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EVERY START IS CHALLENGING: FITTING A NEW ARTIFICIAL LAKE INTO THE LANDSCAPE, ZALAKAROS, HUNGARY

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Abstract

The aim of this study is to conclude the experiences of the maintenance practice of an artificial thermal lake. The first years (2015-2017) of the development of the lake were analysed and evaluated along the following questions: a) What kind of design processes and maintenance interventions are related to the process of fitting the lake into the landscape? b) How have the ecological conditions of the lake evolved in the past period (zonation, succession, plantation and colonization)? c) Which general experiences could be gained from the operation of this artificial thermal lake this far? The authors of the present study were already engaged in the planning process, participating in the preparation of four different design documentations. The planting design and the maintenance instructions were based on a physico-chemical monitoring, phytoplankton, zooplankton and macroinvertebrate sampling, and machrophyte assessment. The significant processes during the three years of the lake are presented by functional groups of biota, separately assessing the characteristics of the changes of macrophytes. In 2017 an individual macroinvertebrate assessment was done, moreover a fish die-off occurred in August 2017, which are mentioned separately as well. The data in total suggested that the water of the lake is highly hypertrophic, further machrophyte introduction can prevent the plant nutriments to be absorbed by algae. Partly the algal growth but also the unlucky coincidence of other factors (e.g. high water temperature, cold weather front, maintenance problems) led to the die-off of the spontaneously overpopulated fish stock in 2017.

Keywords: lake management, lake maintenance, thermal lake, algal bloom, macrophyte, succession, fish die-off, Zalakaros

INTRODUCTION

There are several reasons to create artificial lakes, including flood protection, providing water for irrigation and drinking, fish farming, and by opencast mining a plenty of new lakes appear in the landscape as well. Aquifers and quarry ponds – irrespectively of their primary function –become areas of touristic-recreational development in many cases, moreover they are popular leisure time destinations for locals since their formation (Dávid and Német, 2005; Furgala-Selezniow et al., 2012). Due to the rapid succession of water-related habitats and the intense, diverse demand of utilization, the ecological conditions and the environment of the new lakes change at a quick pace (Hall and Härkönen, 2006). In the interest of landscape sustainability (Musacchio, 2013; Wu, 2011) and the protection and improvement of the ecosystem services of the lake and the lake-shore (Vinkó et al. 2012), changes must be carefully arranged (Boromisza et al., 2015; Illyés et al., 2016). In the course of this, it is equally required to mitigate the probable environmental impacts, to ecologically fit the new landscape feature (lake) into the landscape, to serve the needs of the society (Moss, 2007), to discover the natural values and to schedule the maintenance tasks (Mészáros, 2016). The tools and measures of fitting a new lake into the landscape are similar to lake restoration methods (Annadotter et al., 1999; Bain et al., 2000; Cooke et al., 2005; Estrada et al., 2011; Gulati et al., 2008, Ostendorp et al., 1995; Sondergaard et al., 2008)

In Zalakaros (Hungary) a complex touristic-recreational investment was planned, which aimed to create new facilities for leisure activities beyond the existing thermal bath. A visitor centre, a promenade, a colonnade, a fountain, an artificial lake with an island and bridges, a tale park, a labyrinth, a water obstacle course, a parking, meditation space of the lights, seniors' active recreation park, and a nature trail were among the planned elements. The peculiarity of the lake is its water quality, as it is filled with the drain-off water of the thermal bath.

After creating a new lake, it requires several years for the water ecosystem to evolve (Straskraba, 1994), and might be surprising, especially in case of a thermal lake. Fitting a new landscape element into the landscape is a functional, ecological and aesthetical challenge, which can be actually realised through several designs and numerous interventions. The authors of the present study were already engaged in the planning process, participating in the preparation of four different design documentations. The aim of this study is to conclude the experinces of the maintanence practice of the last three years of an artificial lake. Therefore, in our study the first three years (2015-2017) of the development of the lake were analysed and evaluated, along the following questions:

a) What kind of design processes and maintenance interventions are related to the process of fitting the lake into the landscape?
b) How have the ecological conditions of the lake evolved in the past period (zonation, succession, plantation and colonization)?
c) Which general experiences could be gained from the operation of this artificial thermal lake this far?

STUDY AREA

The study area and the thermal lake is located in Western Hungary, at the administrative area of Zalakaros town. There are closed forests on the eastern side of the lake, and gallery forests on the south (Fig. 1). The surface area of the artificial lake is 12900 m^2, its average water depth is 1.5 m (with a shallow cover of 0.4 m at a part of the lake bed around the “flagstones”), its maximum depth is 1.8 m, its volume is 19000 m^3. The length of the shoreline is 484 m, the shoreline development index is 1.2 without the island, and 1.41 including the island. The lake is isolated; its water supply is ensured by using the drain-off of the thermal water ((in other words: used bathing water). The daily amount of the bath’s excess water is 600-800 m^3. The average detention time in the lake is approximately 30 days. The banks’ average bend is 1:2, and are covered by crushed limestone which unfavourably limits the vegetation growth. The lake is functioning as a “park lake”, providing aesthetical value to the city. It is prohibited to use this lake for bathing and swimming it serves only spectacular purposes and not further balneological ones.

METHODS

The planting design and the maintenance instructions were based on a physico-chemical monitoring (concluded between 2015 and 2017, on average once a month, based on own samplings and data retrievals of the lake’s operator: surface water sampling considering the Hungarian standards MSZ 12750-2:1971, MSZ ISO 5667-1:2007, MSZ ISO 5667-4:1995, MSZ ISO 5667-6:1995). There was a regular sampling in order to analyse phytoplankton (between 2015 and 2017, four times a year, between April and August): the water samples were condensed on a filter, and their qualitative examinations were made under microscope in order to determine the dominant species in the phytoplankton. There were difficulties to filter the sample on the usual 0.45 micrometre pore size filter plate, thus the second occasion 3 micrometres pore size filter plate was applied. Parts of the condensed samples were examined in different enlargements. At the same time of phytoplankton sampling zooplankton was also sampled by using plankton net with 150 micrometre of pore size. Almost 70 l water was filtered through plankton net on site, and the material remained in the sample container of the net was examined under microscope. The dominant species were determined in the sample. The analysis of macrophytes (qualitative characterization, recording the alteration tendencies of certain species) were done twice a year between 2015 and 2017, between April and September. The sampling of the macroinvertebrates took place in September 2017 with net techniques, at four points of the lake, identifying the individuals in place and valuing their prevalence.

The main danger in this lake is the planktonic eutrophication because the algae can prohibit the growth of the macophytes planted in the lake. That is why chlorophyl-a concentration was a dominant water quality parameter that was also measured several times in a year in an accredited laboratory. According to the OECD scales (OECD, 1982) if the chlorophyl-a yearly maximum concentration is between 2.5-8 mg/m^3 than the lake is oligotrophic. 8-25 mg/m^3 is the mesotrophic range, 25-75 mg/m^3 is the eutrophic one and >75 mg/m^3 is the hypertrophic limit. The hypertrophic status can be dangerous for macrophytes and aerobe heterotrophic organisms living in the lake. The high primary production of the phytoplankton can cause very high oxygen level in daytime but oxygen depletion and fish kills in early morning.

Fig. 1 Location of the study area

RESULTS

Evaluating the fitting into the landscape and the lake maintenance

The maintenance decisions regarding the lake are primarily based on the maintenance plan of the lake and it is implemented through numerous – partly continuously or cyclically occurring – interventions (Table 1).

The first challenge appeared before the construction of the new thermal lake's bed: the forest where the lake was going to be constructed was a habitat of protected species: spring snowflake (*Leucojum vernum)* and white hellebore (*Veratrum album*). To solve the problem the habitat map of the protected plant species in 2013 was prepared and a botanical analysis of the transplantation site and the area of the new lake was carried out. The adequacy of the transplantation site was analysed and a recommendation about the transplantation of the protected species was presented. Unfortunately, there has been no monitoring activities going on about the success of the transplantation since it happened, however, based on the experiences of regular field surveys it is obvious that high number of individual plants of both species can be found in the transplantation area. The interpretation and introduction of natural values to visitors were defined as a goal in the transplantation area of the protected species: the next step of the design process was to design a nature trail constructed of plank in 2015. The design and the realization of the nature trail required not only technical work, but also to prepare complex, high quality, unique graphical materials based on ecological and pedagogic knowledge. Thus it became a holistic process, the foundation of creating facilities which provide adventurous and attitude-changing experiences.

Once it was possible to form and fill the new bed, the next design challenge was to accomplish the plantation of the lake – thus contributing to the landscape fitting ecologically as well. Besides their aesthetical and habitat significance (providing hiding-place, foraging space, nesting site and spawning ground to several animal species), aquatic and riparian plants have a striking role in the design area from the aspect of water quality: by their nutrient uptake and shading, they can limit the unfavourable excess growth of algae, moreover the oxygen production of some submersed species is notable in the water as well (Brown et al. 1974; Maberly and Spence, 1989; Scheffer, 2004; Szilágyi, 2001). To prevent the dominance of algae, at least 30-40% of the water surface has to be covered by macrophytes (higher order aquatic and riparian plants) (Brown et al. 1974), which might take several years. Consequently, the primary role of the recommended planting design was to contribute to the conservation of the water quality, to create ornamental plant cover on the water surface and to form aesthetical focal points on the lake.

The method of planting was significantly influenced by the realized construction works and its structure: the formation and isolation of the bed, its bottom and the formation of the banks. The fact that no planting medium and reed berm were created is a determining factor (thus in the case of the banks, a different planting method had to be applied.) In the course of choosing the species and creating the spatial arrangements the lake's natural aptitudes defined the basic criteria: the peculiarity of water quality, exposure to undulation, the morphological aptitudes of the lake – its depth conditions, temperature conditions and solar access. Considering the above aspects, 6 riparian (1446 specimens), 4 floating leaf (248 specimens) and 2 submersed aquatic species (20 specimens) were included on the species list.

While carrying out the different planting methods, adequate timing and setting water level needed for construction works were of high importance. The water had to be let down before planting the aquatic plants. The floating leaf *Nymphaea* species were placed at 1 pcs/3m^2 density, in water planting baskets lined with linen sacks. Considering the depth of the lake, the baskets of younger *Nymphaea* plants were not directly placed on the bottom but raised by brick columns.

Table 1 Overview of the design process and management interventions related to the lake

Design	**Time**	**Construction, intervention, arrangements**	**Time**
Transplantation plan of the protected plants	September 2013	transplantation	October 2013
Planting design of the lake	March 2015	plantation of riparian and aquatic plants	July-August 2015
Nature trail design	November 2015	nature trail	December 2015
Maintenance plan of the lake	April 2016	phyisico-chemical monitoring	2015-2017
		phytoplankton and zooplankton analysis	2015-2017
		macrophyte assessment	2015-2017
		macrophyte replacement	October 2016
		macroinvertebrate assessment	September 2017
		vinegar weed control on banks	April-September 2017
		filamentous green algae removal	April-September 2017
		macrophyte cut-back	October-November 2015-2017
		application of bleaching powder	August 2017

The submersed species also had to be planted directly to the bottom, in a density of 3 pcs/m^2. Planting on the banks protected by rip-rap demanded an untraditional procedure as well. Proper quality rhizomes had to be collected of riparian plants (mostly: *Typha angustifolia*) (Hawke and José, 2002; Henderson et al. 1999; Robinson, 2006) that were surfaced from canal dredging in the region. The rhizomes wrapped in jute sacks had to be fixed between the bank's rocks, 30-50 cm under the operating water level. The riparian plants in the shallow area were distributed at operating water level, at an average stem distance of 50 cm, placing the planting baskets directly on the bottom (Fig. 2).

The maintenance plan of the lake was completed in April 2015, then for the request of the local government it was modified in April 2016 and revised in November 2017. The different monitoring activities and condition analyses were constant maintenance tasks. Certain factors were only analysed occasionally (e.g. the macroinvertebrate assessment was carried out only once in September 2017). Part of the maintenance tasks were previously known, planned and scheduled (e.g. the winter cut-back of macrophytes), while others required individual decisions and quick reactions based on the actual water quality (e.g. application of bleaching powder).

Phyisico-chemical water quality

The first analysis results related to the lake were the abiotic factors. Concluding the data acquired between 2015 and 2017 it was found that the chemical water quality of the lake was characterized by high salinity, relatively high pH, low concentration of plant nutrients, that can be uptaken by algae and low organic matter content. The chemical characteristics of the lake were determined by the water quality of the supply wells, moreover – due to the long detention time – they softened the alterations definitely present in the operation of the bath, thus the changes of the water quality were not significant and slow. The lake was fed by the used thermal water of wells filtered at 1200 m and 2000 m deep, and rainwater.

Analysing the data of 2017 more in details, the following were ascertained (the results of our own samplings are shown in the Table 2). The typical transparency/Secchi depth of the water was 50-75 cm. Regarding the medium depth this means that the light was not able to reach the surface of the sediment constantly on all sites, impeding benthic photosynthesis. Considering that the water of the lake did not constantly contain excess algae, the inorganic colloidal materials, which got to the water through the sediment or could be developed throughout chemical precipitation in the lake, were highly responsible for the low transparency. In total their shade was beneficial as during periods with excess algae benthic photosynthesis was not favourable.

Amongst the plant nutrients, the concentration of the absorbable nitrogen forms was constantly low according to the samplings: the concentration of nitrite and nitrate was usually under the measuring range, and the concentration of ammonium was low as well, not contributing to algae growth. The concentration of phosphorous forms was similarly low, under the measuring range. In the water of the bath the concentration of these nutrients was very low, those that were still present were immediately absorbed by the algae in the lake. As per our opinion, the main nutrient sources were primarily the sand layer covering the lake, secondary the atmospheric drift (dust).

Fig. 2 Formation of the lake bed and the planned macrophyte plantings at the shallow area of the lake (near the "flagstones")

*Table 2 Char*acteristics of physico-chemical water quality, based on the samplings carried out in 2017

Component	15 August 2017	30 August 2017	14 September 2017
Flagstones			
pH	8.74	9.56	8.27
Conductivity (µS/cm)	3860	3860	3620
Dissolved oxygen (mg/l)	12.68	20.02	11.50
Oxygen saturation (%)	154.4	266	127.7
Water temperature (°C)	24.8	29.1	29.3
Arched bridge			
pH	9.56	9.43	8.71
Conductivity (µS/cm))	3840	3840	3800
Dissolved oxygen (mg/l)	21.38	19.82	8.39
Oxygen saturation (%)	266.7	260	95.5
Water temperature (°C)	25.9	28.4	20.6

The chemical oxygen demand of the water was usually low – as it is typical in the case of a water beforehand used for bathing. The high COD values were related to the high algae concentration. In case of the highest a-chlorophyll concentration COD values were close to the values of purified sewage, although it was caused by the high algae organic matter content, which is particularly unfavourable. Salt content is also mentionable (conductivity), including the chloride concentration. It was noticeable that the approximately 2200 µS/cm conductivity measured in winter and spring increased above 3000 µS/cm by the summer, beside a chloride concentration of approximately 1000 mg/l. At the end of August conductivity was stably above 3800 µS/cm, and chloride concentration increased above 1440 mg/l as well. This alteration could be caused by three reasons: (1) The bath availed itself more of the deeper well with higher salinity; (2) The unusually hot summer (with 56 record hot days that year) resulted in the concentration of the lake's water; (3) The input pump was broken for a long time, and the lake received fresh water only through a low performance supplementary pump, which contributed to the concentration of soluble ions including chloride.

At both sampling points the conductivity of the water was high, and similar to each other. At the area around the flagstones the water supply came from the same source as the water supply of the lake, thus there was no possibility for a significant difference. The temperature of the water was 1.1°C colder than at the bridge. Around the steps oxygen supersaturation was observed in the water which is the result of the significant photosynthetic activity. This could be the result of the oxygen production of the phytoplankton and *Cladophora sp*. Though this supersaturation was significant, it would not have required intervention itself. Exceptionally significant oxygen supersaturation was observed in the water around the bridge which was the result of the very high photosynthetic activity of the phytoplankton. The oxygen production was so strong that the produced gas bubbled out of the water. Due to the strong photosynthetic activity the pH became highly alkaline. The data in total suggested that the water of the lake is highly hypertrophic, which was indicated by the greenish-brownish colour of the water as well. It is necessary to avoid the hypertrophic conditions in the lake because the valuable planted macrophyte vegetation can loose the competition for light and plant nutrients against phytoplankton.

Changes of biota

The main goal of fitting the lake into the landscape and the maintenance of the lake was to reach a favourable ecological condition, which was the base of the aesthetical value and the utilization of the lake as well. The significant processes during the three years of the lake were presented by functional groups, separately assessing the characteristics of the changes of macrophytes (Table 3). In 2017 an individual macroinvertebrate assessment was done, moreover a fish die-off occurred in August 2017, which are mentioned separately as well.

As riparian / aquatic plants significantly influenced the ecological condition and the view of the lake, and there was a designed plantation as well, we analysed the situation of macrophytes in detail. The plantation of the lake was not completely assessable, the spectacular fluctuation of the water ecosystem could be expected for years (certain planted species lost ground, others appeared spontaneously) (Table 4). Based on observations done until now, yellow iris *(Iris pseudachorus)* has been the most successful amongst the planted riparian plants. The spectacular late vernal bloom of the robust plants and the 100% remaining rate is a clear sign of its appropriateness. Only a few stems of the flowering rush *(Butomus umbellatus)* planting did not survive, therefore, these plants created a unified patch as well. Dwarf bulrush (*Typha minima*) has been planted in high numbers near the water obstacle course. The observations were ambivalent related to this species. Plants completely perished on the south of the shallow bay, outside the flagstones, however the western side of the same patch was especially aesthetic, almost complete and in good health condition. Plants planted on the north-west of the area showed a transitional image, here the stand was strongly scanty and imperfect (approximately 100 pcs remained of 192 pcs). In total, approximately 240 pcs of the planned 432 remained.

Table 3 Changes of wildlife between 2015-2017

	2015	2016	2017
phytoplankton	In May diatoms were dominating, especially *Navicula* speciescwere characteristic. Filamentous green algae *(Cladophora sp.)* were also observed in different quantities. The bottom of the lakebed was covered by filamentous cyanobacteria. Nitrogen fixing cyanobacteria became characteristic. In the first year of the operation scanty phytoplankton was characteristic of the lake, and the size of algae was also smaller than usual. We assume that the aftereffect of the disinfectant applied in the bath had impacted the lake's phytoplankton.	A few living diatoms (especially *Navicula sp*., and *Nitzschia sp* species) were present in May, and unicellular and thallophyte green algae were characteristic as well. Filamentous green algae (*Chladophora sp*.) developed massive amounts by the middle of the summer.	In the summer of the third year, algae (especially *Euglenophytas*) proliferated in a huge mass. In August 2017 200mg/m^3 a-chlorophyll values were measured. Part of the oxygen produced during the photosynthesis bubbled out of the water. There were few species with extremely high individuals in the samples. Nitrogen fixing cyanobacteria were subdominant (especially *Anabaenopsis sp.)*, besides *Synechococcus sp*., *Gomphosphaeria sp*. and *Croococcus sp*. cyanobacteria were also found. Filamentous green algae (*Cladophora sp.)* were also observable primarily in smaller patches.
macrophytes	A planned plantation was done. In some shore segments a spontaneously spreading, warm-season monocotyledonous weed, barnyard grass (*Echinochloa crus-galli*) appeared in large quantities. Besides the plantation some species started to spread spontaneously in the lake.	From the planted vegetation, populations of water lilies (*Nymphea sp*.), yellow iris (*Iris pseudachorus*) and flowering rush (*Botomus umbellatus*) remained almost completely. In the case of great manna grass (*Glyceria maxima*) the rate of extinction was approximately 30%, in the case of dwarf bulrush (*Typha minima*) approximately 50%, in the case of fringed water lily (*Nymphoides peltata*) approximately 80%. A few stems of lesser bulrush (*Typha angustifolia*), the first completely spontaneously growing riparian plants appeared in the shallow water.	Extensive patches of submersed aquatic plants (Eurasian watermilfoil - *Myriophyllum spicatum*) fixed to the bottom were observable. The significant spreading was noticeable since spring.
zooplankton	The lake's zooplankton was very scanty throughout the three years, the number of species as well as the biomass were remarkably low. Protozoa and rotifers were dominating.	The lake's zooplankton was very scanty as well, with the domination of filtering organisms (*Daphnia sp*., rotifers), predator zooplankton organisms were rarely found.	Ciliate protozoa were present in small number, rotifers were rarely found. Usually the species structure of the zooplankton was scanty, its biomass was low.
macroinvertebrates	The first water bugs appeared, the several exuviae of adder-flies *(Odonata)* were extremely noticeable on the stems of riparian plants. In general the number of macroinvertebrate species and their biomass were low.	Several exuviae of adder-flies *(Odonata)* can be found on the stems of riparian plants like in the previous year. In the shallow water area larvae of mosquitos were not observable, however bloodworm larvae were found in one of the sludge samples.	This functional group is scanty in general, representatives of many groups were missing completely. However the high number of dipterous larvae individuals is remarkable.
vertebrates	There was amphibian spawning in the first spring after the filling.	Adult fish were observed: common bleak (*Alburnus alburnus*) individuals lived in the lake. Several tadpoles and adult frogs belonging to different species were found near the shoreline. The appearance of a reptile species, the grass snake (*Natrix natrix*) is a new finding.	A red-eared slider (*Trachemys scripta elegans*) were also seen during the fieldwork. Fish were never introduced to the lake, in spite of this a fish population evolved. A mass fish die-off occurred killing 1,1t fish, especially common bleak (*Alburnus alburnus*) and silver prussian carp (*Carassius auratus gibelio*).

The great manna grass *(Gliceria maxima)* patch was slightly imperfect in 2016 as well. Only narrow-leaved cattail (*Typha angustifolia*) gave off shoots amongst the plants planted along the north shoreline. These were present on the shoreline in front of the “meditation space of the lights”, on both sides of the bridge, creating a continuous belt in visibly good health condition. By 2017 a significant expansion was observable of this species. On one hand, it reached the lake at the original plantation, on the other hand a spontaneous growth appeared in the obstacle course area. Planted common read did not give off shoots, as it was planted by rhizome in the middle of July which is a not suitable period for planting reed. It was not inevitably necessary to replant this species.

Water lilies *(Nymphea sp.)* were basically planted in three patches and they are the most outstanding eyemark of the lake. Visibly they were in good health condition, and their continuous bloom also suggested that they found favourable conditions. Especially the varieties with yellow flower were healthy. Unfortunately, they were not expanding with adequate speed which might be caused by the algae growth. In the competition for light and nutrients between algae and seaweed, currently algae are in better position as the adequate macrophyte cover (30-40%) has not yet developed in the lake.

Unfortunately, the other floating leaf species planted near the water obstacle course, fringed water lily (*Nymphoides peltata)* population suffered more, right now only a few stems could be discovered from the original planting. The assumable reason for the significant die-off is the unfavourable effect of the filamentous green algae (*Cladophora sp.)* on the young fringed water lily individuals in 2016. Floating seaweed hornwort (*Ceratophyllum sp*.) did not remain in the lake either, currently it is not visible.

In 2016 Eurasian watermilfoil *(Myriophyllum spicatum)* individuals were only visible in some areas, along the lake’s south shoreline. In 2017 this species spontaneously proliferated almost everywhere along the shoreline and near the obstacle course as well. In May 2016 barnyard grass *(Echinochloa crus-galli)* was visible in places along the shoreline – due to maintenance these have already disappeared. The town management company carried out a smaller complement plantation on the lake in October 2016. 80 pcs of flowering rush *(Butomus umbellatus*, 70 pcs of dwarf bulrush *(Typha minima)* and 30 pcs of variegated reed sweet-grass (*Glyceria maxima „Variegata“*) were planted in order to complement the scanty vegetation.

The aquatic macroinvertebrates indicate well the quality of the habitat, many organisms that can be used as indicators belong here. The autumn of 2017 was critical in terms of water quality therefore an assessment was done focusing especially on this group of organisms. 14 taxons were present in the thermal lake in total (Table 5). Only the empty carapaces of a mollusc species were detected in the water which indicates the still perceptible effects of the recent fish die-off (see under). Curiously, many groups of invertebrates were completely missing: vermicules including leeches, mussels and snails, as well as crabs. Above all, it was also ascertainable at the first sight that only adder-flies, true water bugs and diptera are present in the water. The most numerous group consisted of bloodworm and small true water bugs (*Micronecta sp.*, *Plea leachi*). Amongst adder-flies only three common species were detectable in the water. The most populated group was observed in the common area of the emersed and submersed aquatic plant stands, as here the most diverse microhabitat patterns could develop. The several recently leaved adder-fly exuviae on the stems of the narrow-leaved cattail (*Typha angustifolia)* standing in water indicates that this type of environment offers an excellent habitat for these animals.

It is ascertainable that the most diverse group consisted of true water bugs, as 8 from the discovered 14 taxons belonged here. However, regarding the population size diptera was the most numerous in the invertebrate group. In general, the organism group was scanty, species of many groups were completely missing, due to the unfavourable trend of water quality. On the other hand, the high number of dipterous larvae individuals stabilised in the lake was noteworthy. Probably the reason for this is that the threat of the scarcity of direct dissolved oxygen has significantly decreased. Although a regular oxygen supersaturation typical of hypertrophy occurs daily in the lake, probably oxygen is not consumed completely, as these creatures does not utilize atmospheric oxygen like true water bugs, but dissolved oxygen instead. This can be connected to

Table 4 Alteration tendency of macrophyte species

Macrophyte species	**Plantation method**	**Alteration tendency**
Typha angustifolia	by rhizome	expansive
Typha minima	by planting basket	decreasing
Phragmites australis	by rhizome	didn’t take root -
Glyceria maxima	by planting basket	decreasing
Iris pseudachorus	by planting basket	stable
Botomus umbellatus	by planting basket	stable
Nymphaea sp.	by planting basket	stable
Nymphoides peltata	by planting basket	decreasing
Myriophyllum spicatum	by planting basket	increasing

their mass presence and the recent lack of significant fish population in the lake that could decrease the number of these animals by overgrazing.

Table 5 Macroinvertebrate taxons found in the samplings in 2017

Taxon	Sampling points				
	1	**2**	**3**	**4**	**Σ**
Physella acuta			12		12
Ischnura elegans pontica	19	11	6	17	53
Anax imperator	12	9		3	24
Orthetrum cancellatum	2	1	5	3	11
Plea minutissima	67	12	22	10	111
Callicorixa praeusta	1				1
Corixinae Gen. sp.			2		2
Gerris sp. Juv.				1	1
Hesperocorixa linnaei		1			1
Hesperocorixa sp.		3			3
Micronecta sp.	36	5	12	8	61
Sigara sp.			1		1
Chironomidae Gen. sp.	122	69	13	45	249
Stratyomyidae Gen. Sp.	3			1	4
Individual number in total	**262**	**111**	**61**	**88**	**522**

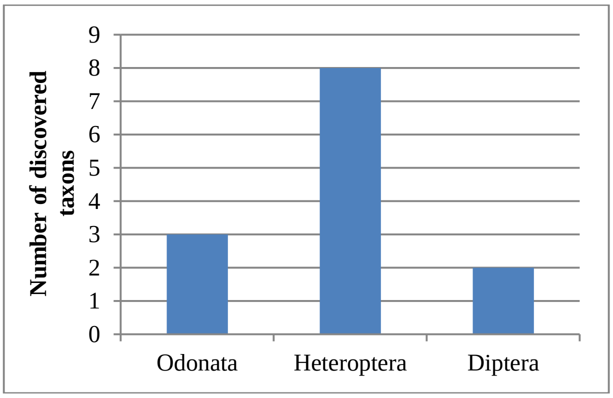

Fig. 3 Number of the discovered taxons/species in the three insect groups

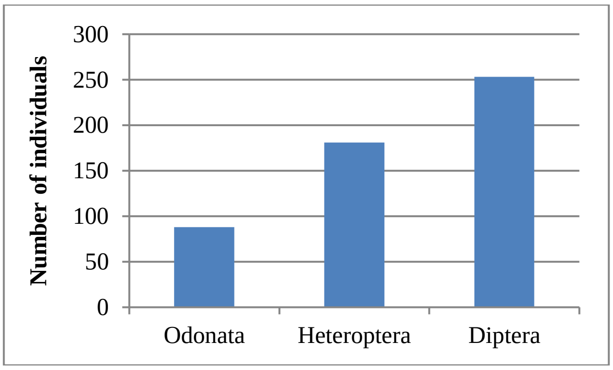

Fig. 4 Number of individuals in the three insect groups

Mass fish die-off occurred in the lake on 29 August 2017. It the phenomena more curious that there was no conscious fish introduction in the past three years, furthermore the lake bed was not connected to any natural surface water. The presence of fish was first observed in spring of 2016, and was also confirmed by a midsummer trial fishing in 2017. The die-off is significant in respect of lake maintenance and requires an extensive analysis. The several reasons for the perishing of approximately 1.1 t fish are concluded here:

- Prior the fish die-off filamentous green algae and nitrogen fixing cyanobacteria had proliferated significantly in the lake. As a result, an oxygen supersaturation had developed by the early afternoon, and part of the oxygen had bubbled out of the water. Algae produces net oxygen during the day, but consumes oxygen at night, as they breathe as heterotrophic creatures in the water. On 29 August by dawn oxygen scarcity occurred which eradicated most (if not all) of the fish stock.
- The heat experienced many times in August, with an average daily temperature above 25ºC had contributed to the algae growth by causing the warming up the of the lake's water. The solubility of the oxygen is inversely proportional to the water temperature, at the same time the oxygen consumption of heterotrophic creatures is directly proportional to it. Consequently, the oxygen produced during the day had been consumed quickly at night (oxygen concentration under 3 mg/l is a danger to the fish stock). Hypoxia was indicated by the aquatic surface respiration of fish.
- Chlorine tolerance of algae was low, most of them perished by 0.3-0.5 mg/l active chlorine. Bleaching powder was not applied when it was recommended by the authors of the present study (19 August 2017), prior to the fish die-off. This could have slowed down the algae growth and could have decreased the oxygen consumption of the bacteria as well.
- In the case of usual water supply the active chlorine present in the input water could have kept in check the phytoplankton. Unfortunately, approximately two weeks before the end of August the input pump broke and only a low performance pump pumped the water to the lake. As a result, neither fresh water nor active chlorine were adequately supplemented and the phytoplankton association overgrew. The minimum one-month long average detention time was enough for this to occur.
- A strong cold front reached Western Hungary by 29 August. Living beings are also affected by fronts. According to an old observation, in case of certain type of fronts hypoxia occurs in lakes (especially in fishponds) at dawn, and if there is no possibility for artificial aeration the third or half of the stock perish. The same kind of cold front arrived at the end of August. It only reached Western Hungary and passed from south to north.

Fish die-off occurred in many fishponds and lakes at the same time, for example tons of fish died in the lake Kis-Balaton. Accordingly, the fish die-off at Zalakaros was not only a local phenomenon. However, it could have been prevented (by applying bleaching powder and installing higher performance input pumps at the appearance of the expansive algae population).

- The lake was strongly overpopulated by fish, few species were present in high individual numbers. This was partly responsible for the perishing of the zooplankton and the macroinvertebrate organisms. We did not assume that without introduction such a large biomass of fish could develop in the lake in three years.
- Probably most of the fish perished already on the 29 August, although most of the carcasses sank to the bottom. These only came up after a few days, as a result of the decomposition gases produced by the dead bodies. That is why aquatic surface respiration of fish was not observed in the next days.

CONCLUSIONS

Zalakaros town is well-known due to its thermal bath offering significant therapic value for many people, however, it lacks other free-time activities. This is compensated by the recently created artificial thermal lake, being under investigation in this study, due to its high aesthetical value and the connected recreational facilities. The artificial lake was a major challenge for the landscape architect as well as for the water quality specialist, as there were few experiences related to similar lakes. The unique characteristics of the lake are the high salinity, the significant concentration of well soluble salts, the low concentration of organic matter and plant nutriments, and the higher water temperature compared to other water-bodies of the nearby area. In the first years of operation the ecological tilting/sways caused extra work for both the maintenance and the consulting experts. As the new lake itself is an artificial-like element with ruined surfaces it was a fundamental aspect for us to naturalize it and to improve the diversity of habitats. The maintenance of the water quality and ecological condition requires regular and professional lake maintenance work, including the important tasks of operating the monitoring and treating the atypical phenomena.

The newly created aquatic ecosystems can frequently change dramatically year to year (tilting or swaying). This is their normal behavior that can last 5-10 years. Sways are still significant in the ecosystem of the thermal lake of Zalakaros. The massive overpopulation of filamentous green algae in 2016 and filamentous green algae and cyanobacteria in 2017 caused problems. On the other hand, the macroinvertebrate group and the zooplankton had few species and small biomass in the lake. The reason for this requires further analysis. Partly the algal growth but also the unlucky coincidence of other factors led to the die-off of the spontaneously overpopulated fish stock in 2017. This could have been decreased by certain interventions and adequate timing. However, it is probable that in few years the fish population will grow again in the lake, but this process should be regulated by colonizing predator fish in small numbers.

Plantation can prevent the plant nutriments to be absorbed by algae, instead of macrophytes. However, plantation is expensive, and in case adequate macrophyte cover cannot be reached, algae growth can cause serious water quality issues. Keeping the water level low in spring in order for the macrophytes to grow up from the bottom can serve as an alternative solution. In spite of the numerous plants planted in this lake controlling the algae and the macrophytes have not succeed yet, as macrophytes require a long time to spread. Besides the further plantations it is suggested to establish such built elements that enhance the lake's attraction as well as the species and habitat diversity, and habitat complexity in the same time (e.g. man-made bird island, nesting holes).

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