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Composition and abundance of oligochaetes in Scandinavian lakes in the 1970s in full compatibility with the ”morpho-edaphic index”. Do these relationships still hold 40 years later?

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Abstract

In the 1960s it became fairly well-known that biological indices through their supposedly integrative power could be more robust measures of the water quality than separate chemical data. Oligochaetes and chironomid larvae in the bottom fauna hereby played an important role. Precision, however, increased dramatically if the relationship between oligochaetes and the so-called morpho-edaphic index, i.e. the average total phosphorus content in µg/l divided by the mean depth (in meters) of the lake (Ryder *et al.*, 1974), was used in stead (Milbrink, 1978). The percentage composition and total abundance of oligochaetes in a number of lakes or selected basins of large lakes in southern Sweden and Norway were thus tested against this index in the 1970s. In logarithmic scales these relationships turned out to be more or less linear. The immediate conclusions were then that this method of classifying lakes could be of considerable scientific as well as practical value. Today we know a lot more about the ecological preferences of oligochaete species and characteristic species associations. The oligochaete fauna of the large lakes of southern Sweden, Mälaren, Vättern, Vänern and Hjälmaren, have been studied in detail over many years—over 100 years in the first three of these lakes and in the last lake for over 50-years. Effects of generally applied advanced sewage treatment in Sweden since the late 1960s are easily recognizable in the material. We have a situation of oligotrophication. With our new knowledge it comes natural today to study changes in species composition after trophic change and to investigate if the above close relationships in abundance are still largely linear.

Introduction

In the early 1960s the species composition of profundal freshwater oligochaetes largely proved to be indicative of the actual water quality (Brinkhurst, 1966). However, this relationship between oligochaetes and, for example, the average concentrations of total phosphorus in the water, was found to be rather unprecise. Precision increased dramatically if the relationship between oligochaetes and the so-called morpho-edaphic index (Ryder *et al.*, 1974), was used in stead (Milbrink, 1978). The morpho-edaphic index is the average total phosphorus content in µg/l in surfacial water strata divided by the mean depth (in meters) of the lake—or a particular basin of the lake.

In 1977 a comprehensive figure (Figure 1) was presented showing the actual relationships between profundal oligochaetes in the large lakes in southern Scandinavia (Figure 2) and a few additional lakes and the morpho-edaphic index (Milbrink, 1978). At that time Figure 1 was in black and white. Each lake locality is thus marked in the figure in the form of a histogram positioned along the abscissa showing the morpho-edaphic index (logarithmic scale). Each histogram shows the average percentage composition of oligochaetes with reference to their known sensitivity to eutrophication (cf. Table I). The ordinate which also has a logarithmic scale shows the mean abundance of oligochaetes in each locality and moment. Thus in a double-logarithmic scale abundance values representing the different localities roughly fell along a straight line. The original Figure 1 also shows oligochaete indicator communities marked Group I, Group II and so forth. In the present Figure 1 patterns in black-and-white symbolizing the different indicator communities have been

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replaced with a colour scale in accordance with the original ”Saprobien System” designed by Liebmann (1962) and Zelinka & Marvan (1961). In that system red stands for tolerant species and bad conditions and blue for the opposite, i.e. sensitive species and favourable conditions. Striking red colours dominate the right part of the figure, whereas shades of blue dominate the left (see below for further explanations). With reference to the morpho-edaphic index oligochaetes thereby would have an indicator value both qualitatively and quantitatively. This is quite obviously an advantage both from a scientific, as well as a practical point of view. We have today much more information from lakes of all kinds in Scandinavia and elsewhere. With all the new information of the profundal oligochaete fauna we have, the question is now, do these relationships based upon fairly preliminary data from the 1960s and 1970s hold 40–50 years later? The main hypothesis is that this is true.

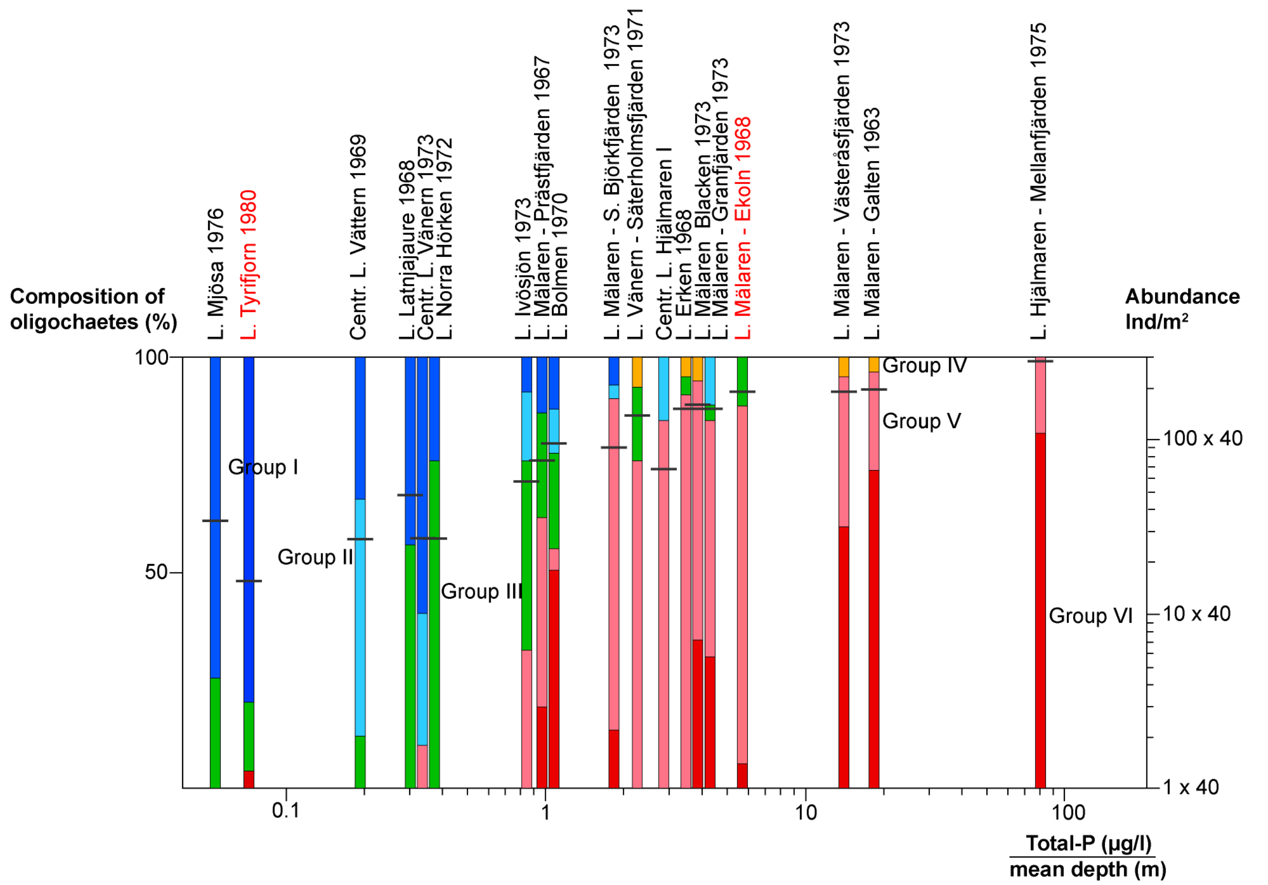

FIGURE 1. Percentage composition of profundal oligochaetes in lakes of different nutrient standard and size in Scandinavia (redrawn from Milbrink, 1978). Each histogram in the diagram shows the percentage composition of oligochaetes in a particular site at a particular time in accordance with the continental colour scale (Liebmann, 1962; Zelinka & Marvan, 1961) thus forming characteristic species groups with known specific sensitivity to oxygen deficiency (see explantion in text). Each diagram is positioned along the abscissa with reference to the morpho-edaphic index value (Ricker *et al.*, 1974). Oligochaete abundance is also given on the ordinate. Both axes are logarithmic. Abundance values form an approximate straight line.

Material and Methods

Information about profundal oligochaete communities in Scandinavian lakes were mainly based upon mean values obtained from 3–5 parallel Ekman grab samples taken in the 1960s and 1970s. From the large lakes of southern Sweden-Mälaren, Vänern and Vättern—oligochaete collections from representative station networks exist from the start of the 20th century. We thus have the Ekman collection from Lake Vättern (1911–1914), the Alm collection from Lake Mälaren (1915–1916), the Nybelin collection from the same lake (1933–1935), and the Nordqvist/Vallin collection from Lake Vänern (1922). All bottom samples were taken with the

Ekman grab sampler once in the spirit of getting as much information as possible about the bottom fauna as potential food-source for fish. The entire oligochaete material, which was mainly well-preserved in 70% alcohol, has been analyzed by the author.

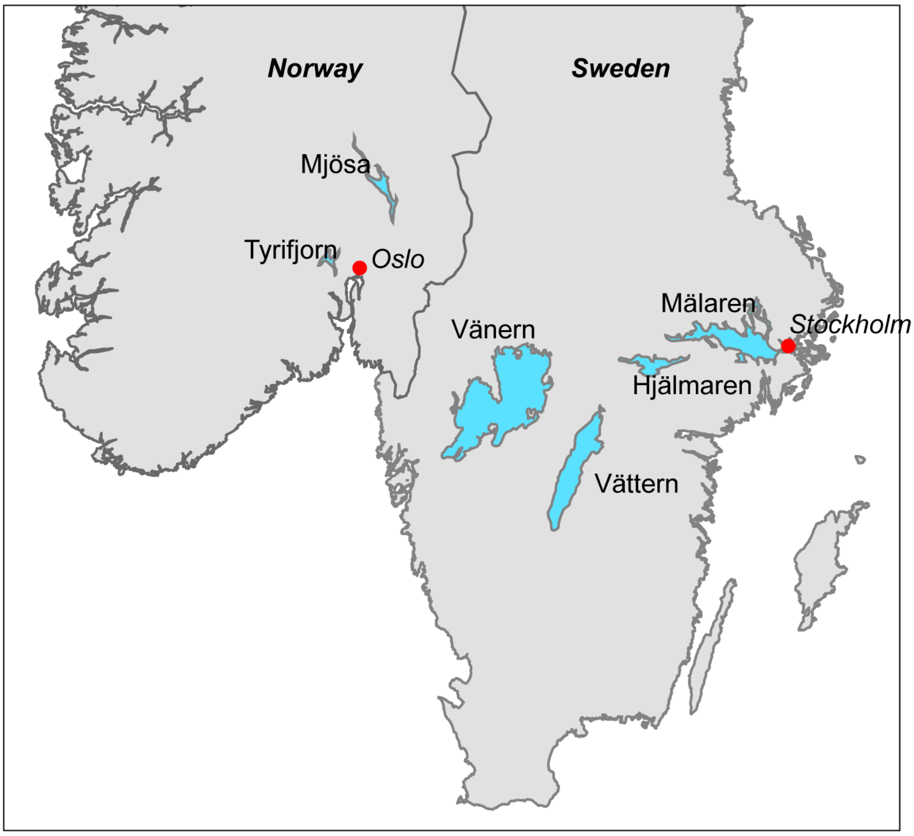

FIGURE 2. Map of southern Scandinavia showing the large lakes in south Sweden—Vänern, Vättern, Mälaren and Hjälmaren—and in south Norway—Mjösa and Tyrifjorn. The geographic positions of Oslo , the capital of Norway, is in WSG84, 59.914°N 10.752°E. Similar for Stockholm, the capital of Sweden, is 59.329°N 18.069°E.

Key localities within station nets in these large lakes plus Lake Hjälmaren in southern Sweden have since 1975 been sampled every three years as part of a routine—at least until 2010, often longer. Three parallel samples out of five on each locality each time have likewise been analyzed by the author. The bottom material has usually been sieved through 0.5 mm meshes and the animal residues have been sorted out and thereafter been kept in 70% alcohol.

It is, of course, fully understood that the below information is based upon the mean values of parallel representative samples. It also stands quite clear that if there had only been few parallel samples available for each analysis each time, for example from the early collections, the information value would be more limited. Statistical methods are on the whole hard to apply.

As said above, Group I in Figure 1 stands for the most sensitive oligochaete species we know, i.e. *Spirosperma ferox* (Eisen) and *Stylodrilus heringianus* Claparède, Group II stands for the likewise sensitive species *Psammoryctides barbatus* Grube. Group III stands for the ambivalent species *Tubifex tubifex* (Stolc) and *Eiseniella tetraedra* (Savigny), Group IV for species with little known ecological requirements, Group V for the tolerant species *Potamothrix hammoniensis* (Michaelsen) and a number of species with similar ecological demands, for instance several Ponto-Caspian *Potamothrix*-species, and lastly Group VI for the very tolerant species *Limnodrilus hoffmeisteri* Claparède.

For references to the actual depth of each sampling station and to its geographical position, the reader is referred to the legends.

TABLE I. Mean occurrence of freshwater oligochaetes in Scandinavian lake-types (redrawn from Milbrink 1978). The mean percentual occurrence of each species in the oligotrophic, mesotrophic and eutrophic environments, respectively, as estimated by the author. Full names of the species in the table are, *Limnodrilus hoffmeisteri* Claparède, *Potamothrix hammoniensis* (Michaelsen), *Limnodrilus claparedeanus* (Ratzel), *Aulodrilus pluriseta* (Piguet), *Potamothrix heuscheri* (Bretscher), *Ilyodrilus templetoni* (Southern), *Potamothrix vejdovskyi* (Hrabè), *Potamothrix bedoti* (Piguet), *Limnodrilus udekemianus* Claparède, *Potamothrix moldaviensis* (Vejdovský & Mrázek), *Lophochaeta ignota* (Stolc), *Aulodrilus limnobius* Bretscher, *Bothrioneurum vejdovskyanum* Stolc, *Aulodrilus pigueti* Kowalewski, *Psammoryctides albicola* (Michaelsen), *Rhyacodrilus coccineus* Vejdovský, *Rhyacodrilus falciformis* Bretscher, *Psammoryctides barbatus* (Grube), *Limnodrilus profundicola* (Verrill), *Spirosperma ferox* (Eisen), *Rhynchelmis limosella* Hoffmeister, *Stylodrilus heringianus* Claparède, *Eiseniella tetraedra* (Savigny).

Species	Oligo	Meso	Eut	Species	Oligo	Meso	Eut
Limnodrilus hoffmeisteri	1	2	7	*Aulodrilus limnobius*	2	5	3
Potamothrix hammoniensis	1	3	6	*Bothrioneurum vejdovskyanum*	2	5	3
Limnodrilus claparedeanus	1	3	6	*Aulodrilus pigueti*	3	5	2
Aulodrilus pluriseta		4	6	*Psammoryctides albicola*	4	5	1
Potamothrix heuscheri		4	6	*Rhyacodrilus coccineus*	4	6	
Tubifex tubifex	5		5				
Eiseniella tetraedra	5		5	*Rhyacodrilus falciformis*	(5)	(5)	
Ilyodrilus templetoni		5	5				
Potamothrix vejdovskyi		5	5	*Psammoryctides barbatus*	5	5	
Potamothrix bedoti		5	5	*Limnodrilus profundicola*	7	3	
Limnodrilus udekemianus	1	4	5	*Spirosperma ferox*	8	2	
Potamothrix moldaviensis	2	4	4	*Rhynchelmis tetratheca*	8	2	
Lophochaeta ignota	2	4	4	*Stylodrilus heringianus*	9	1	

Presentation

Most information behind, for instance, Figure 1 (as well as Figure11 below) is the result of oligochaete analyses made on material obtained from station nets in the large lakes of southern Scandinavia (see Figure 2), Mälaren (1.072 km2), Vänern (5.650 km2), Vättern (1.893 km2), Hjälmaren (483 km2), Mjösa (368 km2), and Tyrifjorn (136 km2). All histograms and abundance values in the original Fig. 1 showed the situation in the 1960s and 1970s. Now some 50 years later we know a lot more. Figure 1 is largely based upon Table I from Milbrink (1978), now slightly modified. In this table each oligochaete species had been given 10 points in total—equivalent to 100% . The table shows how frequently each species, on the average, is found in oligotrophic, mesotrophic or eutrophic environments. The very sensitive species *S. ferox* and *S. heringianus* are thus given 8 and 9 points, respectively, in oligotrophic environments, 2 and 1, respectively, in mesotrophic environments and none in eutrophic environments. These species forming the Group I in the original figure have now been given a deep blue colour. Another fairly sensitive species, *P. barbatus*, was given 5 points in the oligotrophic enviroment and 5 in mesotrophy has been given a light blue colour in the histograms. On the other hand the very tolerant species *L. hoffmeisteri* was given 7 points in eutrophic environments, 2 in mesotrophy and 1 in oligotrophy. This species has been given a deep red colour in the histograms. The likewise very tolerant species *P. hammoniensis* was given 6 points in eutrophic environments, 3 in mesotrophic and 1 in oligotrophic environments, etc. The colour given to the latter species and to some other species with rather similar ecological requirements is light red. The somewhat ambivalent species *T. tubifex* and *E. tetraedra* forming Group III in the original figure were given a green colour and finally species with little shown preferences or those species with little known ecological demands have been given a yellow colour. Thus, as said above, the very first impression is that the left side of Figure 1 is mainly blue while the right side is mainly red.

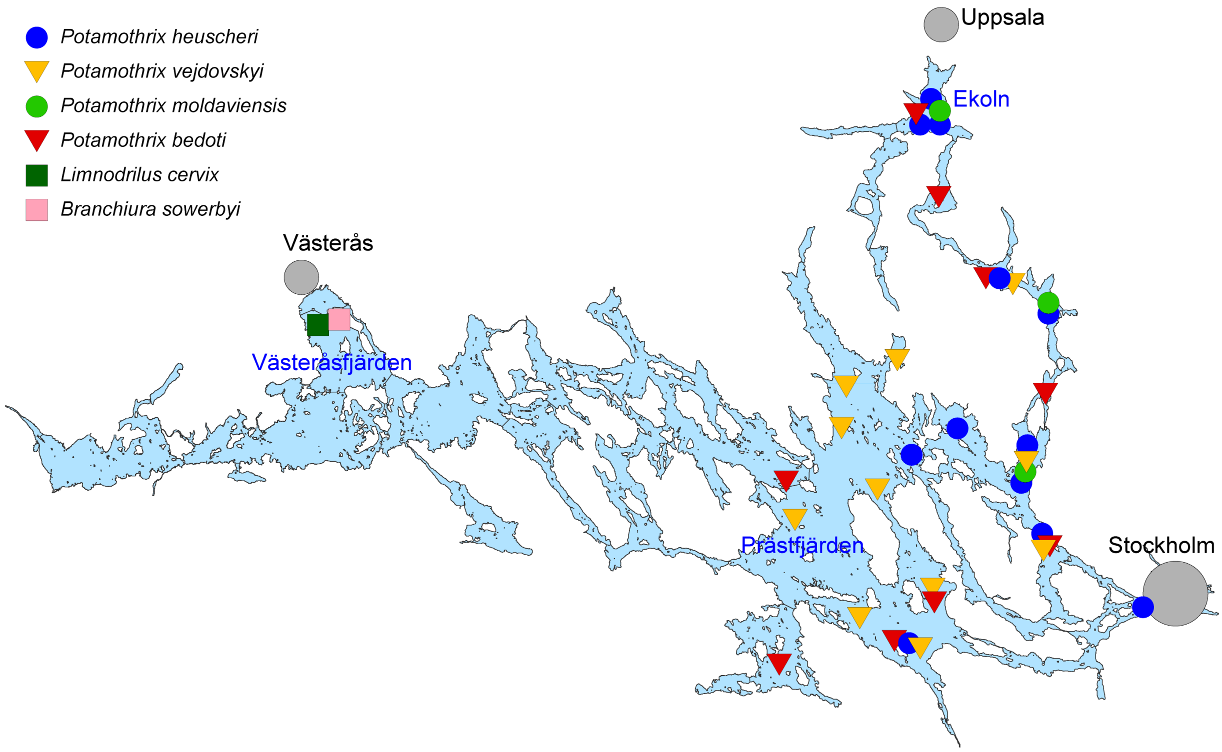

FIGURE 3. Map of Lake Mälaren showing its different basins and the sampling stations once defined by the Swedish EPA, such as the basins of Västeråsfjärden in the west (mean depth about15m, mean total-phoshorus concentrations about 40 µg/l), Prästfjärden in the centre (depths varying between 30 and 50 m, mean total-phosphorus concentrations about 15–20 µg/l), and Ekoln in the north (mean depth about 40 m, mean total-phosphrus concentration about 40 µg/l). Thus Lake Mälaren is eutrophic in its western and northern parts and mesotrophic in its central parts. The map also shows records of invading Ponto-Caspian *Potamothrix* species from the east and *Branchiura sowerbyi* Beddard from the sub-tropics (Milbrink, 1999).

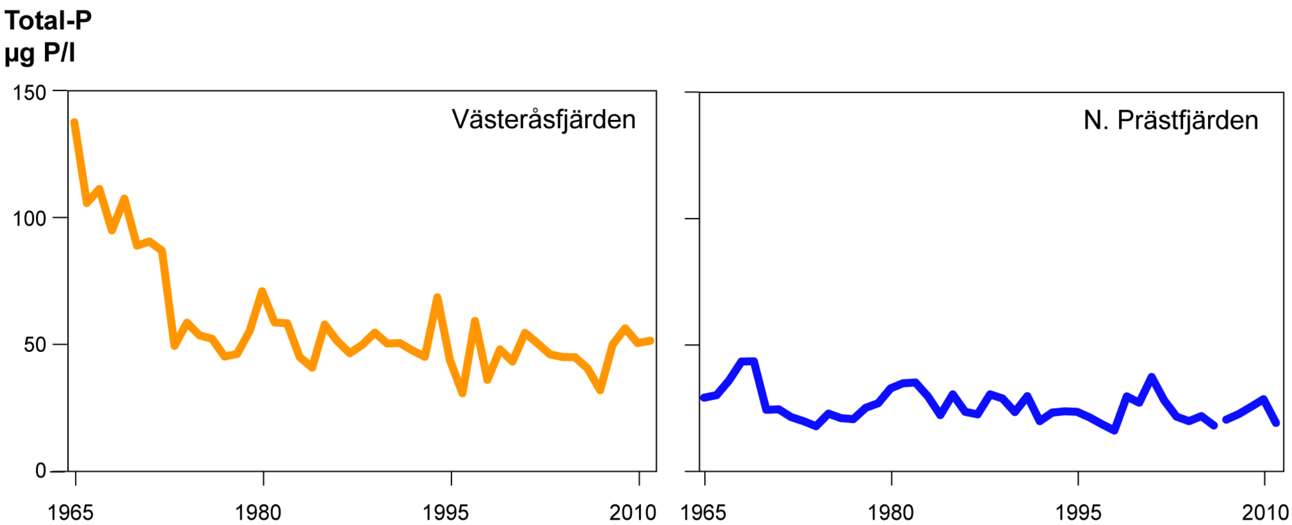

FIGURE 4. Total-phophorus concentrations (in µg/l) over time in surficial water layers in the basins of Västeråsfjärden and Prästfjärden in Lake Mälaren (1965–2011).

In the original Table I in Milbrink, 1978, however, a few very characteristic oligochaete species had been ommitted because of the above mentioned ambivalence. One of these species, *T. tubifex*, actually tends to occur on either side of the ecological spectrum (Milbrink, 1978) and would rather have obtained 5 points in both eutrophic and oligotrophic environments but none in mesotrophy (the present Table I). *E. tetraedra* is also a frequently occurring species but with little known preferences. This species is most often found in oligotrophy but can obviously also stand eutrophied environments. Also this species would be given similar points as *T. tubifex* (Table I).

Figure 3 is a map of Lake Mälaren primarily showing how far the Ponto-Caspian oligochaete fauna has reached into the lake (Milbrink, 1999). The names of some of the basins discussed here are also given. In Figure 1, for instance, the histograms of both Västeråsfjärden and Prästfjärden basins could be seen. In both basins the oligochaete fauna is dominated by *P. hammoniensis*. In Västeråsfjärden the very tolerant species *L. hoffmeisteri* complements the latter species, while in Prästfjärden there is a substantial share of the sensitive species *S. ferox* (about 20%) but also of *T. tubifex* and *L. hoffmeisteri*. Figure 4 shows the mean values of total-phosporus (in µg/l) in surficial water layers in the same two basins. In Västeråsfjärden in the 1960s and 1970s, i.e. before sewage treatment, values were very high reaching more than 100 µg/l which means that the water was not suitable for human consumption. Today values have come down to 30–40 µg/l implying ”nearly suitable water quality for human needs”. The very high total phosphorus values in Västeråsfjärden in the 1960s is the situation corresponding to the oligochaete histogram above from 1973 (cf. Figure 1). Oligochaete abundance values were at the same time very high also indicating a polluted situation. At the start of the new century the qualitative composition had remained nearly the same, whereas abundance had become considerably lower. Västeråsfjärden is thus still eutrophic. In Prästfjärden in central Lake Mälaren, on the other hand, eutrophication has been much milder and total phosphorus values have since the 1960s stayed between 15 and 20 µg/l indicating that the water is ”suitable for human consumption”. In Figure 1 the histogram for Prästfjärden from 1967 shows a typical mesotrophic situation, a substantial share of sensitive species, a similar share of tolerant species, and medium-high abundance values. Water chemistry and oligochaete composition and abundance would seem to go hand in hand.

FIGURE 5. Map of Lake Vättern with the two main sampling stations ”Jungfrun” (position 58.5008°N14.6784°E) and ”Omberg” (position 58.2450°N14.5784°E). Water depth for both stations is about 100 m.

Figure 5 shows a map of Lake Vättern, an ultra-oligotrophic lake, which became markedly eutrophied, mostly in its southern part, from the 1950s to the 1970s. due to outflows of untreated sewage water from the two cities of Jönköping and Husqvarna. Figure 6 is an aerial view of the city of Jönköping facing southern Lake Vättern. The lake is deep—more than 100 m, its contents of dissolved salts is particularly low, and the water transparency is very high (today around 4 µg of total-phosphorus/l and secchi disc values are again back to 15–16 m). The water retention time is also extreme—about 50 years. Lake Vättern is perhaps the best example of how effective sewage treatment starting at the end of the 1960s could be, and likewise the best example of how well this first phase of eutrophication and the succeding phase of oligotrophication is reflected in the oligochaete fauna (see Figure 11 below). From the histograms in Figure 1 it is easily recognizable that central Lake Vättern and the very deep Norwegian Lakes Mjösa (maximum depth about 475 m, total-phosphorus concentrations 4,5–6 µg/l) and Tyrifjorn (maximum depth about 295 m, total-phosphorus concentrations about 4 µg/l)) are all dominated by deep blue colour, which in its turn says that here is a dominance of *S. ferox* and *S. heringianus.* Values of total abundance of oligochaetes are also particularly low (see further text below).

FIGURE 6. Aerial view over Lake Vättern from the south with the city of Jönköping in the foreground and the Island of Visingsö in the back-ground (Photo: courtesy the County Administration in Jönköping).

In Figure 7 mean values of total-phosphorus, as well as water transparency in central Lake Vättern are shown over time (1978–2011). This would be the least affected part of the lake, far from sewage outfalls. Over this time-period total-phosphorus actually decreases from around 10 µg/l to 2–3 µg/l (sic.), while Secchi disc readings increase from about 10 m to 13,5 m. Figure 8 shows the total abundances of oligochaetes and chironomids in central Lake Vättern from about 1975 to 2003. Interestingly enough oligochaete abundance successively decreases from a maximum in the 1970s to very low values, whereas profundal chironomids, usually very reliable indicators of the environment, do not demonstrate the same trend as the oligochaetes at this time. Unfortunately abundance values from 2005 and on must be considered a bit uncertain due to changes in sampling methods (see legend to Figure 8).

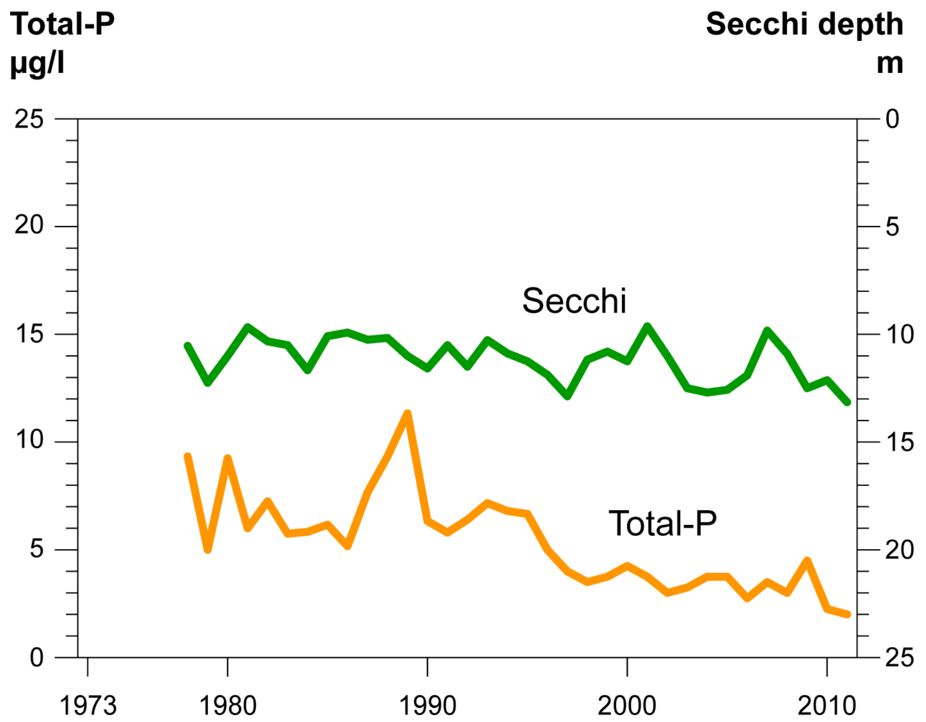

FIGURE 7. Total phosphorus concentrations (in µg/l) over time (1975–2011) in surficial water layers and Secchi disc readings (in m) in central Lake Vättern (station ”Jungfrun” (position, see above).

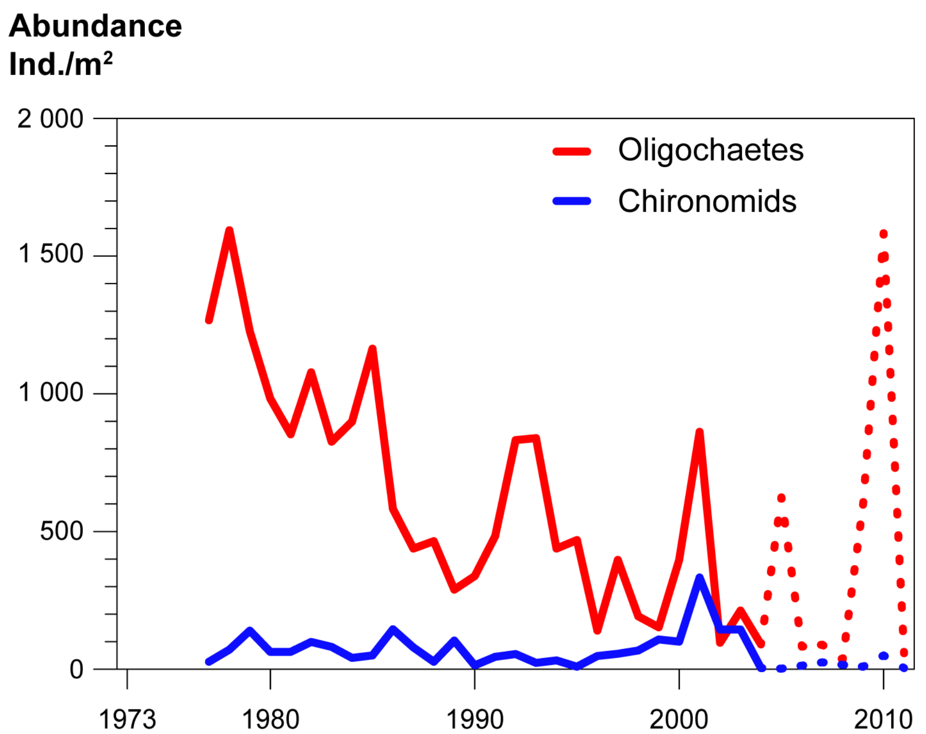

FIGURE 8. Mean abundance of oligochaetes and chironomid larvae over time (1973–2005) at a depth of about 100 m in central Lake Vättern (station ”Jungfrun” (position, see obove). Due to changes in sampling methods applied, values from 2005 and on are considered less reliable and therefore connected by broken lines.

Figure 9 is a map over Lake Vänern, the largest lake of south Sweden. Maximum depth is about 60 m, and its mean total-phosphorus concentrations is about 6 µg/l. The water quality is oligotrophic and the water colour is slightly brownish due to humic substances from forest ground in the northern parts of its drainage area. In its northern part the lake is surrounded by bays and so-called ”fjords” heavily affected by domestic and industrial outfalls (Milbrink & Sonesten, unpublished). Like the other large lakes in south Sweden Lake Vänern became eutrophied in the 1950s and 1960s with values of total-phosphorus reaching 10–15 µg/l even in its central parts. Figure 10 shows the constant decrease in concentrations of total-phosphorus on the two open-water stations given in Figure 9—Tärnan and Megrundet. Today concentrations are down to 6–7 µg/l. The oligochaete fauna of most of Lake Vänern is totally dominated by *S. ferox*, *S. heringianus* and with *P. barbatus* in low abundance (see Figure1). On the other hand, those bordering bays and ”fjords” of the lake which have since long been affected by eutrophication and industrial outflows are characterized by *P. hammoniensis*, *L. hoffmeisteri* and other tolerant species in high abundance (Milbrink, 1983).

FIGURE 9. Map of Lake Vänern with two open-water reference stations marked ”Megrundet”(position 58.8462°N12.8140°E, depth about 40 m), and ”Tärnan” (position 59.0912°N13.4639°E, depth about 60 m).

Lake Hjälmaren, the smallest of the four large lakes, is eutrophic (cf. Figure 2). It is shallow (maximum depth about 20 m) and has no thermal stratification. In the 1950s the lake became heavily eutrophied in its western basins receiving sewage water from the city of Örebro. After efficient sewage treatment in the 1960s the lake has recovered quite substantially, but it is still eutrophic with total-phosphorus values steadily between 30 and 40 µg/l. The oligochaete fauna is characterized by *P. hammoniensis* but with a rising share of *P. barbatus* (from about 20% to nearly 40% today)—another good example of oligotrophication due to efficient sewage treatment (Milbrink, unpublished).

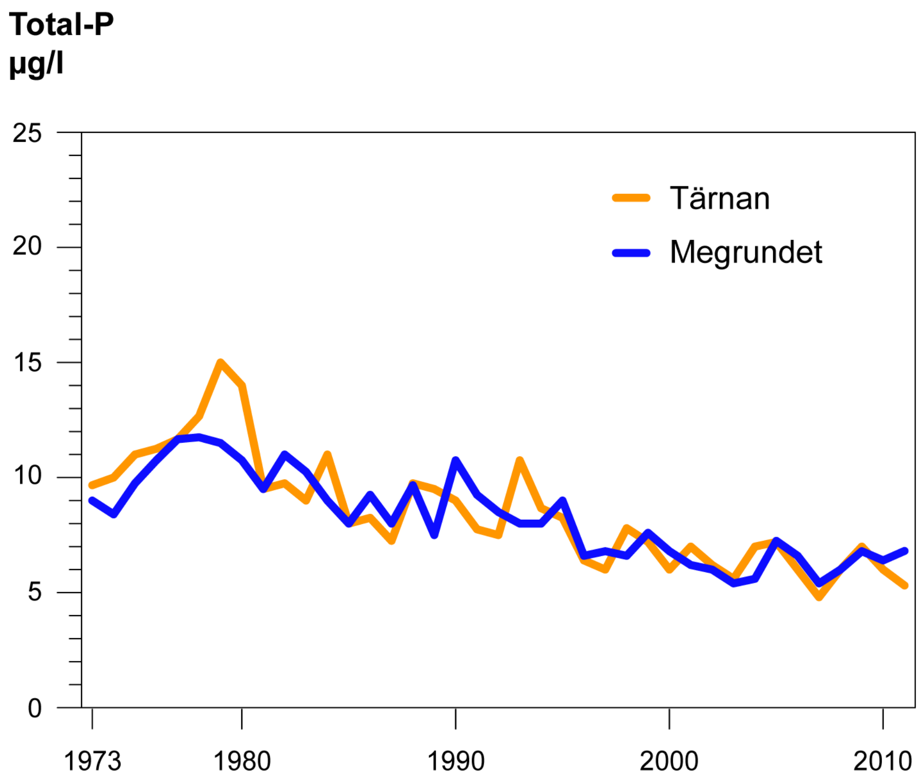

FIGURE 10. Total phosphorus concentrations (in µg/l) over time (1973–2011) in surficial water layers on two open-water reference stations in Lake Vänern (see Figure 9, above).

Thus due to advanced sewage treatment conditions in all the large lakes of south Sweden have improved quite significantly. It is, in deed, a success story.

Returning to Figure 1 the author found it important to scrutinize what had actually happened to the oligochaete fauna in the process, with first eutrophication and then oligotrophication. Changes over time over the whole trophic spectrum are quite obvious, especially in the oligotrophic part. Also in the eutrophic parts of the diagram differences are substantial. Remember that the abscissa in the figure showing the morpho-edaphic index is logarithmic, which means that the distance between the histograms representing different lakes and localities is in reality much wider. For the purpose let us take Lake Vättern as an example and compare the oligochaete composition and abundance in 1911–1914, 1969 and 2011(Figure 11). Due to the fact that total-phosphorus concentrations had changed very much during this period the morpho-edaphic index has changed, as well, and the histograms become widely spread. Because total-phosphorus concentrations in mesotrophic central Lake Mälaren or in eutrophic central Lake Hjälmaren had not changed that much over the same time period the histograms showing the situation before eutrophication took place and after sewage treatment do not diverge as much as for Lake Vättern.

In 1911–1914 Lake Vättern was clearly very oligotrophic with total-phosphorus concentrations likely to have been around 3 or 4 µg/l. We have, however, no chemical data from that time verifying this. As is shown in Figure 11, the oligochaete composition at that time was totally dominated by species of Group 1, i.e. *S. ferox* and *S. heringianus* (about 70 %), *P barbatus* (about 15%) and *Tubifex tubifex* (about 15%). In 1969, on the other hand, after a long period of eutrophication total-phosphorus values varied between 7 and 10 µg/l. Group 1-species had fallen to about 30% and finally after oligotrophication from the 1970s this group had again increased to about 50% in 2011. Total-phosphorus values had by then decreased to between 2 and 3 µg/l (Figure 7). Oligochaete abundance in central Lake Vättern had at the same time changed from about 500 specimens/m2 in 1911–1914, to about 1000 in the early 1970s, and again back to about 600 at the start of the 2000s. All abundance values plotted in Figure 11 tend to fall along a straight line irrespective of the trophic situation. It should be emphasized that even after the eutrophication maximum in the 1960s central Lake Vättern was still very oligotrophic in character.

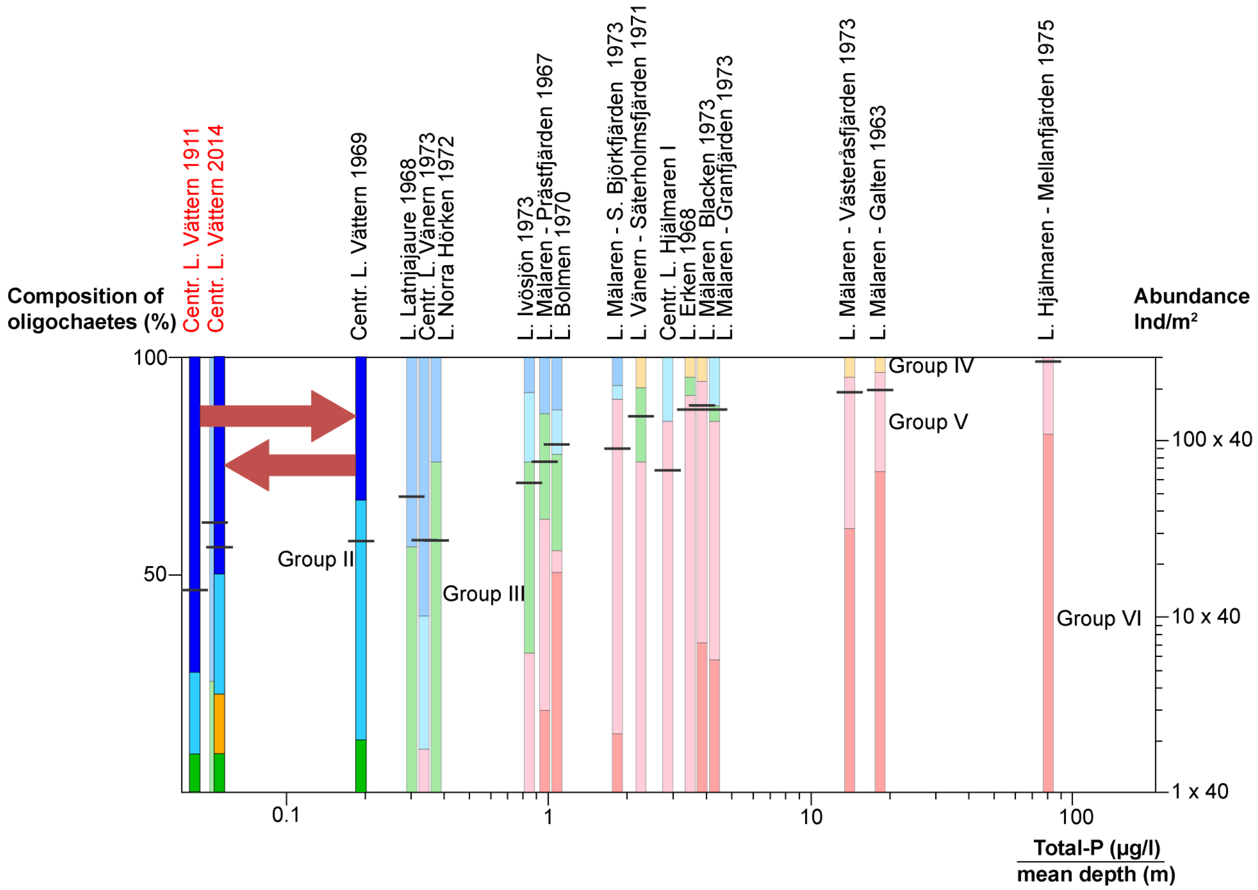

FIGURE 11. Modification of Figure 1 with particular reference to oligochaete bottom samples from Lake Vättern 1911–1914, 1969 and 2014. Oligochaete composition and abundance as in Figure 1. Arrows show the development from one time period to the next.

Discussion

The species composition of oligochaetes in relation to the morpho-edaphic index has greatly increased precision in the characterization of inland waters. Expressing this index along a logarithmic scale facilitates illustration such as in Figure 1. Furthermore putting abundance values on a logarithmic scale has likewise made it possible to combine oligochaete species identifications and abundance values by reducing the impact of extreme amplitudes. Figure 1 would seem to combine all that was known at that time about oligochaetes as indicators of the water quality. Many more lakes have been investigated with reference to oligochaetes since the 1960s and 1970s. Allthough the original Figure 1 was mainly based upon preliminary data from lakes all over Scandinavia, new data have since confirmed that the previous information was largely correct.

For a long time it has been well-known that profundal oligochaetes are reliable indicators of eutrophication (Milbrink, 1978;1980;1999). In the process the share of sensitive species decreases while the share of tolerant species increases. Few studies, however, have shown that under oligotrophication after sewage treatment, the reverse is possible, i.e. sensitive species increase while tolerant species yield. In this study it has clearly been demonstrated that the four large lakes of southern Sweden have behaved this way. The best example would definitely be Lake Vättern, in which eutrophication has had great consequences for the oligochaete fauna and also other fauna components. During the eutrophication phase in the 1960s, fisheries in Lake Vättern, for instance, was depenant upon big catches of whitefish (coregonids). Those fish populations have virtually dwindled during the succeding phase of oligotrophication and so had to a great extent local fisheries. Coarse fish like roach (*Rutilus rutilus*) have likewise retreated from the pelagic in the southern part of the lake, etc. Eutrophication in Lake Vättern was obviously a rather slow process whereas oligotrophication which came after sewage treatment and diversion in the 1970s was comparatively quick. There is a similar series of events described from Switzerland. In the early 1980s Lang (1984) could show that the eutrophication of the large Swiss Lakes Geneva and Neuchatel made tolerant oligochaete species like *L.hoffmeisteri* and several Ponto-Caspian *Potamothrix* species such as *P. vejdovskyi* and *P. moldaviensis* take over more and more. Lang & Reymond (1996) could later document that after large-scale sewage treatment both lakes had slowly recovered implying that sensitive oligochaete species such as *S. heringianus* had come back and *Potamothrix* species had decreased in proportion.

The question has been, to what extent had all the information gathered in Figure1 from 1978 survived till the present day, information that was mainly based on preliminary species identifications from the 1960s and 1970s. It is a time-span of no less than 40–50 years, and many new species analyses have been done during this period. In the opinion of the author there is no doubt that our information on oligochaete composition and abundance has survived and the hypothesis that new data would bring considerable changes to the figure and to our base of knowledge could be rejected.

Acknowledgements

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