Limnological Review 3 (2003) 143–150

The changes of the Starogrodzkie Lakes and their basin in the light of palynological and physical-chemical analysis

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Abstract: The article presents the results of a palynological study of sediments from the bottom of the Southern Starogrodzkie Lake, as well as, the study of physical-chemical properties of lake waters. It identifies four stages of the lakes' evolution since their formation (ca. 2630±160 BP). It illustrates the role of natural and anthropogenic conditions in the negative changes of the lakes. It highlights the changing function of the lakes in accordance to the degree of contamination and degradation.

Key words: Holocene, palaeochannel, palynological analysis, human impact.

Introduction

Lakes are essential to the natural environment, as well as, to local communities. In ancient times, they provided local populations with a source of water and food, but also served as natural obstacles used in battles against enemies. The earliest settlements and strongholds were formed near lakes. Traces of an ancient stronghold of the Lusatian culture, dated for the Hallstatt period, survived on a clearly isolated promontory of moraine plateau, in the area of the sloping Vistula valley, which borders the Starogrodzkie Lakes. In the 10th century, at the same site, there formed a community (Kałdus), which exploited the surrounding environment, including the lakes (Chudziak, 1998). The development of civilization gave rise to the extent to which the lakes were being utilized. The water resources of the lakes were increasingly used in agriculture, manufacturing industry, communal economy and tourism, which posed a serious threat to their well-being. The danger increased in the 20th century, when the greatest transformations in the basin of the lakes took place and when a series of mistakes were committed in water management and engineering.

The Starogrodzkie Lakes (Northern and Southern) played an important role for the population of the nearby city of Chełmno (about 22 thousand inhabitants). Water sports and fishing were practiced and, at the Northern Starogrodzkie Lake, a public resort was created. The lakes became the most important element of the attractive recreational area. In spite of their role, it was impossible to save them from anthropogenic degradation, which by the end of the 20th century devastated so many lakes in various parts of the world.

The degradation of the Starogrodzkie Lakes was mainly caused by the exploitation and management of their drainage basin. The documentation of these changes was enabled by the analysis of the results of palynological research of lake sediments and the study of lake waters. The objective of the work at hand is therefore to present the changes in the Starogrodzkie Lakes drainage basin since the lakes' formation, as well as, to show the effects of these transformations on the degradation of lake waters. Furthermore, this work also draws attention to the errors committed in the attempt to diminish the negative effects of the lakes' degradation.

Study methods

Pollen analysis was conducted on a core obtained from the central part of the Southern Starogrodzkie Lake (Fig. 1) using a Livingstone-type core sampler modified by Więckowski (Więckowski, 1970). The studied sediment consists of clayey gyttja, at the bottom of which there are deposits of river sand. The data for the palynological study was prepared at the laboratory applying Erdtman's acetolysis method (Faegri, Iversen, 1975). The sandy fraction was removed by decantation and the clayey part by boiling in hydrofluoric acid. Due to very low concentration, floatation method using $ZnCl_2$ was applied in the maceration of some samples. The authors attempted to count at least 500 grains of trees and herbaceous plants (AP + NAP). The results of the pollen analysis were presented in the form of an abbreviated percentage diagram (Fig. 2). The sum of pollen from trees with shrubs and herbaceous plants were used as the basis for calculating the percentage participation of all forms. The total sum excluded pollen of aquatic plants, as well as, spores of moss (*Sphagnum*), pteridophytes (*Polypodiaceae*), and exotic pollen (rebedded). The latter was represented by, among other, pollen grains of *Nyssa* and *Sequoia*, which probably came from boulder clay that builds up the sloping side of the adjacent moraine plateau. Certainly, they were carried into the lake along with water from the seepages, which can also be found today. In order to further identify the nature of the lake, an additional physical-chemical analysis of the sediment was conducted.

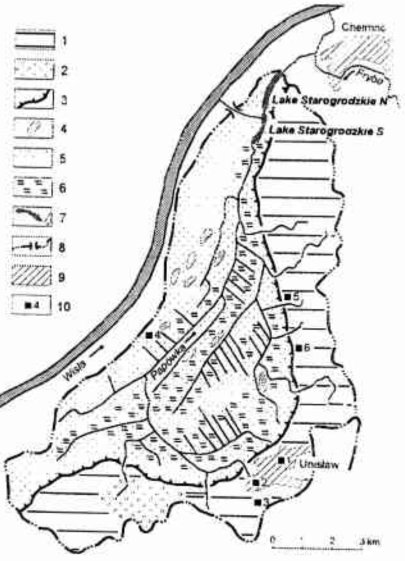

Fig. 1. Map of the Starogrodzkie Lakes drainage basin. Legend:
1 – flat moraine plateau, 2 – outwash, 3 – side of the moraine plateau, 4 – dune banks, 5 – bottom of the river valley with sand deposits, 6 – bottom of the river valley (mud) with some peat, 7 – lakes and streams, 8 –watershed and watershed gate, 9 – towns, 10 – key sites of the discharge of sewage (1 – sugar plant, 2 – fruit-vegetable company, 3 – distillery, 4 – creamery, 5 and 6 – agricultural companies)

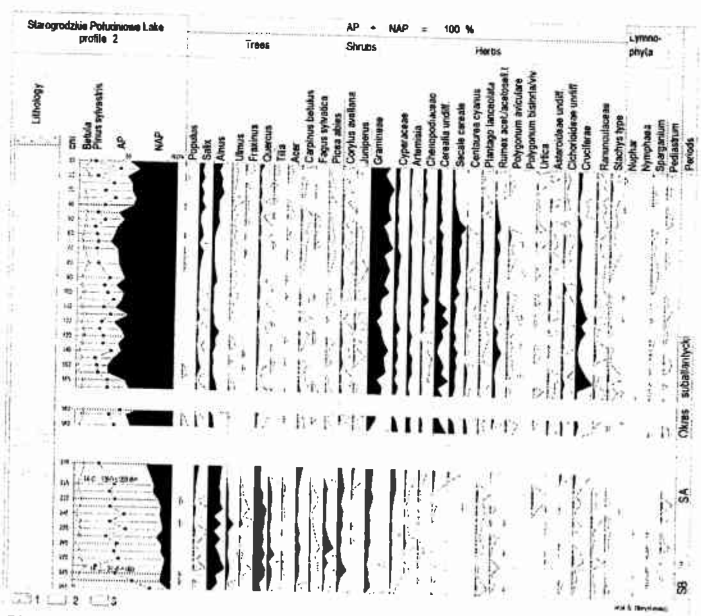

Fig. 2. Pollen diagram of profile 2 from Southern Starogrodzkie Lake:
1 – water, 2 – clayey gyttja, 3 – sand

The analysis of physical-chemical and biological properties of lake waters was based on research conducted in 1984 and 1993 by the Provincial Environmental Protection Inspectorate in Toruń, as well as, based on the authors' own research from 1998. In most cases, the studies were carried out in the summer months of July and August. The extent of research included, among other, the vertical distribution of oxygen, the amount of phosphorus and nitrogen compounds, and main anions and cations, electrolytic conductivity of water, transparency and hue, chlorophyll and coliform index.

Study area

The Starogrodzkie Lakes are located in the Vistula valley, at the foot of the steep edge of the Chełmno Moraine Plateau. Genetically, these are palaeochannels with a very elongated shape, which formed about 2600 years ago. In the beginning, only one lake emerged. As time passed, it was divided by the alluvial cone that developed at the opening of the erosion valley, as well as, due to mounding of a soil dam. In the dam, a waterway was installed to enable the waterflow between the two parts of the lake. Tab. 1 displays current morphometric data.

Hydrographically, the Starogrodzkie Lakes are located in the drainage basin of Papówka. It is a rather small stream, some 21 km long, whose waterflow below the lakes is about 0.4 m/s. The area of lakes' basin measures about 110 km and contains portions of two completely different geomorphologic units: the Vistula river valley and the moraine plateau (Fig. 1).

Table 1. Morphometric data of the Starogrodzkie Lakes (according to the Inland Fisheries Institute in Olsztyn)

Lake	Area ha	Volume $m^3 x 10^6$	Maximum Depth m	Average Depth m	Maximum Length (L) m	Maximum Width (W) m	Length/Width Ratio L/W
Northern Starogrodzkie	18.5	0.49	5.2	2.7	1525	175	8.7
Southern Starogrodzkie	8.8	0.15	4.7	1.7	1050	110	9.5

The valley section of the Starogrodzkie Lakes basin is located at 24–27 meters above sea level, that is, just barely 2–5 meters above the average water level of the Vistula. It consists of sand, river mud, peat and gyttja. The only distinguishing feature of this flat area are single dune banks, just several meters high. Slightly below the surface of the terrain, there are underground waters, whose level depends on the water level of the Vistula. As much as 100 years ago, a dense network of drains was created in this area due to frequent flooding.

The eastern and southern area of the drainage basin includes fragments of the moraine plateau. In contrast to the Vistula valley, there are many kinds of clay-type formations. The moraine plateau is elevated at 50-60 meters above the Vistula valley. The boundary between the mentioned geomorphologic units is created by a steep side, which is cut by small valleys and ravines with short streams of water seeping through them. There are many springs dripping out of the side of the moraine plateau and more than 20 of them supply the Starogrodzkie Lakes.

The Starogrodzkie Lakes are characterized by remarkably unfavorable natural conditions, which is proved by high Schindler factor values, 225 for the Northern Starogrodzkie Lake and, as much as, 690 for the Southern Starogrodzkie Lake. Furthermore, the lakes drainage basin is dominated by farmlands, which make up about 70% of the area, and includes several sites where sewage is disposed into the surface waters.

The greatest threat to streams and lakes was posed by sewage from a sugar plant and a fruit and vegetable company in Unisław, as well as, a Kokock creamery, a Raciniew alcohol distillery and several agricultural companies (Fig. 1). Since the beginning of the 1990s, these sewerages were practically never cleaned. According to the water law of the time, companies that polluted surface waters most heavily were exempt from installing sewage treatment plants. In the early 1980s, the surface waters of the Starogrodzkie Lakes basin collected over 10800 m of sewage per day, most of which was disposed at the time of a sugar campaign. More than half of the waterflow in the center of Papówka's run consisted of this sewage. The biggest loads of waste contained beet flume sewage from the sugar plant in Unisław: BZT_5 – up to 3050 kg O_2/day, ChZT – up to 4500 kg O_2/day, and total suspension – over 1100 kg/day. The contamination reached the Starogrodzkie Lakes causing their degradation. During just one of the sugar campaigns, over 110 tons of suspension was released into the Southern Starogrodzkie Lake. This activity accelerated the accumulation of bottom sediments with specific physical-chemical qualities. The suspension consisted of small particles of loam derived from rinsing sugar beets, as well as calcium compounds from the so-called limestone used in the production of sugar.

In order to prevent the contamination of the Northern Starogrodzkie Lake, in 1975 a waterway was built to regulate the waterflow between the lakes. It enabled water to pass freely into the Northern Starogrodzkie Lake only during post-campaign periods. At the time of sugar campaigns, the water in the Southern Starogrodzkie Lake was directed though a canal to a pump station and further on into the Vistula. Since then, the heavily contaminated waters of Papówka flowed solely into the Southern Starogrodzkie Lake which, in this way, continued to function as a sedimentation basin for industrial and agricultural sewage.

As a consequence of radical changes in water and sewage management instigated in the early 1990s, the amount of sewage released into Papówka and its tributaries decreased almost five times and, currently, measures about 2400 m^3/day. Furthermore, almost all sewage now undergoes biological treatment and holds small amounts of contamination.

Study outcomes and discussion

Palynological study

Pollen analysis of sediments from the Southern Starogrodzkie Lake makes it possible to trace the history of vegetation communities developing in its vicinity and provides evidence in regards to the effect of the climate and anthropogenic activities on the natural environment (Fig. 2). Several stages in the evolution of the lake and the surrounding vegetation were identified in the study. The accumulation of lake sediments began towards the end of the Subboreal period (sample from the depth of 280 cm was dated at ^{14}C 2630 ±160 BP). It marks the time of the termination of waterflow and thus, the formation of the lake.

The first stage is a period of undisturbed lake sedimentation (depth 295–230 cm). During that time, loam containing 3.1-4.8% of organic substance (loss-on-ignition) and 5.2–6.3% of carbonate accumulated in the lake. Mineral residue was measured at 89.0–91.5% (Fig. 3). At the time, the lake was surrounded by deciduous forests marked by an abundance of plant life and an ecological diversity of vegetation communities. In wet soils, there was a proliferation of forests, which included alder (*Alnus* max. 18.1%), willow (*Salix* max. 1.7%), ash (*Fraxinus* max. 0.6%) and elm (*Ulmus* max. 7.4%). Depending on the degree of moisture, there were alder swamp forests, alder or ash-elm floodplain forests, most likely similar to the remains of plant life communities presently found in the Vistula valley (Rejewski 1971). The sloping side of the moraine plateau adjoining the lakes from the south offered a suitable habitat for dry-land forests with the presence of oak and hornbeam (*Quercus* max. 13.3%, *Carpinus* max. 5.4%), as well as, with a slight occurrence of lime (*Tilia* max. 6.9%), beech (*Fagus* max. 1.7%), elm and maple (*Acer* max. 0.4%). Patches of communities exhibiting a similar combination can still be found in smaller areas, in so-called ravines and erosion grooves at the edge of the Vistula valley, not far from the Starogrodzkie Lakes (Rejewski 1971). The sum of herbaceous vegetation (NAP) was recorded at 20.2% maximum. Most common here were the grasses (*Gramineae* max. 7.6%) and the cyperaceae (*Cyperaceae* max. 3.6%) growing in the banks of the lake. They were accompanied by, among others, *Artemisia* (max. 2.4%), *Plantago lanceolata* (max. 1.2%), and pollen of the family *Crucifereae* (max. 1.1%). The lake was of a eutrophic type, with the presence of *Potamogeton sec. Eupotamogeton* (max. 0.2%), *Nymphaea* (max. 0.2%), as well as, *Sparganium* (max. 0.2 %) and *Typha latifolia* (max. 0.4 %) growing on its banks. The samples taken from the mentioned depth (1 LPAZ) showed a regular, although rather small count of algal colonies (*Pediastrum* max. 1.1%). The analysis of malacofauna showed a presence of clams (*Pisidium miotessierianum, Unio sp., Sphaerium sp.*), crushed shells of snails and, in ostracods, *Candona sp.* was recognized (Krzymińska, 2003). Their presence is associated with the development of a typical lake.

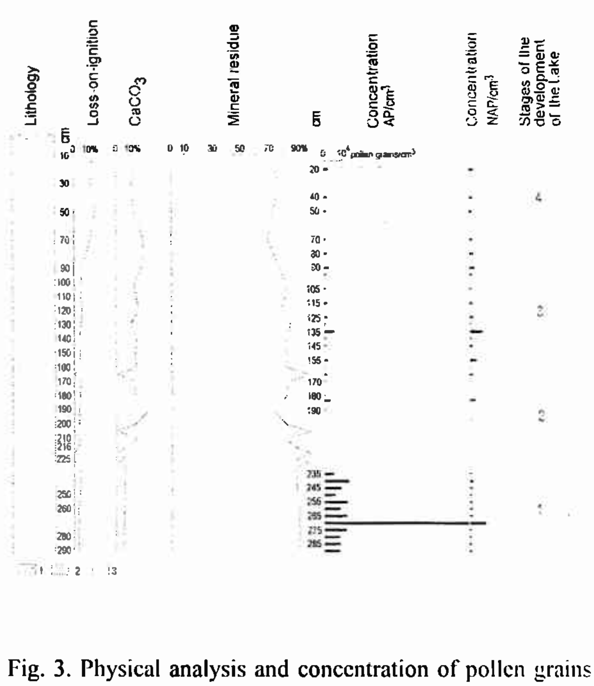

Fig. 3. Physical analysis and concentration of pollen grains in the bottom sediment of the profile 2 from Southern Starogrodzkie Lake. Legend:

1 – water, 2 – clayey gyttja, 3 – sand

The second stage of the lake's subsistence (220–170 cm) distinguished itself in the core in the form of several layers of sand. The peaceful sedimentation was most likely interrupted by the inflow of floodwaters, which caused parts of the accumulated sediment to be washed away. In this fragment of the core, there is either lack of, or extremely low, concentration of sporomorphs. In such a low presence of sporomorfs, there is a frequent occurrence of pollen grains redeposited from pre-Quaternary (*Nyssa, Sequoia, Taxodium*). Furthermore, this segment of the core does not show any presence of malacofauna (Krzymińska 2003).

The radiocarbon age of this disturbed fragment of the core, sampled at the depth of 225 cm, was calculated for 1350±150 BP. The pollen sample from this depth continues to show a domination of deciduous forests on a substantial area surrounding the lake. The participation of herbaceous vegetation does not exceed 15%. A similar type of vegetation is represented by a sample from the depth of 216 cm. However, the overlaying sediment found at 210–160 cm is more similar to that of the upper part of the core, in which the contribution of herbaceous vegetation was counted at several dozen percent.

The next stage of the lakes' evolution (170–70 cm) falls in the Middle Ages. The pollen spectra representing this period reveal great changes brought about by human settlement in the close vicinity of the lake (Chudziak, 2002). The pollen diagram shows almost complete deforestation of the Vistula valley surrounding the Starogrodzkie Lakes. It is evidenced by high pollen influx values for herbaceous vegetation (NAP max. 62.1%). An important element of these were pollen grains indicating a presence of human activity (Behre, 1981), such as, *Secale cereale* (max. 9.6%), *Cerealia undiff* (max. 14.4%), *Fagopyrum* (max. 0.4%), blue *Centaurea cyanus* (max. 2.1 %), *Plantago lanceolata* (max. 2.3%) and *Rumex acetosa/acetosella* (max. 5.1%). This combination of sporomorphs indicates that a great part of the valley surrounding the lakes was being agriculturally cultivated. The presence of plantain and sorrel pollen proves that the area was also covered by lots of meadows and pastures. The identified fauna included ostracods (*Cyclocyparis laevis* and *Candona neglecta*), clams (*Pisidium sp., Dreissena polymorpha, Anodonta*), and a land snail (*Chodrukla tridens*), most likely carried into the lake by floodwaters.

The most recent period registered in the examination of the bottom sediment (80–10 cm) is marked by an increased eutrophication of the lake, as well as, a strong anthropic pressure of the surrounding area. Large quantities of waste in the form of suspension poured into the Southern Starogrodzkie Lake (see text above), which accelerated the accumulation of sediment and increased percentage values showing loss-on-ignition (10.7–14.8%) in the sediment. The area surrounding the lakes continued to be intensely exploited for agriculture. The highest percentage values of rye were found in pollen spectrum at the depth of 50 cm (14.3%). However, already in the overlaying spectra, the pollen count of rye decreases dramatically (min. 1.7%). At the same time, there is a rise in the percentage curve of the pollen of trees growing in wet habitats (*Alnus* max. 11.2%, *Salix* max. 6.4%, *Populus* max. 0.5%, *Fraxinus* max. 0.8%). This combination of pollen grains can be an indication of the rising level of water and, therefore, the shrinking of habitats suitable for cultivation. The newly formed habitats became occupied by swamp or floodplain forest communities. The fauna is represented by groups of aquatic mollusks and ostracods: mollusks: snail (*Armiger sp.*), clams (*Dreissenia polymorpha*) and ostracods (*Cyclocypris laevis, Candona neglecta, Candona angulata* and *Cypridopsis vidua*).

Lake water study

The physical, chemical and biological characteristics of the waters of the Starogrodzkie Lakes reflect the negative effects of anthropic pressure, which led to their degradation. The earlier presented data reveals that, in 1975, efforts to protect the Northern Starogrodzkie Lake from further contamination began when a waterway was built between the lakes to prevent the inflow of the heavily polluted waters. In spite of that, other events caused the ecological disaster of the Northern Starogrodzkie Lake, thus making it completely impossible to utilize the lake in any way for many years to come.

In the summer of 1980, some exceptionally severe rainfalls have caused waters to reach very high levels in rivers, including in Fryba, a tributary of Papówka, just below the Starogrodzkie Lakes (comp. Fig. 1). The elevated waters of Fryba washed away a part of the edge of the high plain. As a result, there was a massive accumulation of suspension and silting up occurring at the point of Papówka's entry into the Vistula. There was a shift in the direction of Fryba's and Papówka's discharge, from the north into the Vistula, towards the south, into the Northern Starogrodzkie Lake. The change in the direction of discharge of Fryba and Papówka caused a rapid rising of water level in the Northern Starogrodzkie Lake (by 120 cm), which began to overflow through the waterway into the Southern Starogrodzkie Lake. In these circumstances, water from the Southern lake was pumped into the Vistula through a canal. It should be emphasized that, at the time, the water of Fryba was highly toxic and it was considered one the most contaminated in Poland. Its introduction into the Northern Starogrodzkie Lake produced great oxygen depletion and, as a result, massive dying of fish. Within several weeks, the concentration of oxygen in the water fell to just 0.5 mgO_2/l. This dramatic oxygen decline was caused by the mineralization of the accumulated organic contaminants drained into the lake along with the sewage from Fryba.

As a consequence of the heavy contamination of lake waters, as well as, due to the effects of bottom sediments, the worsened oxygen conditions in the lakes turned out to be long-lasting. During 1983–1998, unusual and varied oxygen distribution was observed in the deepest areas of the lakes (Fig. 4). Despite the fact that these lakes are not very deep, the amount of oxygen tends to decline radically at about 1–2 m above the bottom. This indicates that there are intense processes of biodegradation of organic matter, which results in using up of the dissolved oxygen. On the other hand, in August 1984, there occurred a massive overoxigenation of the surface layers of water, up to 217% in the Northern Starogrodzkie Lake and to 170% in the Southern Starogrodzkie Lake. These events were associated with intense algal blooms and photosynthesis occurring rapidly in very high water temperatures. In general, diminishing oxygen in the water of the studied lakes and declining oxygenation of the layer above bottom was observed.

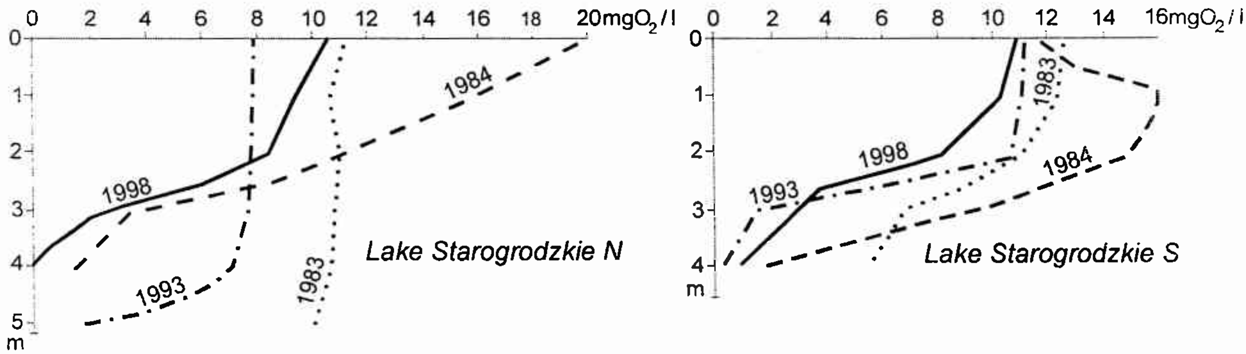

Fig. 4. Vertical distribution of oxygen in the deepest areas of the Starogrodzkie Lakes in August (various years)

Completely uncharacteristic oxygen levels were noted in autumn, at the time of sugar campaigns, when Papówka transmitted large quantities of sewage into the lakes (Fig. 5). The amount of oxygen in the vertical profile of the Starogrodzkie Lakes was declining then to 2 mg O_2/l, although these were periods of homothermia and thorough blending of the lake waters. During this period, there were also cases of fish dying.

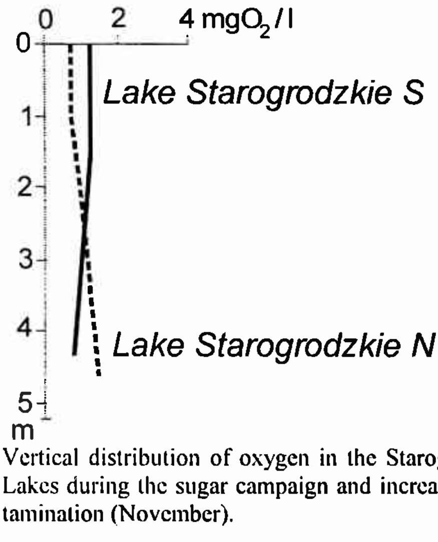

Fig. 5. Vertical distribution of oxygen in the Starogrodzkie Lakes during the sugar campaign and increased contamination (November).

Other physical, chemical and biological properties of lake waters also indicate a high level of contamination, as well as great eutrophication and even polytrophication. Furthermore, despite stopping the contamination of lakes, a substantial improvement in the quality of water was not accomplished by the end of the 20th century. In terms of the presence of biogenic substances or chlorophyll, the situation in the Southern Starogrodzkie Lake even worsened (Tab. 2). A rather low water transparency is due to massive growth of phytoplankton. The overall body of water of the Southern Starogrodzkie Lake shows a very high presence of organic matter, as well as, of the primary production, as evidenced by the value of chlorophyll (as much as 160 mg/m). The high rate of electrolytic conductivity (over 800 S/cm) shows a great presence of mineral compounds. It should also be noted that there is a high concentration of calcium (over 100 mgCa/l) which, as mentioned earlier, was introduced into the lakes along with the sewage from the sugar plant.

In the deepest part of the Southern Starogrodzkie Lake, an unusually dramatic change in magnesium concentration was observed, an increase from about 20–24 mg/l at the surface to over 120 mg/l at the bottom (at barely 4.5 m depth). In all probability, this was due to magnesium being released from the bottom sediments into the lake water in the form of hydrocarbonates. At the same time, it was noted that the overall hardness of water increased from about 7 to 17 mval/l, while alkalinity increased minimally from 11 to 12 mval/l.

Table 2. Comparison of selected values of the Starogrodzkie Lakes water towards the end of the 20th century (surface layer of the water, beginning of August). Based on materials from the Provincial Environmental Protection Inspectorate (WIOŚ) in Toruń and the authors' own research from 1998

Index	Southern Starogrodzkie Lake		Northern Starogrodzkie Lake	
	1984	1993	1984	1993
Water transparency m	0.4	0.8	0.4	1.1
Water color mg Pt/l	50.0	15.0	50.0	15.0
Conductivity S/cm	900	845*	870	814*
BOD mgO_2/l	20.0	9.9	20.0	5.3
Phosphates mgP/l	0.11	0.10	0.14	0.05
Total phosphorus mgP/l	0.10	0.11	0.30	0.04
Mineral nitrogen mgN/l	0.65	0.54	0.70	0.32*
Total nitrogen mgN/l	4.05	5.12	3.31	2.97
Calcium mgCa/l	118.0	102.5	110.0	88.1
Magnesium mgMg/l	24.0	34.0	-	25.3
Chlorides mgCl/l	49.0	30.0	35.0	28.0
Sulphates $mgSO_4/l$	20.0	15.0	29.0	26.0
Seston (dry mass) mg/l	14.8	24.4	11.0	9.2
Coliform index	0.1	20	0.1	20
Chlorophyll „a" mg/m^3	140.0	160.2	44.0	42.8

* based on data gathered in August 1998

The improvement of water quality in the Starogrodzkie Lakes is not very significant in comparison to the clearly recovering waters of its tributaries, especially in Papówka (as earlier mentioned, in 1990, radical steps were taken in water and sewage management of the Unisław sugar plant and the remaining companies). It seems that the main cause of the poor water quality in the lakes is the presence of the contaminants accumulated in bottom sediments. Within a period of over 100 years, the lakes experienced transformations showing anthropogenic degradation, which will be very difficult to reverse. Some contamination from the bottom sediments makes its way back into the surface waters as it blends many times throughout the year. In order to restore the environmental and recreational qualities of the lakes, recultivation efforts should be undertaken along with the removal of the bottom sediments deposited in the 20th century.

Final comments

The results of the multifaceted study of the Starogrodzkie Lakes made it possible to reconstruct their evolution and to identify their function in the environment. Four stages in the development of the lakes can be distinguished:

- undisturbed sedimentation in the early period of the lake's formation (starting at about 2700 years ago);
- disturbed sedimentation resulting from the inflow of floodwaters of the Vistula (from about 1400 years ago);
- undisturbed sedimentation in the Middle Ages (and more recent period), marked by apparent changes, registered by the pollen spectra, associated with the deforestation of the Vistula valley and the introduction of farming of cereal plants;
- accelerated sedimentation in the 20th century, caused by a variety of suspensions and other contaminants creating, among others, declining numbers and types of bottom fauna.

In terms of the changing function of the Starogrodzkie Lakes, the following should be emphasized:

- regulating local water interactions in the drainage basin of Papówka;
- providing water and food to the inhabitants of nearby settlements since the 10th century;
- enabling the practice of water sports and recreational activities since the end of the 19th century;
- accumulating suspensions and other contaminants similar to those of sewage settling plants.

It should be noted that the transformation of the lakes into sewage settling plants completely eliminated or greatly diminished their earlier functions. Even their role in regulating the interactions between the waters was limited. Since the end of the 20th century, there has been more reliance on artificial regulation of the waterflow from the Southern Starogrodzkie Lake directly into the Vistula.

The Starogrodzkie Lakes are among the youngest of lakes in Poland (which are more than 5 ha in size). In spite of that, they have a rich history in terms of their evolution, as well as, their function. The varying trends of changes of the studied lakes are a consequence of an extremely diverse natural environment of their basin, as well as, a strong influence of human activity.

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Streszczenie

Jeziora Starogrodzkie (Północne i Południowe) położone są w dolinie Wisły, na terasie zalewowej (ok. 22,7 m n.p.m.), w odległości około 3 km od miasta Chełmno (Fig. 1, tab. 1). Pod względem genetycznym są to typowe starorzecza Wisły, które powstały pod koniec okresu subborealnego. Początkowo stanowiły jedno jezioro, które później zostało rozdzielone stożkiem napływowym oraz groblą ziemną z przepustem umożliwiającym przepływ wody.

Badania palinologiczne, malakologiczne oraz fizyczno-chemiczne wykonano w osadach dennych w profilu pobranym w najgłębszej (400cm) części jeziora Starogrodzkiego Południowego (ryc. 2). Na podstawie przeprowadzonych badań można wykazać kilka etapów rozwoju badanego jeziora. Pierwszy etap to okres spokojnej sedymentacji jeziornej, którego początek datowany jest radiowęglowo na okres 2630± 160 BP. Sedymentacja jeziorna przerwana została na skutek dopływu wód powodziowych czego dowodem jest warstwa iłów pozbawionych malakofauny jeziornej, kilkakrotnie przedzielona piaskami rzecznymi. Kolejny etap to już średniowieczna historia jeziora, gdy w osadach dennych zarejestrowane zostały duże zmiany wywołane osadnictwem. Diagram wskazuje na prawie całkowite odlesienie doliny Wisły wokół jezior Starogrodzkich. Najmłodszy okres zarejestrowany w osadach dennych reprezentuje czas silnej degradacji wyrażony zwiększonymi wartościami procentowymi strat na prażeniu (Fig. 3), wzrostem tempa akumulacji, a także najwyższymi wartościami procentowymi ziaren pyłku roślin synantropijnych.

Największym zagrożeniem dla badanych jezior w XX wieku były ścieki z cukrowni i zakładów rolnych, które obciążały jeziora w ilości do 10800 m^3/dobę. Do początku lat 90. nie były one oczyszczane i okresowo stanowiły nawet 50% objętości dopływu do jezior. Ponadto podczas jednej tylko kampanii cukrowniczej dostarczano do Jeziora Starogrodzkiego Południowego ponad 110 ton zawiesiny. Nastąpiła silna degradacja wód jeziornych (tab. 2, ryc.,4 i 5), wzmożona akumulacja osadów dennych, zanik ichtiofauny i fauny dennej. Sytuację dodatkowo skomplikowały niekorzystne warunki meteorologiczno-hydrologiczne oraz błędy w inżynierii wodnej. Ograniczenie dopływu i tym samym wymiany wody znacznie pogorszyło stan Jeziora Starogrodzkiego Północnego. Zahamowanie silnego zanieczyszczenia jezior w latach 90. XX wieku nie spowodowało dotychczas polepszenia stanu ekosystemów jeziornych. Ze względu na warunki morfometryczne oraz rodzaj i miąższość osadów dennych wydaje się, że wyraźną poprawę stanu jezior można uzyskać przy zastosowaniu prac rekultywacyjnych.