that the paucity of species in profundal samples is due to the special conditions there and does not apply to the lake as a whole. While this series from Lake Geneva included at least seven species of tubificids only 3 were found at 27.5 m, the depth taken to represent the profundal (Table 3). Lastly, we may note that the proportion of mature individuals in some populations varies with depth; with numbers of mature *L. hoffmeisteri* exceeding immature specimens at 12.5 m, mature *Limnodrilus* spp. much less numerous than immatures at 17.5 and 21.0 m, and mature *L. spiralis* considerably more abundant than immatures at 24.5 m. A careful analysis of a situation of this sort through the course of a year could indicate more precisely the proportion of immatures attributable to each taxon and indicate conditions conducive to maturation and breeding of the species.

Samples taken in Devils Lake at three depths on several dates further illustrate vertical zonation of oligochaetes as well as seasonal variations in the abundance of some species. Samples taken on two dates at two nearshore stations (Table 4) included variable numbers of three species of naidids. Doubtless, a series of samples taken throughout the summer and winter would have reflected greater fluctuations in abundance. Muttkowski (1918) noted strong seasonal variation in abundance of naidids in Lake Mendota, with higher population densities associated with seasonal development of the littoral macrophytes.

Aulodrilus pluriseta in Devils Lake also seemed to undergo a seasonal change in abundance (Table 4). This is, in the extremes indicated here, unusual for a tubificid but apparently not unusual for *A. pluriseta.* In a series of samples taken monthly in two British lakes, Bala and Windermere, Brinkhurst (1964) found strong seasonal fluctuations in abundance of *A. pluriseta,* with maxima in mid- to late summer. He reported that very few sexually mature specimens were found and suggested that asexual

TABLE 4. ESTIMATES OF ABUNDANCE OF AQUATIC OLIGOCHAETES, AS INDIVIDUALS PER SQUARE METER, AT TWO NEARSHORE STATIONS ON DEVILS LAKE

	8.0 Meter Station — Date —		10.0 Meter Station — Date —	
	2 VI 70	19 X 69	2 VI 70	19 X 69
Naididae				
Arcteonais lomondi	22	133		44
Dero digitata	44			
Stylaria fossularis	44		22	
Total	110	133	22	44
No. species	3	1	1	1
Tubificidae				
Aulodrilus limnobius	22	89		
A. pigueti	22	178	178	44
A. pluriseta			1133	
Ilyodrilus templetoni	22			44
Potamothrix moldaviensis			22	
Undetermined immatures;				
with hair chaetae	22	89	22	
without hair chaetae		178	133	267
Total	88	534	1488	355
Apparent No. species	3	4	4	3

reproduction was occurring. In Bala Lake more breeding specimens were found, especially in late summer and this may be the time of a single annual period of sexual activity (Brinkhurst 1964). No breeding specimens were observed in the Devils Lake samples and the seasonal fluctuation is thus believed to be the result of rapid asexual reproduction.

On several dates naidids appeared in samples taken at a mid-lake station with a depth over 13 m. Maximum numbers were observed here in fall (Table 5), and may reflect active or passive movement, or both, of the worms from littoral areas as macrophytic vegetation died down. Most, if not all, naidids are capable of swimming.

Of the three *Aulodrilus* species found at the nearshore station, only *A. pigueti* was recorded from mid-lake (Table 5). To the best of my knowledge, swimming has not been recorded for *Aulodrilus* and dispersal may thus not occur as readily as with naidids.

Again, the full richness of oligochaete fauna of the lake was not reflected in profundal samples. While samples from Devils Lake have revealed six species of tubificids (Tables 4, 5) only three have been found at the mid-lake station (Table 5).

TABLE 5. ESTIMATES OF ABUNDANCE OF AQUATIC OLIGOCHAETES, AS INDIVIDUALS PER SQUARE METER, AT A MID-LAKE STATION ON DEVILS LAKE

	Date					
	8 III 70	21 V 70	2 VI 70	4 VIII 72	21 IX 69	19 X 69
Naididae						
Arcteonais lomondi		22			1555	
Dero digitata	44	67			1866	711
Ophidonais serpentina						89
Stylaria fossularis		22				
Total	44	111	0	0	3421	800
No. species	1	3	0	0	2	2
Tubificidae						
Aulodrilus pigueti		22	22			133
Ilyodrilus templetoni	44	44	67			
Limnodrilus hoffmeisteri	44		22	44		44
Undetermined immatures;						
with hair chaetae	178	156	222	111	400	44
without hair chaetae	1244	267	822	1056	1378	978
Total	1510	489	1155	1211	1778	1199
Apparent No. species	2	2	3	2	2	3

SUMMARY

This paper presents records of twenty-eight taxa of aquatic Oligochaeta from the inland waters of Wisconsin. Most of these were not previously reported from the state.

An investigation of the profundal oligochaete fauna in a series of lakes revealed no consistent correlation of abundance or species composition with lake type. In general, the profundal worm fauna is species poor; species other than *Limnodrilus hoffmeisteri, Ilyodrilus templetoni,* and *Tubifex tubifex* are seldom found.

Samples taken from shallower depths in two lakes provided evidence of vertical differences in composition of the worm fauna, with littoral samples containing species not found in the profundal benthos.

ACKNOWLEDGEMENTS

Thanks are due to Dr. Robert Calentine for allowing me to examine his specimens from Lake Mallalieu, and to Ted Ringger who provided samples from Theresa Marsh.

Professors A. M. Beeton and A. D. Hasler assisted greatly by making available facilities of the Center for Great Lakes Studies and the Trout Lake Biological Station, respectively.

These investigations were given financial support through a grant from the Wisconsin Department of Natural Resources.

LITERATURE CITED

BRINKHURST, R. O. 1964. Observations on the biology of lake-dwelling Tubificidae. Arch. Hydrobiol. 60:385–418.

———. 1969. Changes in the benthos of Lakes Erie and Ontario. Bull. Buffalo Soc. Natur. Sci. 25:45–65.

——— and B. G. Jamieson. 1971. The Aquatic Oligochaeta of the World. Univ. Toronto Press, Toronto and Buffalo. xi + 860 pp.

BRUNDIN, L. 1949. Chironomiden und andere Bodentiere der Sudschwedischen Urgebirgseen. Inst. Freshw. Res. Drottningholm Rept. No. 30:1–914.

———. 1958. The bottom faunistical lake type system and its application to the southern hemisphere. Verh. Internat. Verein. Limnol. 13:288–297.

CALENTINE, R. L., and B. L. DeLONG. 1966. *Archigetes sieboldi* (Cestoda: Caryophyllaeidae) in North America. J. Parasitol. 52:428–431.

——— and J. S. MACKIEWICZ. 1966. *Monobothrium ulmeri* n. sp. (Cestoda: Caryophyllaeidae) from North American Catostomidae. Trans. Amer. Microsc. Soc. 85:516–520.

DAHL, I. 1970. Borsteorme (Oligochaeta) fra indvande i Thy. Flora og Fauna 76:49–65.

DEEVEY, E. S. 1941. Limnological studies in Connecticut VI. The quantity and composition of the bottom fauna of thirty-six Connecticut and New York lakes. Ecol. Monogr. 11:413–455.

HILSENHOFF, W. L., and R. P. NARF. 1968. Ecology of Chironomidae, Chaoboridae, and other benthos in fourteen Wisconsin lakes. Ann. Entomol. Soc. Amer. 61:1173–1181.

HILTUNEN, J. K. 1967. Some oligochaetes from Lake Michigan. Trans. Amer. Microsc. Soc. 86:433–454.

———. 1969a. Invertebrate macrobenthos of western Lake Superior. Michigan Acad. 1:123–133.

———. 1969b. Distribution of oligochaetes in western Lake Erie, 1961. Limnol. Oceanogr. 14:260–264.

HOOPER, F. F. 1969. Eutrophication indices and their relation to other indices of ecosystem change. p. 225–235 *In* Eutrophication: Causes, Consequences, Correctives. Nat. Acad. Sci., Washington, D.C.

HOWMILLER, R. P. 1972. The oligochaete fauna of central Lake Michigan. p. 58–62 *In* R. P. Howmiller and A. M. Beeton. Report on a Cruise of the R/V Neeskay in Central Lake Michigan and Green Bay, 8–14 July 1971. Wisconsin—Milwaukee, Center for Great Lakes Studies Spec. Rept. No. 13.

——— and A. M. BEETON. 1970. The oligochaete fauna of Green Bay, Lake Michigan. Proc. 13th Conf. Great Lakes Res. pp. 15–46.

JERNELOV, A. 1970. Release of methyl mercury from sediments with layers containing inorganic mercury at different depths. Limnol. Oceanogr. 15: 958–960.

JONASSON, P. M. 1972. Ecology and production of the profundal benthos in relation to phytoplankton in Lake Esrom. Oikos Suppl. 14:1–148.

LUESCHOW, L. A., J. H. HELM, D. R. WINTER and G. W. KARL. 1970. Trophic nature of selected Wisconsin lakes. Trans. Wisconsin Acad. Sci. Arts Lett. 58:237–264.

MUTTKOWSKI, R. A. 1918. The fauna of Lake Mendota: a qualitative and quantitative survey with special reference to the insects. Trans. Wisconsin Acad. Sci. Arts Lett. 19:374–482.

SCHMID, M., and H. AMBUHL. 1965. Die Bestimmung geringster Mengen von Gesamtphosphor im Wasser von Binnenseen. Schweiz. Z. Hydrol. 27:184–192.

THIENEMANN, A. 1922. Biologische Seetypen und die Grundig einer hydrobiologischen Anstalt am Bodensee. Arch. Hydrobiol. 13:347–370.

ZVETLOVA, L. I. 1972. Oligochaeta in the oxygen balance of reservoirs. Proc. Symp. Aquatic Oligochaeta in Tartu, 1967. pp. 118–125. (Russian, English Summary).