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Long-term Development of the Hydroecosystem of the Lake Engure and its Influencing Factors

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***Abstract* - Investigations of water chemical composition and biota of Lake Engure have been carried out since 1995 by using standard methods for inland surface waters. Time series of air temperature and precipitation for the Mersrags meteorological station for the period 1928 to 2009 are used for the trend analysis. The results show that the long-term development of the hydroecosystem is related to such environmental factors as the lake's geographical location, basin and morphology, as well as the lake's history and relationship of biotic and abiotic factors.**

***Keywords* - Lake Engure, shallow lagoon lake, water chemical composition, lake biota, long-term changes**

I. INTRODUCTION

Lake Engure is the largest shallow coastal lake remaining from the age of the Littorina Sea in the territory of Latvia. The lake and its surroundings are characterised by high biodiversity [1]. In 1995 the lake was included in the list of Ramsar sites, and in 1998 the Lake Engure Nature Park was established.

Nowadays it has been found that shallow lakes are particularly sensitive to climatic changes going on all over the world [2]. It is necessary to understand the complex of factors creating a threat to the high diversity and clear-water state, with consequent impoverished ecosystemic and social values [3]. As shallow lakes are one of the most studied ecosystems in the world regarding stability aspects, it is known that many factors influence a lake's change from clear water to turbid state, e.g. a lake's depth, size and climate [2]. Climate change can promote shift from a clear to a turbid state, due to higher nutrient loads and decreased critical nutrient loadings [4], and enhanced sediment resuspension and release of nutrients [5]. Increasing water temperatures lead to changes in algal communities [6]. However, there is no clear pattern of how shallow lakes will react to the warming [2].

The aim of this article is to determine the main trends in climatic (large-scale) and local or small scale abiotic factors (water chemical composition) in relation to planktic and benthic communities of Lake Engure. Lake Engure belongs to long-term ecological research sites, and data available for Lake Engure might be used to understand the role of different-scale factors and their impact on the shallow lagoon lake development.

II. SITE DESCRIPTION, MATERIAL AND METHODS

Lake Engure is located west of the Gulf of Riga, Latvia, in the western part of the Coastal Lowland. It is separated from the sea by a 1 to 3 km wide dune zone. There are five rivers flowing into the lake, and a canal built in 1842 connects the lake with the Gulf of Riga. The surface area of the lake is 40.46 km^2. Maximum depth is 2.1 m, mean 0.4 m, volume of the lake is 0.168 km^3, mean water exchange is 7.2 times per year, and the catchment area to lake surface ratio is 15.6:1 [7]. The lake has sandy bedrock and sediments are formed mainly by organic mud or gyttja. The lake supports rich submerged, emerged and floating macrophytes [1].

Annual, monthly mean and seasonal time series of air temperature and precipitation for the Mersrags meteorological station (closest to Lake Engure) were used for trend analysis. The climatic data for the period of 1970 to 2009 have been obtained from the Latvian Environment, Geology and Meteorology Centre.

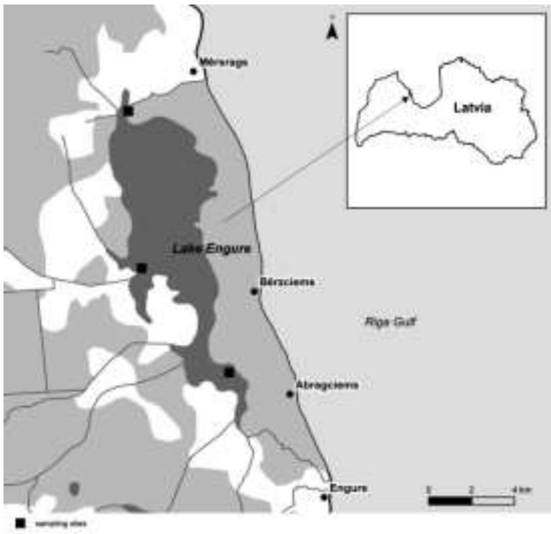

Fig. 1. Location of sampling sites in Lake Engure and meteorological station Mersrags (northern part – at Mersrags channel, middle part – at Dzedrupe inflow, southern part).

Chemical and biological studies in Lake Engure were carried out yearly during the vegetation period (end of June – beginning of July), starting in 1995. Sampling was conducted in three sampling sites situated in thqe southern, middle (at the inflow of the River Dzedrupe) and northern (at the outflow of Mersrags channel) parts of the lake (Fig. 1).

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The chemical composition of water was determined by standard methods - nitrates using diazotisation of [8, 9]. The molar ratio of nitrogen N to phosphorus P was calculated.

Phytoplankton samples were preserved with Lugol’s solution and analysed using the Utermöhl inverted microscope technique. Species composition, density, and cell dimensions were determined under a Leica DMIL microscope (200 and 400 fold magnification). Cell counts were converted to biovolumes (fresh weight mg L-1), calculated using measured cell dimensions applied to simple geometrical shapes.

Benthic invertebrates were sampled using an Ekman-Birge bottom sampler with the sampling area of 0.25 m^2 and samples were rinsed through sieves with 0.5 mm meshes. Organisms were fixed with 4.0% solution of formaldehyde. Besides, quantitative and qualitative samples were collected. The number of individuals and weight of organisms were determined according to standard methods [9].

A field survey of aquatic macrophytes was performed in July and August 2010 during the vegetation period. The assessment was based on the presence and cover of submerged, emergent, floating-leaved, free-floating vascular plants, bryophytes and charophytes. The areas occupied by typical communities were mapped on the bases of species domination, using aerial photo maps and GPS. Species communities were described, detailed in 2 x 2 m areas.

The Mann-Kendall test [10] was applied separately to each variable for the detection and analysis of trends in time series. The trend was considered as statistically significant at $p \leq 0.01$, if the test statistic was greater than 2 or less than -2.

III. RESULTS

Large-scale climate change impact to Lake Engure involves changes in air temperature and precipitation. The trend analysis of temperature series for the period 1970-2009 showed a statistically significant increase of annual mean temperatures (test statistics 2.04; p 0.02). Summer (June – August; test statistics 1.81; p 0.03) and spring (March – May; test statistics 1.62; p 0.05) temperatures also have the increasing trends (Fig. 2).

The average annual amount of precipitation at Mersrags for the period 1970 – 2009 was 636 mm. During the examined period, there were no significant trends in either annual or seasonal precipitation.

In general, the dominating ions in the lake are bicarbonates HCO_3^- (up to 60-70% of the ion content) and calcium Ca^{2+}. Concentration of calcium in most cases was about 30 mg/l. The content of these ions are comparatively higher at the inflow of Dzedrupe.

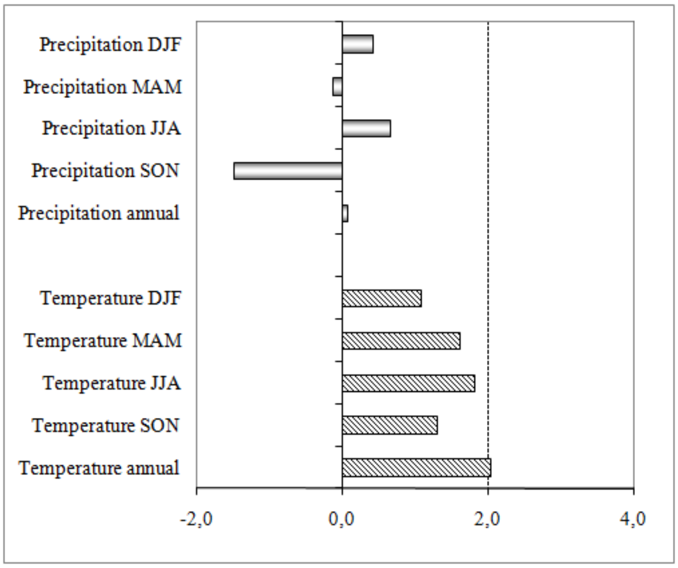

Fig. 2. Mann-Kendall test statistics of the time series for annual and seasonal temperatures and precipitation at Mersrags meteorological station, 1970-2009.

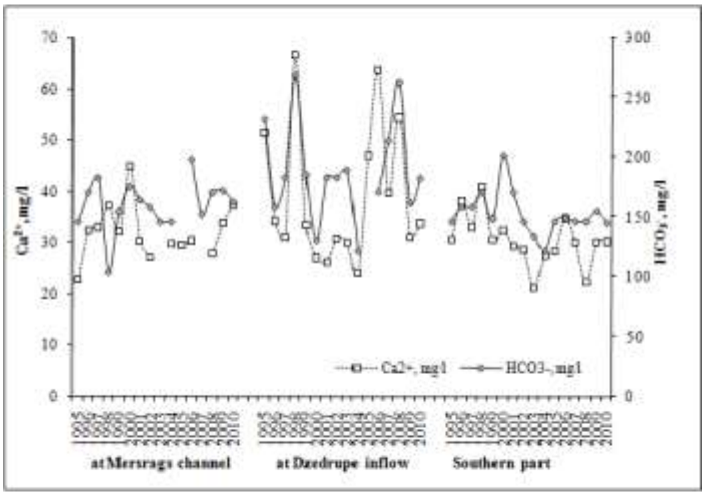

Fig. 3. Concentrations (mg/l) of dominating bicarbonate HCO_3^- and calcium Ca^{2+} ions in water of Lake Engure.

Oxygen content in Lake Engure is rather homogenous and typically exceeds 7.0 mg/l in the vegetation period. The lake is in clear-water state and transparency of water reaches the bottom.

Since 1995 no principal changes in phosphorus $P\text{-}PO_4^{3-}$ and nitrogen $N\text{-}NO_3^-$ and $N\text{-}NH_4^+$concentration has been observed at three sampling points. In general, for the entire lake, the limiting role of phosphorus for development of algae is confirmed by the molar N : P ratio that varied from 38:1 to 140:1 and has a positive trend ($R^2=0.25$, $p<0.05$, N=13). Values of BOD_5 varied from 0.3 to 9.9 mg/l and those of COD_{Mn} from 22.0 to 58 mg/l without evident trends.

pH values of water correspond to an alkaline reaction (7.6 – 9.8).

Concentrations of chlorides, natrium and potassium ions clearly differed among sampling points (Fig. 4), as well as those of magnesium and sulphates. All values of these ions are higher at the lake’s outflow at Mersrags channel.

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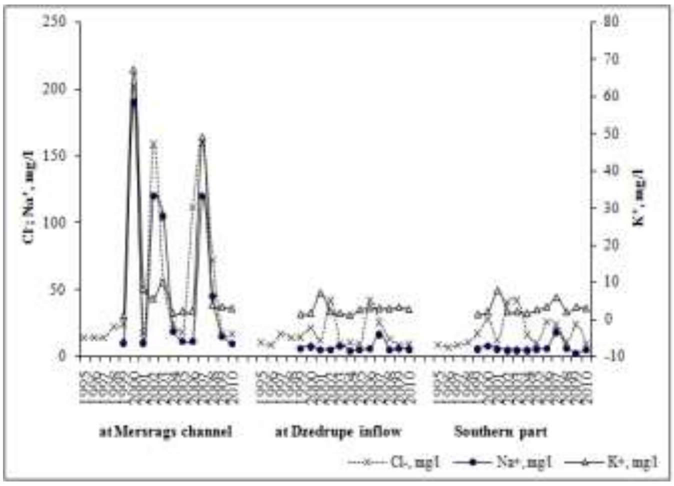

Fig. 4. Concentrations of chloride Cl^- , natrium Na^+ and potassium K^+ ions in water of Lake Engure.

During the entire period of investigation, Lake Engure had a low phytoplankton biomass (0.13-0.39 mg/l). The phytoplankton community was formed by Chrysophyceae, Chlorophyceae, Dinophyceae, Cryptophyceae, Bacillariophyceae, Euglenopyceae and Cyanophyceae (Cyanobacteria). In total, more than 150 algal species were recorded. Among diatoms, epiphytic algae dominated. Taxonomic composition of algal community since 1995 has fluctuated without an evident trend (Fig. 5).

The benthic samples collected since 1995 contain 110 species and 43 higher taxonomic units of invertebrates. The dominating macroinvertebrate groups are chironomids, oligochaetes, crustaceans, mayflies, caddisflies and molluscs.

The largest taxonomic diversity (Fig. 6) and abundance of benthic invertebrates is established at the inflow of Dzedrupe. At the Mersrags channel, oligohaline and mesohaline benthic species are common.

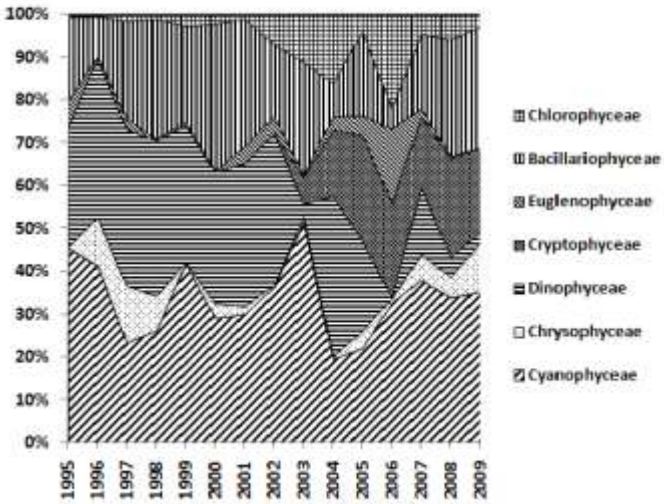

Fig. 5. Distribution (%) of dominated algae groups in of Lake Engure, 1995-2009.

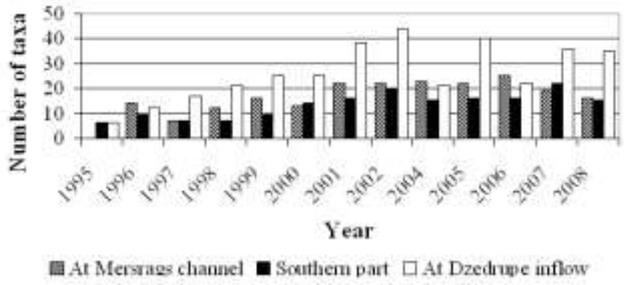

Fig. 6. Number of taxa of macroinvertebrates in Lake Engure, 1995-2008.

The Lake Engure is characterized by macrophytes typical for very shallow, hard water lakes. In the lake, the most dominant submerged macrophytes were charophytes. Here *Chara aspera, C. contraria, C. globularis, C. hispida, C. intermedia, C. rudis, C. tomentosa, C. virgata, Nitellopsis obtusa,* as well as *C. polyacantha* were found.

Emergent flora is dominating by *Phragmites australis, Scirpus lacustris, Typha angustifolia.* The richest species abundance are characteristic for the northern part of the lake, where varied species communities formed in numerous coves.

IV. Discussion

Development of the Lake Engure ecosystem has been affected by changing climate and human impact over the past 8-9 thousand years [11, 12].

It is known that shallow lakes are particularly sensitive to climatic changes that act via increased water temperature, reduced ice cover, climatic extremes and water level fluctuations [13, 2]. For the Lake Engure area, increase of mean annual, summer and spring temperature were shown. At the same time, precipitation was not changed evidently.

The most evident anthropogenic impact on the lake is construction of the channel connecting Lake Engure with the Gulf of Riga in 1842, which lowered the water level of the lake by 1.5 m. The water volume has decreased considerably from the early 20th century till nowadays (43 million m^3 to 16.8 million m^3). The circulation of organic and mineral matter in the lake is driven by rapid water exchange (7 to 16 times annually), and is reflected in the lake deposits [11]. At the beginning of the 20th century, eutrophication of the lake was not evident [14]. Nowadays eutrophication is expressed by extensive development of higher vegetation. It could be more associated with lowering of the lake's level, rather than with the influx of nutrients [11]. In the lake's catchment area, no significant changes in land use patterns are observed in the 20th century, but since 2000 areas of the agricultural lands decrease evidently [15]. At the same time, decrease of pastures and haymaking is a typical feature for the lake's foreland [1].

The role of the Mersrags channel is important also for the lake's physico-chemical composition and, consequently, its biotic components. The channel that connects the lake with the Gulf regulates the water level in Lake Engure. In the northern part at the channel outflow, there are higher concentrations of chlorides and sulphates, natrium, potassium and magnesium.

According to sulphate, chloride, sodium and potassium ion concentrations, brackish water inflow through the channel during the vegetation season at the end of the 20th century was low [16]. The impact of inflowing water from the Gulf may be increasing due to more frequent and stronger storms [17], although the overgrowth of the channel, as well as the lake's area at the outflow, is evident.

In the community of bottom invertebrates, no oligohaline and mesohaline species are found in the other area of the lake. The most diverse higher vegetation is developed in this part of the lake.

The influence of inflowing streams, e.g. Dzedrupe, is seen in the heightened concentrations of bicarbonate HCO_3^- and calcium Ca^{2+} ions that are typical for Latvian streams.

The impact of Dzedrupe plays role also for eutrophication expressed by species composition of higher vegetation [18] dominated by *Typha angustifolia*, as well as *Ceratophyllum demersum*, *Potamogeton pectinatus* and *Lemna minor* were often found.

The fact that the lake is an unstratified oxygen-rich hard-water one provides the prevalence of submerged vegetation and charophytes dominate in the lake. Our results show that concentration of calcium in most cases was about 30 mg L-1. This level is in the upper range given as a long-term median Ca-concentration for hard water lakes [19]. The lake's geology, as a natural local factor, has the leading role for phosphorus availability – phosphorus in the lake is found mainly in speciation with calcium compounds [16]. A major part of the phosphorus budget of morphometrically eutrophic lakes can be internal phosphorus loading [20], which is typical for Lake Engure [16]. Large amounts of nutrients can be stored for a long period without availability for phytoplankton [21, 22].

Our results demonstrate that since 1995 no principal changes have occurred in the concentrations of biogenic elements. At the same time, the N: P ratio varied from 38:1 to 140:1, with an increasing trend confirming the limiting role of phosphorus.

The amount of phosphorus released in Lake Engure is 2 to 3 times lower than that in similar experiments with sediment from a highly eutrophic lake [23]. It could be explained with the presence of charophytes. They efficiently protect sediments from wave action, reduce the amount of suspended matter in water and strengthen resilience. Charophytes have a strong positive effect on water transparency; they compete with phytoplankton for phosphorus and have an allelopathic effect on phytoplankton [24]. Thus, although climate change is evident in Lake Engure, low phytoplankton biomass and quite constant species composition is typical in the lake. At the same time, it must be mentioned that, due to eutrophication stands of other macrophytes than charophytes, as well as unvegetated area, are increasing.

The impact of higher vegetation concerns also benthic fauna of the lake. The dominating functional feeding group is gatherers-collectors, but phytophilic species associated with submerged charophyte vegetation also have a significant biomass, possibly because plants having finely dissected leaves support large numbers of macroinvertebrates, compared with plants with broader, undissected leaves [25].

V. Conclusions

Global factors affect Lake Engure by increase of annual, summer and spring temperatures. No significant changes of precipitation are found.

Among local factors, the highest importance has an anthropogenic impact to the lake - the channel built in the middle of the 19th century and connecting Lake Engure with the Gulf of Riga. The channel has changed the lake's morphometry and influences water chemical composition and biological communities' structure.

The lake's geology plays a leading role for such peculiarities as high concentration of calcium (hard water lake) and a low level of reactive phosphorus. The impact of inflowing streams is important too.

Abundant macrophyte stands with charophytes provide clear water state of the lake. At the same time, the lake's overgrowth by higher vegetation expresses ongoing eutrophication.

Development of phytoplankton and benthic invertebrates is related mainly to local factors.

In general, anthropogenical (channel) and natural (geology, geographical location) local-scale factors till now are leading in the development of the Lake Engure ecosystem.

Acknowledgements

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Gunta Spriņģe, Agrita Briede, Ivars Druvietis, Laura Grīnberga, Inga Konošonoka, Elga Parele, Valērijs Rodinovs, Agnija Skuja. Engures ezera hidroekosistēmas ilgtermiņa attīstība un to ietekmējošie faktori
Engures ezers ir lielākā reliktā ūdenstilpe Rīgas līča piekrastē. Tas ir sekls, morfometriski eitrofs caurplūstošs ezers. Ezers ir Ramsāres vieta, atrodas Engures dabas parkā, kas ir bioloģiski daudzveidīga teritorija. Ezera ilgtspējīgas attīstības iespējas saistītas ar vairākiem faktoriem. Engures ezerā ūdens ķīmiskā sastāva un planktisko un bentisko sabiedrību izpēte notiek kopš 1995.g., izmantojot hidroķīmiskās un hidrobioloģiskās standartmetodes. 2010.g. veikta arī augstāko augu sabiedrību izpēte. Klimata datu analīzei izmantoti Latvijas Vides, ģeoloģijas un meteoroloģijas centra dati no Mērsraga meteoroloģiskās stacijas par laiku no 1928.g. līdz 2009.g, Rezultāti liecina, ka Engures ezera reģionā notikusi būtiska gada vidējās temperatūras palielināšanās, temperatūras pieauguma tendences vērojamas arī vasarā un pavasarī. Būtiskas nokrišņu izmaiņas nav novērotas. Ezers joprojām ir dzidrūdens stāvoklī, fitoplanktona biomasas ir zemas un nav novērojamas izmaiņas dominējošo aļģu grupu struktūrā. No lokālajiem faktoriem visbūtiskāk ezera ekosistēmu ietekmējusi antropogēnā darbība – 19.gs. vidū izraktais Mērsraga kanāls, kas savieno ezeru ar Rīgas līci. Tas izmainījis ezera morfometriju un ietekmē ezera ziemeļu daļas ūdens ķīmisko sastāvu, kā arī organismu sabiedrību sugu sastāvu. Tikpat būtiska ir ezera ģeoloģija un ezerā ietekošās upes, kas ietekmē ūdens cietību, līdz ar to – fosfora atrašanos saistītā formā un mieturaļģu attīstību, kas kavē sedimentu resuspensiju. Fitoplanktons vāji izmanto saistīto fosforu un ezera eitrofikācija izpaužas pastiprinātā augstāko augu attīstība. Kopumā lokālo faktoru (gan antropogēno, gan dabisko) loma ir noteicoša pašreizējā ezera attīstības stadijā.

Гунта Сприньге, Бриеде Агрита, Ивар Друвиетис, Лаура Гринберга, Инга Конощенок, Элга Пареле, Валерий Родинов, Агнита Скуя. Долгосрочное развитие озера Энгурес и влияющие на него факторы
Озеро Энгуре – крупнейшее реликтовое озеро побережья Рижского залива. Мелководное, морфометрически эвтрофное проточное озеро. Озеро Энгуре является объектом Рамсарской конвенции, а также основной частью природного парка Энгуре, имеющего статус территории биологического разнообразия. Долговременное развитие озера связано с несколькими факторами. Относительно регулярные исследования химического состава вод, планктонных и бентосных сообществ озера с использованием стандартных гирохимических и гидробиологических методов проводятся с 1995 года. В 2010 году проведены картирование и анализ высшей водной растительности. Для анализа климатических показателей использованы данные Латвийского центра среды, геологии и метеорологии (станция наблюдений Мерсрагс) за период с 1928 по 2009 годы. Анализ результатов измерений показывают, что в регионе озера с 70-х годов прошлого века существенно увеличились средняя годовая температура воздуха, увеличились тренды средних температур весной и летом. Среднегодовое количество осадков значительно не изменилось. Озеро прозрачное, биомассы фитопланктона низкие и значительные изменения в структуре доминирующих групп водорослей не найдены. В историческом плане существенное антропогенное вмешательство в экосистему озера произошло в середине 19 века - прорытием канала, соединившего озеро с Рижским заливом. Это изменило морфометрию озера, периодическое проникновение солоноватых вод залива повлияло на химический состав, особенно северной части, а также отчасти на видовой состав сообществ организмов. На остальные части озера столь существенно влияют геологическое строение водосбора и приток рек в озеро, обуславливающий гидрокарбонатную жесткость воды, содержание фосфора в связанной форме, что в свою очередь влияет на развитие харовых водорослей, задерживающих ресуспенсию донных отложений. Форма связанного фосфора слабо используется фитопланктоном, поэтому главную роль в эвтрофировании озера на данном этапе принадлежит высшей водной растительности.