2nd International Conference - Water resources and wetlands. 11-13 September, 2014 Tulcea (Romania); Available online at http://www.limnology.ro/water2014/proceedings.html
Editors: Petre Gâştescu ; Włodzimierz Marszelewski ; Petre Bretcan; ISSN: 2285-7923; Pages: 204-211;

EFFECT OF HUMAN INDUCED DRASTIC WATER-LEVEL CHANGES TO ECOLOGICALLY SENSITIVE SMALL LAKES

Egert Vandel, Tiit Vaasma, Jaanus Terasmaa, Tiiu Koff; Marko Vainu
Institute of Ecology, Tallinn University
Uus-Sadama 5, Tallinn, 10120, Estonia, Email *egert.vandel@tlu.ee*

Abstract

This study focuses on the impact of anthropogenically caused intense water-level changes on three small ecologically sensitive Natura habitat lakes, on their ecology and restoration. The three studied lakes (Lake Martiska, Lake Kuradijärv and Lake Ahnejärv) are situated in central area of Kurtna Kame Field which is a naturally unique area due to a high density of lakes (around 40 lakes on 30 km^2) and total of 18 lakes are under protection as Natura Habitat lakes (Natura 2000 network). Controversially the area is also under a high stress of human impact. Although the area is surrounded by oil shale mines and related industry, the major negative impact comes from a groundwater intake established in 1972 in the vicinity of three studied lakes. Due to the exploitation of groundwater the water-levels dropped drastically. In 1980s the water-level drop was measured to be up to 3 to 4 meters in all the three relatively shallow lakes, thereof causing a decline in lake area and water volume. Most severely were affected L. Martiska and L. Kuradijärv where 29 % and 45 % of lake area respectively and only 21 % of total volume remained. This in turn led eventually to a decline in the lakes' water quality and increase in trophicity. Before or during the initial years of severe human impact two lakes were described as oligotrophic lakes with characteristic macrophytes present such as *Isoëtes lacustris* L. and *Lobelia dortmanna* L. During the last decades the lakes can be described as meso- or even eutrophic and the characteristic species for oligotrophic lakes have disappeared. In the 1990s the volume of groundwater abstraction decreased and the water-levels started to recover but have still not reached the natural levels of pre-anthropogenic impact period. Instead, the abstraction wells were renovated and the pumping rate increased again in 2012 causing a new decrease in water-levels. Even though nowadays the lake-water nutrient levels are low, the lakes still categorize as meso- or eutrophic and macrophyte composition has not recovered naturally but rather needs anthropogenic reintroduction. The water-level monitoring alongside with the macrophyte monitoring gives us a unique case study of how the drastic water-level changes affect the lake ecosystem and if or to what extent the lakes can recover during few decades of increased water-levels.

Keywords: water-level, lake, macrophytes, human impact, *Lobelia dortmanna*, eutrophication, *Isoëtes lacustris*, water chemistry

1. INTRODUCTION

Even in lakes with most pristine state small-scale lake-level changes are common and natural as they depend on the climatic conditions derived from seasonal changes. These natural fluctuations may even have positive effects on ecological condition of the lake (Coops & Hosper, 2002) as well on macrophyte diversity (Keddy & Reznicek, 1986). Although lake-level manipulation is in some cases used as a control for unwanted macrophyte species (Cooke, 1980), it can also have severe negative impact on the lake ecology. Study from Swedish small oligotrophic lakes (Lillieroth, 1950) showed that water-level lowering (up to 2 m) tended to affect the lakes macrophytic and planktonic communities towards slightly more eutrophic direction. Water-level fluctuations can also affect the balance between clear water and turbid states through abundance of submerged macrophytes (Blindow, 1992). Once the equilibrium is tipped, the new state can be long-termed without natural scenario to preliminary state as the decreasing submerged vegetation can lead to wind driven sediment resuspension (Liu et al., 2013), hence limiting the photic conditions required for submerged macrophytes. With resuspended sediments nutrients also become more available for phytoplankton causing their bloom which also leads to reduced photic conditions in water column (Schallenberg & Burns, 2004). In case when submerged vegetation is replaced by dominating floating-leaved plants it can eventually become a stable state (Scheffer et al., 2003) as the increased floating leaved plants limit the light availability for submerged vegetation.

Although there are case studies showing the response (Wallsten & Forsgren, 1989) and recovery (Havens et al., 2004) of submerged vegetation to increased water-levels, recovery from extremely lowered lake-level conditions are not that common. In most cases when dealing with historically recorded natural, seasonal and human managed water-level changes we speak about relatively small changes whether in terms of temporal or spatial scale or both. Therefore Kurtna Lake District offers a valuable case study where human induced lake-level lowerings are long-termed (up to few decades) and vast as only less than quarter of the lake volumes remained. It also presents an opportunity to observe if and to which extent the vegetation and ecological status of once oligotrophic lakes have recovered after partial water-level recovery.

2. STUDY AREA

Kurtna Lake District is located in North-Eastern Estonia, Europe (Figure 1). It resides in the Kurtna kame field and holds approximately 40 lakes on 30 km^2 of which 18 are under protection as Natura Habitat lakes (Natura 2000 network). It is an area with the most highest lake density in Estonia and it is also under protection as Kurtna Landscape Conservation Area. The lakes are kettlehole lakes and were formed during Preboreal after the retreat of the continental ice sheet (Punning, 1994). The shape, size, drainage area, hydrological regime and trophic status vary among lakes, but mostly they can be described as small (under 100 ha) and shallow (depth up to around 10 m) lakes.

The Kurtna Kame Field area lies in a transitional zone between a densely populated and heavily industrialized oil shale mining and processing region, and a sparsely inhabited territory with extensive forests and mires (Punning, 1994). The underground oil shale mining and the abstraction of groundwater started at the end of the 1950s. Most of the lakes in the area were more or less affected by the mining industry through the groundwater exploitation. There has been a continuous decline in the production of oil shale after the reorganization of the local economy in the 1990s. Even though mining industry has affected all the lakes in some extent, three lakes in the centre of the Kurtna Lake District have mostly been affected by the groundwater intake wells established in 1972 (Punning, 1994). The intake wells were established in the vicinity of Lake Martiksa (hereafter L. Martiska), Lake Kuradijärv (hereafter L. Kuradijärv) and Lake Ahnejärv (hereafter L. Ahnejärv) which are all under protection as Natura Habitat lakes (Natura 2000 network) belonging to type 3110 (oligotrophic waters containing very few minerals of sandy plains). In the 1990s the volume of groundwater abstraction decreased, but in 2012 abstraction wells were renovated and the pumping rate increased again.

2.1 Lake Martiska

L. Martiska (Figure 1) is a small closed dimictic lake (3.0 ha) with maximum water depth of 7.8 m and mean depth of 2.2 m. L. Martiska has been described as an oligotrophic lake but its trophicity has increased in the last decades. During 1946–1987 lake-level dropped from 46.0 m a.s.l. to 42.6 m a.s.l. (Erg & Ilomets, 1989). In may of 2012 lake-level was measured to be 44.2 m a.s.l. L. Martiska used to be *Lobelia-Isoëtes* lake. Before the industrial impact and water-level lowering the vegetation was described as scarce and poor in species (Riikoja, 1940; Miljan, 1958). Helophyte zone consisted dominantly of *Carex* spp. but also *Sparganium angustifolium* was found. *Nymphaea candida* and *Nuphar lutea* formed the majority of floating-leaved species, but the lake was rich with oligotrophic species such as *Lobelia dortmanna* and *Isoëtes lacustris*.

2.2 Lake Ahnejärv

L. Ahnejärv (Figure 1) is a small closed dimictic lake (5.8 ha) with maximum water depth of 9 m and mean depth of 3.3 m. L. Ahnejärv has been described as a oligotrophic lake but its trophicity has increased in the last decades. During 1946–1987 lake-level dropped from 46.8 m a.s.l. to 43.9 m a.s.l. (Erg & Ilomets, 1989). In may of 2012 lake-level was measured to be 44,9 m a.s.l. In 1936 before the industrial impact and water-level lowering the helophyte zone composed only of *Carex* spp. Five species of floating-leaved plants were found: *Nymphaea candida, Nuphar lutea, Potamogeton natans, P. alpinus* and *Sparganium angustifolium*. Among submerged species *Isoëtes lacustris* was found. (Riikoja, 1940; Miljan, 1958).

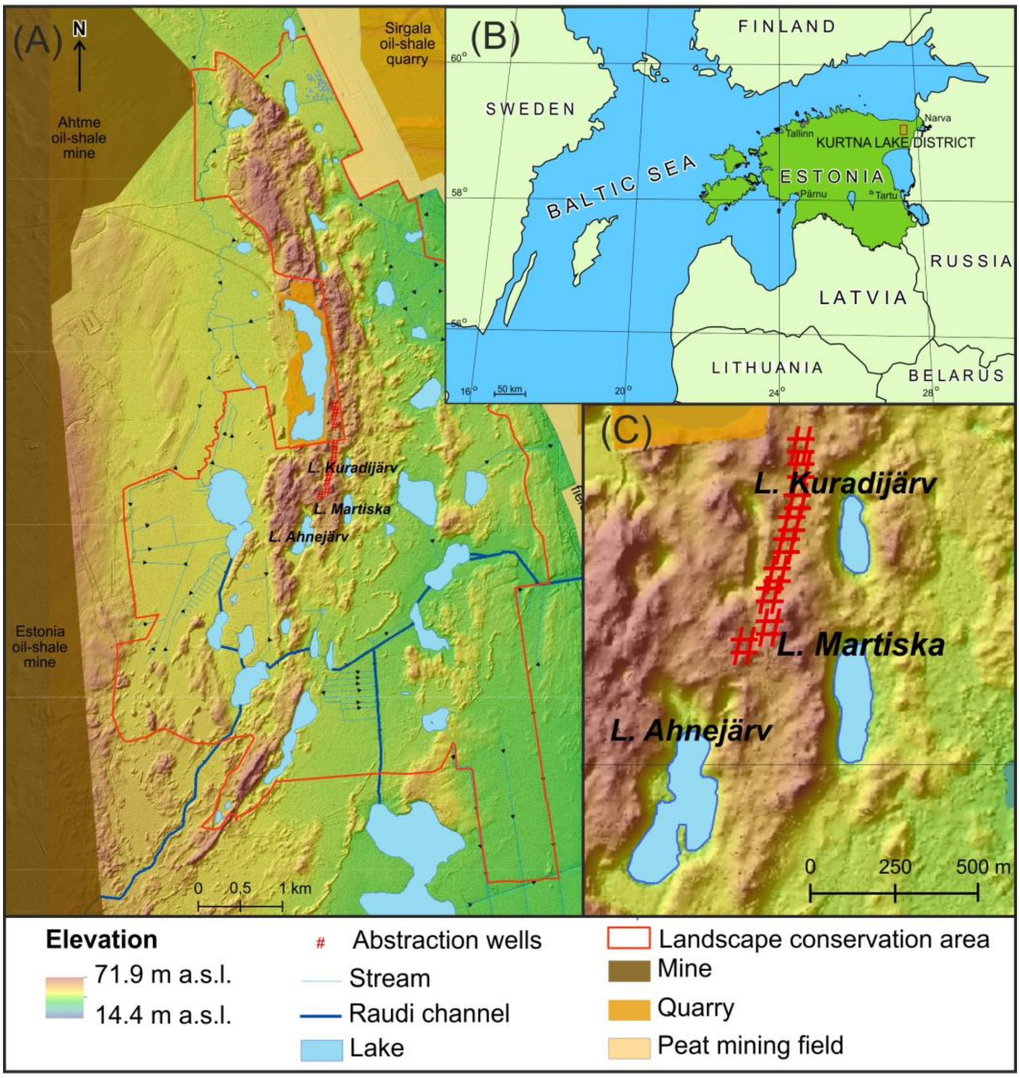

Figure 1. Location of Estonia (B), Kurtna Lake District (A) and three studied lakes (C).

2.3 Lake Kuradijärv

L. Kuradijärv (Figure 1) is a small closed dimictic lake (1.5 ha) with maximum water depth of 7.2 m and mean depth of 2.8 m. L. Kuradijärv has been described as oligotrophic, but the lake has gone through severe changes during last decades and can be described as mesotrophic. During 1946–1987 lake-level dropped from 46.0 m a.s.l. to 42.2 m a.s.l. (Erg & Ilomets, 1989). In may of 2012 lake-level was measured to be 44.0 m a.s.l., but by november it has already dropped to 43.5 m a.s.l. Before the industrial impact and water-level lowering in 1936 there was no vegetation in submerged or helophyte zone and only *Sphagnum* mats infiltrated the waterline in some parts (Riikoja, 1940).

3. METHODS

In order to describe and map the modern vegetation in lakes, the whole littoral zone was traversed by boat and the species composition and depth limits of different plant groups were recorded. For submerged aquatic plants, which were not readily visible, five throws with a grapple were made around the boat. As the distinction between an aquatic and a terrestrial plant is often blurred, many aquatic species can have both submersed and emerged forms, and many terrestrial plants are able to tolerate periodic submersion we divided the macrophytes into three groups: helophytes, floating-leaved and submerged plants. In order to compare nowadays vegetation to the past vegetation and relate the possible changes to anthropogenic impact historical records of vegetation, water-quality and groundwater abstraction were used. As the past vegetation records are mainly descriptive, therefore the comparison and analysis is more of qualitative than quantitative nature.

3. RESULTS AND DISCUSSION

The lake-level changes in all three lakes have quite good records but they are not always consistent. Most reliable records are from 1946, 1987 and 2010, when based on the measurements also water surface area and water-body volume is calculated (Figure 2). But as the intense groundwater abstraction started already in the 1970s and the vegetation mapping records hold also essential data and show changes from that period, it is important to use all the data we could collect concerning the changes in water-levels of three studied lakes (Figure 3). Even though the available historical records are sometimes controversial they still give some insight about the temporal and spatial scale of the changes.

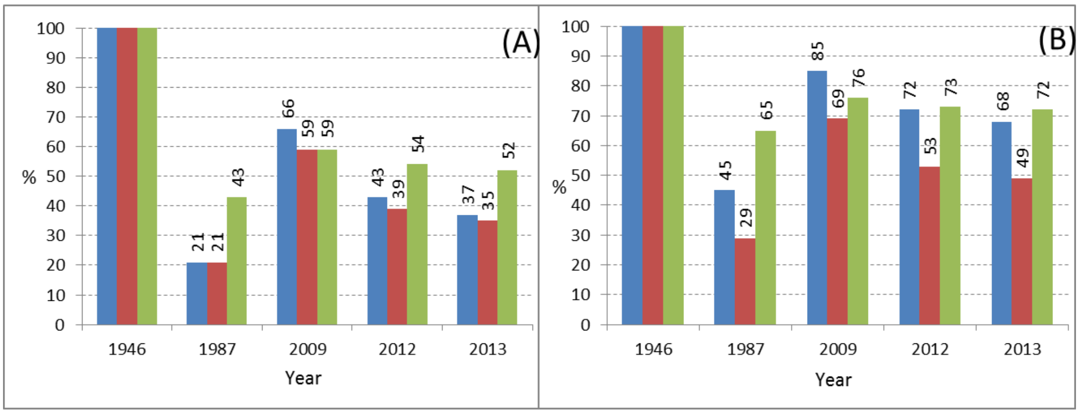

Figure 2. Changes in volume (A) and surface area (B) of three studied lakes (precentages show residue from initial values). Blue column – L.Kuradijärv, red column – L. Martiska and green column – L. Ahnejärv.

When looking at the more detailed records (Figure 3) we can see that the lake-levels started to decrease already before the establishment of groundwater intake in 1972. It can be partially explained by the changes in vegetation on the catchment (Vainu & Terasmaa, 2014), as During World War II the pine forest in the central part of the Kurtna Kame Field was burnt and therefore at the end of the 1940s the area was covered with post-fire moor-like vegetation. The vegetation was fully recovered by 1960. As full-grown pine trees are able to evapotranspirate significantly more water than sparse and shallow-rooted moor vegetation (Allen et al., 1998), less water reached the lakes from the catchment (Vainu & Terasmaa, 2014). As the changes in vegetation can't explain whole 1 m lake-level drop as in case of L. Ahnejärv, rest can be put on the account of groundwater abstraction from the oil shale mines. But when comparing data from the 1970s and the 1990s we can see, that the lake-level drop which followed the initial decrease is much more extensive (Figure 3).

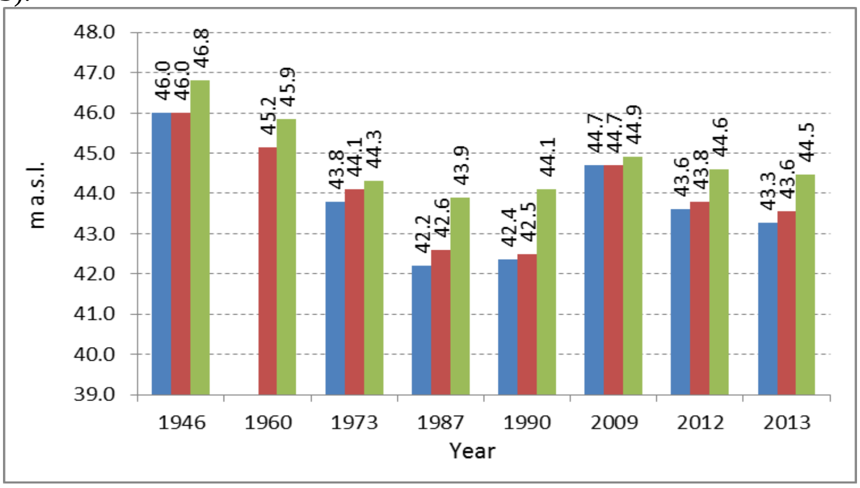

Figure 3. Water surface records from three studied lakes. Blue column – L.Kuradijärv, red column – L. Martiska and green column – L. Ahnejärv. Past water levels taken from: ELB, 1973; Erg & Ilomets, 1989; Põder et al., 1996.

In overall during the period of 1946-1987 the lake-level dropped 2.9 m in L. Ahnejärv, 3.8 m in L. Kuradijärv and 3.4 m in L. Martiska, affecting also the water surface area and lake volume. Due to the shape of lake basins the change in water body volume was even more drastic as in cases of L. Martiska and L. Kuradijärv only 21% of the original volume remained (Figure 2). After the decrease in groundwater abstraction in 1990s the water levels as well as volumes started to recover.

The water-level drop also slightly affected the lake water chemistry but not uniformly in all three lakes (Table 1). The content of $SO4^{2-}$ has slightly risen in all three lakes. Contents of all other minerals have decreased in L. Ahnejärv, changed very little in L. Martiska and increased in L. Kuradijärv. Considering the magnitude of changes in lake water bodies, the response in water chemistry is surprisingly minor.

Table 1. Water chemistry in 1937 (Riikoja, 1940) and 1986-1987 (Sagris, 1989)

Lake	HCO^{3-} (mg/l)		Ca^{2+} (mg/l)		Mg^{2+} (mg/l)		$SO4^{2-}$ (mg/l)	
	1937	1986-1987	1937	1986-1987	1937	1986-1987	1937	1986-1987
L. Ahnejärv	154	36.7	32.2	9.4	10.8	4.7	5.8	16.4
L. Kuradijärv	7.5	27.9	1.4	5.5	1	2.1	2.9	11.4
L. Martiska	27.2	25.4	7.5	5.1	0.7	1.7	1.9	10.7

The trends in vegetation changes are quite different for all three lakes as also the initial conditions are not similar (Table 2). When looking at the vegetation monitoring data it is important to take into account that data from different years and sites have varying monitoring quality as in some years the vegetation was only observed from the lake shore. Therefore it is important to look at overall trends in changes.

The most drastic change occurred in L. Kuradijärv - once vegetation free lake became moderately rich with macrophytes (Table 2). Good records of vegetation monitoring show that in 1958 still no macrophytes were found but in 1976 there was already patchy helophyte zone consisting mainly of *Carex* spp., *Phragmites australis* and *Typha* spp. Also floating-leaved vegetation zone was formed by *Potamogeton natans*. *Elodea Canadensis* was recorded among submerged vegetation. Unfortunately this leaves almost a 20 year wide cap in the monitoring data (Table 2) into which also falls the start of groundwater abstraction and extreme water level drop. Therefore it is hard to say if the changes started before or after the beginning of groundwater abstraction. Also the data for water levels is missing for L. Kuradijärv from the year 1960 (Figure 3). Considering the fact that in overall the water levels of all three lakes have quite similar trends in change during last 60 years we can assume that the water level in L. Kuradijärv started to decrease at least in some extent before 1972. Afterwards the water level fell even more (Figure 2, 3), but there is no vegetation data until 2011. Nowadays, when the water level has slightly recovered, the vegetation is mostly formed by helophyte zone where the number of species has increased. The floating-leaved plant cover has also increased as of *Potamogeton natans* forms almost a constant zone along the shoreline. Only the submerged vegetation is missing.

In L. Ahnejärv the line of changes were different as the lake was initially inhabited by such oligotrophic species as *Lobelia dortmanna* and *Isoëtes lacustris*. In 1971 when already slight water level decrease had occurred (Figure 3) there were some changes in vegetation. Helophyte zone had greater number of species and also the composition of floating-leaved plant species had changed (Table 2). Most important is the disappearance of *Isoëtes lacustris*, even though its presence was just noted in 1968 (Mäemets, 1977). Therefore some shifts in vegetation took place already before ground water abstraction began. For the time in 1976 when next vegetation monitoring took place the water level had dropped even more (Figure 3) being at least 2.5 meters lower than in 1946 (water level measurements took place in 1973 just a year after the plant was established, but vegetation was monitored 4 years after). This also reflects in the vegetation composition as the helophyte zone has increased in mass as in species. Bigger helophytes such as *Phragmites australis, Schoenoplectus lacustris* and *Typha* spp. had colonized the shoreline. Of floating-leaved plants *Potamogeton natans* dominated. Most notable change is the disappearance of *Lobelia dortmanna* and *Sparganium angustifolium* which were found just 6 years ago. In case of L. Ahnejärv it is quite clear that the establishment of the groundwater intake in 1972 and the rapid water level drop had direct negative impact on the vegetation just in 4 years. Even though Mäemets (1977) suggested that the disappearance of *Lobelia dortmanna* is likely due to high mineral levels in lake water, data shows (Table 1) that mineral levels have rather dropped. The disappearance of oligotrophic and increase in more eutrophic species is more likely linked to the changes in lake level. Nowadays when the lake level and volume have slightly recovered, the vegetation has not. *Phragmites australis* dominates the helophyte zone, floating-leaved plants cover most of the near shore areas and only *Myriophyllum* sp. is found from the submerged species.

Table 2. Results of vegetation monitoring in three studied lakes. Data from years with italic font style are based on overall description from less thorough studies. Data from years with bold font style are from thorough studies with species list. Past macrophyte data taken from: Riikoja, 1940; Miljan, 1958; Mäemets, 1977; Pallo, 1977; Ott, 2001; 2006

	L. Kuradijärv					L. Ahnejärv				L. Martiska					
Species	*1935-1936*	**1958**	**1976**	*2006*	**2011**	*1935-1936*	**1971**	**1976**	**2011**	*1935-1936*	**1968**	**1976**	**1980-1981**	**1985**	**2001**
Phragmites australis (Cav.) Trin. ex Steud.			x	x	x			x	x			x	x	x	x
Schoenoplectus lacustris (L.) Palla								x	x				x		
Typha latifolia L.			x		x		x	x	x			x	x	x	
Typha angustifolia L.			x					x				x			
Carex spp.			x		x	x	x	x		x	x	x	x	x	x
Juncus spp.			x		x		x	x				x			x
Lycopus europaeus L.					x							x			
Equisetum fluviatile L. em Ehrh.					x			x	x				x	x	x
Molinia caerulea (L.) Moench					x				x						
Lobelia dortmanna L.						x	x			x	x	x	x		
Lysimachia thyrsiflora L.							x								
Alisma plantago-aquatica L.							x		x						
Glyceria maxima (Hartm.) Holmb.								x							
Potentilla palustris (L.) Scop.								x	x						
Peucedanum palustre (L.) Moench									x						
Bidens sp.												x			
Rorippa sp.												x			
Glyceria maxima (Hartm.) Holmb.															x
Calamagrostis sp.															x
Sparganium sp.			x								x	x	x	x	
Sparganium angustifolium Michx.						x	x			x	x	x			
Potamogeton natans L.			x	x	x	x	x	x	x			x	x	x	x
Potamogeton praelongus Wulfen													x		x
Potamogeton alpinus Balb.						x	x						x	x	
Potamogeton berchtoldii Fieber													x	x	
Polygonum amphibium L.				x											x
Nymphaea alba L.					x		x	x	x					x	
Nymphaea candida C. Presl						x				x	x				
Nuphar lutea (L.)						x		x		x	x				x
Nuphar pumila							x								
Spirodela polyrrhiza (L.) Schleid.															x
Myriophyllum sp.									x						
Isoëtes lacustris L.						x				x	x	x	x		
Elodea Canadensis Michx.			x					x			x	x	x	x	
Nitella spp.							x								
Ceratophyllum sp.								x				x			
Chara spp.													x		x

L. Martiska was also initially inhabited by *Lobelia dortmanna* and *Isoëtes lacustris*. Fortunately there are vegetation records between the initial slight water level drop and extreme water level changes. In

1968 the vegetation was similar to that in 1936. *Lobelia dortmanna* and *Isoëtes lacustris* were found in moderate amount and also *Sparganium angustifolium* was still present. Overall species composition and amount had not changed much (Table 2). In 1976 when the water level had dropped at least around 2 m (Figure 3) vegetation showed some changes but nothing catastrophic. Number of helophytes had increased but still *Carex* spp. dominated. *Potamogeton natans* had colonized the floating-leaved plant zone where *Nymphaea alba* and *Nuphar lutea* had disappeared. Regardless to these changes *Lobelia dortmanna*, *Isoëtes lacustris* and *Sparganium angustifolium* were still found. *Lobelia dortmanna* and *Isoëtes lacustris* were also found in 1980-1981 but in lower amounts. We can also assume that for this period the water level had dropped even more as the peak in the drop was recorded only a few years later. Also the helophyte and floating-leaved plant zones had become more abundant. In 1985, just two years before the water level had dropped 3.4 meters and only 21% of the original lake volume remained (Figures 2, 3), *Lobelia dortmanna* and *Isoëtes lacustris* had disappeared. The helophyte zone was abundant and *Potamogeton* species thrived. Even though these rare oligotrophic species endured initial water level drop and did not disappear as quick as in L. Ahnejärv, the abundance still gradually decreased leading to eventual disappearance 13 years after the ground water abstraction began. In 2001 the lake level had already started to increase but vegetation showed no signs of recovery. Based on the gradual disappearance of *Lobelia dortmanna* and *Isoëtes lacustris* in L. Martiska we can hypothesize that if the lake level changes would have been more subtle and expanded on longer time period, it is possible that these oligotrophic species could have adapted to new conditions and habitat areas as the water chemistry in lake changed very little. The experiment of reintroduction of *Lobelia dortmanna* is being considered but the ecological conditions of the sediment and water needs prior studies.

4. CONCLUSIONS

Rapid water level drop caused by the groundwater abstraction had severe impact on the vegetation of three studied lakes. Even though the lakes were initially different and had different train of changes, they were all affected by the extreme reduction of lake water volume when only 21-43% of the initial volume remained. Most extreme water level drop occurred in L. Kuradijärv where once vegetation free lake became colonized by extensive zones of helophytes and floating-leaved plants. In L. Ahnejärv the oligotrophic species *Isoëtes lacustris* disappeared already after a slight water level drop and *Lobelia dortmanna* and *Sparganium angustifolium* were missing four years after the extreme lowering of water level. In L. Martiska the oligotrophic species *Lobelia dortmanna* and *Isoëtes lacustris* withstood water level lowering for 13 years with gradual decrease in abundance leading to eventual disappearance. Even though the water levels have partially recovered after the beginning of 1990s in all three lakes, the vegetation shows no sign of recovery.

Acknowledgements

The authors thank the Environmental Conservation and Environmental Technology R&D Programme Project "EDULOOD", Estonian Research Council grants ETF8189 and SF0280016s07 and the colleagues from the Institute of Ecology at Tallinn University.

REFERENCES

Allen, G. R., Pereira, S. L., Raes, D. & Smith, M. 1998, *Crop Evapotranspiration Guidelines for Computing Crop Water Requirements FAO Irrigation and Drainage Paper 56*. FAO, Rome, 300p.

Blindow, I. 1992, Long- and short-term dynamics of submerged macrophytes in two shallow eutrophic lakes, *Freshwater Biology*, **28**:1, 15-27.

Cooke, G. D. 1980, Lake level drawdown as a macrophyte control technique, *JAWRA Journal of the American Water Resources Association*, **16**:2, 317-322.

Coops, H. & Hosper, S. H. 2002, Water-level Management as a Tool for the Restoration of Shallow Lakes in the Netherlands, *Lake and Reservoir Management*, **18**:4, 293-298.

ELB [Estonian Land Board]. 1973. Topographical map. A 1:10 000.

Erg, K. & Ilomets, M. 1989, *Mäetööde mõju Kurtna järvede veetasemele seisund ja prognoos [The effect of mining on the water level of Kurtna lakes – current state and prognosis*]. In Kurtna järvestiku looduslik seisund ja selle areng II [Natural Status and Development of Kurtna Lake District II] (Ilomets, M., ed.), pp. 47-54. Valgus, Tallinn [in Estonian].

Havens, K. E., Sharfstein, S., Brady, M. A., East, T. L., Harwell, M. C., Maki, R. P. & Rodusky A. J. 2004, Recovery of submerged plants from high water stress in a large subtropical lake in Florida, USA, *Aquatic Botany*, **78**:1, 67-82.

Keddy, P. A. & Reznicek, A. A. 1986, Great Lakes Vegetation Dynamics: The Role of Fluctuating Water Levels and Buried Seeds, *Journal of Great Lakes Research*, **12**:1, 25-36.

Lillieroth, S. 1950, Über Folgen kulturbedingter Wasserstandsenkungen für Makrophyten- und Planktongemeinschaften in seichten Seen des südschwedischen Oligotrophiegebietes; eine Studie mit besonderer Berücksichtigung der angewandten Limnologie: eine Studie mit besonderer Berücksichtigung der angewandten Limnologie. Edit: Thunmark, S. *Acta Limnologica*, **3**, 288p. [In German, summary in English].

Liu, X., Zhang, Y., Yin, Y.,Wang, M. & Qin, B. 2013, Wind and submerged aquatic vegetation influence bio-optical properties in large shallow Lake Taihu, China, *Journal Of Geophysical Research: Biogeosciences*, **118**, 1-15.

Mäemets, A. (ed.) 1977, Eesti NSV järved ja nende kaitse, (Lakes of Estonian SSR and the protection), Edit. Valgus, Tallinn, 263p [in Estonian].

Miljan, A. 1958, *Toitainetevaeste järvede vegetatsioonist Eesti NSV-s [Vegetation of oligotrophic lakes in Estonian SSR]*. In Botaanika-alased tööd [Studies in Botany] (Vaga, A., ed), 119-137, Tartu Riikliku Ülikooli Toimetised, Tartu [In Estonian].

Ott, I. 2001, *Eesti väikejärvede monitooring 2001 (Monitoring report of Estonian small lakes 2001)*. EPMÜ Zooloogia ja Botaanika Instituut , 67p, [Monitoring report in Estonian].

Ott, I. 2006, Eesti väikejärvede seire 2006. *(Monitoring of Estonian small lakes 2006)*. Eesti Maaülikooli põllumajandus- ja keskkonnainstituut, 173p, [Monitoring report in Estonian].

Pallo, S. 1977, Kurtna järvestik, (Kurtna Lake District), diploma, Tartu Riiklik Ülikool, Füüsilise geograafia kateeder [manuscript in Estonian].

Põder, T., Riet, K., Savitski, L., Domanova, N., Metsur, M., Ideon, T., Krapiva, A., Ott, I., Laugaste, R., Mäemets, A., Mäemets, A., Toom, A., Lokk, S., Heinsalu, A., Kaup, E., Künnis, K. & Jagomägi, J. 1996, *Mõjutatav keskkond [Affected environment]*. In Keskkonnaekspertiis. Kurtna piirkonna tootmisalade mõju järvestiku seisundile [Environmental Assessment. The Effect of Industrial Areas in the Kurtna Region on the Status of the Lakes] (Ideon, T. & Põder, T., eds), pp. 16-48. AS Ideon & Ko, Tallinn [in Estonian].

Punning, J.-M. (ed) 1994, The influence of natural and anthropogenic factors on the development of landscapes. The results of a comprehensive study in NE Estonia, Edit. Institute of Ecology, Estonian Academy of Science, Publication 2, 227p.

Riikoja, H. 1940, Zur Kenntnis einiger Seen Ost-Eestis, insbesondere ihrer Wasserchemie. In: *Eesti Teaduste Akadeemia juures oleva Loodusuurijate seltsi aruanded, XLVI*, Tartu, 1-167.

Sagris, A. 1989, *Kurtna järvestiku läbivoolujärvede kemismist [The chemistry of flow through lakes in Kurtna Lake District*]. In Kurtna järvestiku looduslik seisund ja selle areng II [Natural Status and Development of Kurtna Lake District II] (Ilomets, M., ed.), pp. 122-133. Valgus, Tallinn [in Estonian].

Schallenberg, M. & Burns, C. W. 2004, Effects of sediment resuspension on phytoplankton production: teasing apart the influences of light, nutrients and algal entrainment, *Freshwater Biology*, **49**, 143–159.

Scheffer, M., Szabó, S., Gragnani, A., van Nes, E. H., Rinaldi, S., Kautsky, N., Norberg, J., Roijackers, R. M. M. & Franken, R. J. M. 2003, Floating plant dominance as a stable state, *Proceedings of the National Academy of Sciences of the United States of America*, **100**:7, 4040-4045.

Vainu, M. & Terasmaa, J. 2014, Changes in climate, catchment vegetation and hydrogeology as the causes of dramatic lake-level fluctuations in the Kurtna Lake District, NE Estonia, Estonian Journal of Earth Sciences, 63:1, 45-61.

Wallsten, M. & Forsgren, P.-O. 1989, The effects of increased water level on aquatic macrophytes, *Journal of Aquatic Plant Management*, **27**, 32-37.