

**Research Article**

## Changes due to invasion of *Myriophyllum sibiricum* in a shallow lake in Åland, SW Finland\*

Tore Lindholm\*, Eeva Rönholm and Kerstin Häggqvist

Environmental and Marine Biology, Åbo Akademi University, FIN-20520 Åbo/Turku, Finland

\*Corresponding author

E-mail: [tore.lindholm@abo.fi](mailto:tore.lindholm@abo.fi)

Received: 30 September 2007 / Accepted: 6 February 2008 / Published online: 23 March 2008

### Abstract

Lake Österträsk, a shallow, 25 ha lake in Åland, SW Finland, was invaded by the common watermilfoil, *Myriophyllum sibiricum* Komarov 1914 (Magnoliophyta: Haloragaceae), in the 1990s. In summer 2006 the dense vegetation, up to 2.5 m tall, richly branching *Myriophyllum* shoots, caused pH values of about 10 and oxygen supersaturation near the surface. Deeper layers were hypoxic throughout the season. The surface water Chlorophyll *a* values were about 10 µg L<sup>-1</sup>. Shoot formation from the turions was temperature dependent and enhanced by nutrient as well as sediment addition. Decaying plants release nutrients to the water, produce organic sediments, and cause bottom oxygen depletion, changing the chemistry, nutrient dynamics and plant structure of the lake.

**Key words:** high pH, invasion, *Myriophyllum sibiricum*, shallow lake, turion growth

### Introduction

Dense macrophyte vegetation causes great water quality and habitat changes in shallow lakes at different time scales (e.g. Smith and Adams 1986; Wetzel 2001). Submerged macrophytes depend on, but also modify, the underwater light conditions. Their photosynthesis and respiration alters the pH and oxygen levels markedly within hours. Dense submerged vegetation also traps particles, reduces water movements, and alters water and sediment chemistry. Seasonally, some plant species fill shallow lakes and the decaying plant biomass causes hypoxia in water and sediments. Rooted plants may also transport phosphate from the sediments to the water (Carignan and Kalff 1982). Finally, excessive plant growth reduces the recreational value of lakes.

Watermilfoil invasion and changing conditions in Lake Österträsk in Åland, SW Finland (Figure 1), were first mentioned in a local survey (Lindholm and Hägg 2001). Water users also complained of profuse watermilfoil growth. In late August 2005 Lake Österträsk resembled an underwater jungle of common watermilfoil *Myriophyllum sibiricum* Komarov 1914 (Magnoliophyta: Haloragaceae) and the surface water pH exceeded 10. These observations lead to a seasonal study in 2006 to explore the limnology of the lake and the conditions and effects of watermilfoil growth. Also restoration aspects were kept in mind. As the lake was studied in the 1920s (Cedercreutz 1934, 1947), the 1960s (Sundblom and Moliis 1962), and later (Storberg 1980; Carlsson 2001), some comparisons of water chemistry and vegetation were possible. Old photographs of the lake shores were also available (courtesy Berit and Roine Johanson).

\* This paper was presented at the special session "Ecology and Ecotoxicology of Invasive Species in Inland Waters" of the 30th Congress of the International Association of the Theoretical and Applied Limnology (SIL), August 12-18, 2007, Montreal, Canada

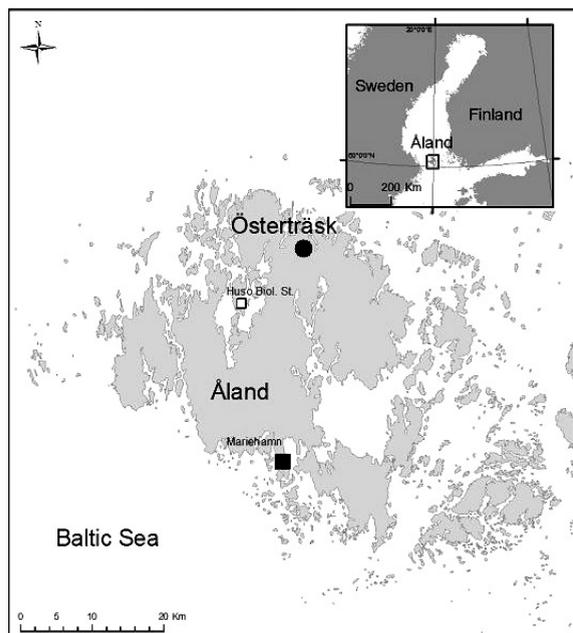


Figure 1. Map of the study area.

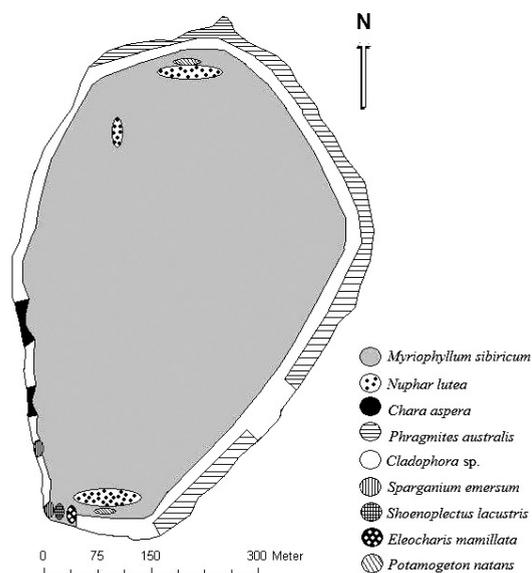


Figure 2. Distribution of vegetation in Lake Österträsk in August 2006.

### Study area, materials and methods

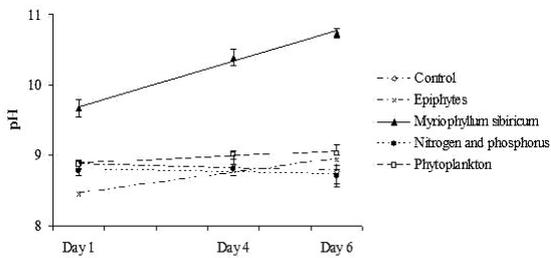
Österträsk (Figure 1) is a 25 ha lake in Åland, SW Finland. The average depth in the lake is 2 m, maximum depth is about 4 m (Lindholm and Hägg 2001). The lake is, to a certain extent,

used as a local source of drinking water (Lindholm and Hägg 2001). It is situated 12 m above sea level. Assuming the postglacial land uplift to be 5 mm/year (Lindholm 1991), Lake Österträsk was isolated from the sea about 2500 years ago. Coniferous forests and granite rocks dominate the catchment area (3.5 km<sup>2</sup>), which also includes two small farms and another 25 ha lake. Lime occurs in the moraine. The lake is almost round and fairly exposed to winds. The western shore is rocky but in other areas sandy and clayey shores dominate. The water level may fluctuate within almost 1 m, but was unusually low throughout 2006.

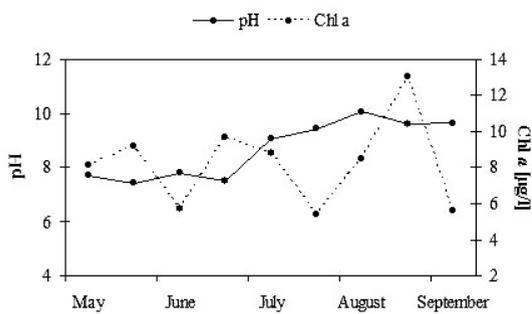
The vegetation of the lake was mapped along transects 50 m apart. Water samples were taken 1-2 times per month during the period March-September 2006 and analysed for temperature, pH, dissolved oxygen (DO), colour, Chlorophyll *a*, total phosphorus and total nitrogen according to Finnish standards. Microstratification was studied by siphon sampling (Lindholm and Fröjdö 1996) on five occasions. Tests in 500 ml polyethylene bottles were used to study shoot growth of turions in daylight, darkness, + 6°C and +20°C (duration 2 weeks). Factors regulating shoot growth (phosphorus, nitrogen, sediment) were studied using *in situ* enrichment assays with hanging 9 L polyethylene bags (Lindholm 1978). Causes of high pH were also studied in similar bag experiments in order to reveal the role of phosphorus, nitrogen (by doubling the ambient concentrations), watermilfoil shoot apices (30 cm), epiphytic algae and phytoplankton. Two-fold phytoplankton enrichment (measured by fluorescence) was obtained by reverse filtration. As the watermilfoil was almost clean, epiphytes for enrichment were collected from other aquatic plants to get an initial three-fold increase in fluorescence in the bags. The enrichment experiments were run for 6 days with 5 replicates.

### Results

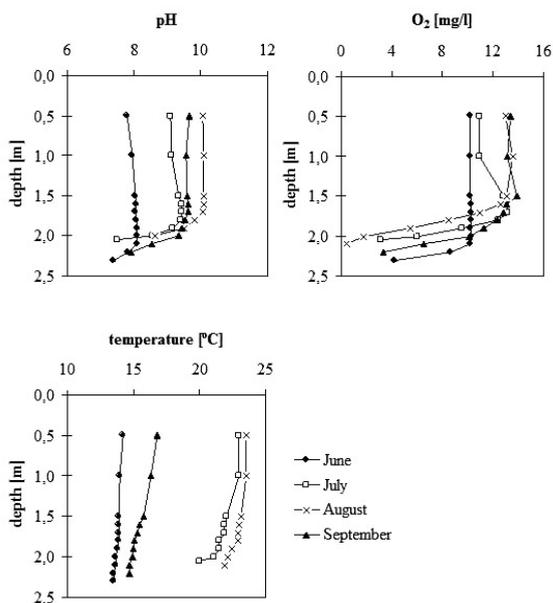
Dry weather and low water level characterised the summer 2006 and, as in the previous summer, the watermilfoil *Myriophyllum sibiricum* growth was profuse in Lake Österträsk (Figure 2). The watermilfoil had almost excluded other plants than *Nuphar lutea* (L.) Sibth. & Sm. and (sparsely growing) *Potamogeton praelongus* Wulfen Locally, *Potamogeton gramineus* L. and *Chara aspera* Deth. ex Willd. dominated in very



**Figure 3.** Effects on pH of enrichments with phytoplankton (doubling of fluorescence), epiphytes (tripling of fluorescence), *Myriophyllum* (3 apices), and phosphorus and nitrogen addition ( $40$  and  $400 \mu\text{g L}^{-1}$ , respectively).



**Figure 4.** Surface water pH and Chlorophyll *a* during the growing season 2006.



**Figure 5.** Vertical structure of pH, DO and temperature during the 2006 sampling period.

shallow, ice-influenced areas. The tallest *Myriophyllum* shoots became about 2.5 m. Shoot and root formation from turions started in May. In late summer almost the whole lake area was covered by *M. sibiricum*. Shoot elongation from turions, about 10 cm in 15 days, was observed in the bottle tests in April in warm, dark, warm light and cool dark conditions. However, in light and cool conditions, the turions grew only about 1 cm. In an enrichment assay using hanging bags *in situ* (8-15 May, water temperature about  $+15^{\circ}\text{C}$ ), single phosphorus, nitrogen, and sediment addition had no significant effects, but sediment added in combination with nutrients somewhat increased shoot elongation (means  $>3.3$  cm with sediment,  $< 2$  cm without). As in previous years, in 2006 the surface water pH rose to about 10 in late summer. In a separate bag experiment 12-18 July, with phytoplankton, epiphytes and nutrients added, conditions remained relatively unchanged (pH 8.5-9). However, in bags with *Myriophyllum* shoots pH increased significantly, to above 10 (Figure 3).

The Secchi depth varied between 2.9 m in May and 2.2 m in September. Chlorophyll *a* varied little ( $5$ - $13 \mu\text{g L}^{-1}$ ) in the top layers during the growing season (Figure 4). Siphon sampling revealed somewhat higher values ( $15$ - $20 \mu\text{g L}^{-1}$ ) near the bottom in August. The surface total phosphorus and total nitrogen values in July and August were  $20$ - $28 \mu\text{g L}^{-1}$  and  $250$ - $600 \mu\text{g L}^{-1}$ . The water colour ranged from about  $70 \text{ mg Pt L}^{-1}$  in May to about  $40 \text{ mg Pt L}^{-1}$  in August. Light was always available at the bottom. Despite available light, poor bottom oxygen conditions were revealed by siphon sampling both before and after full development of the watermilfoil biomass. This indicates strong oxygen consumption by plant respiration and microbes involved in plant matter decomposition. In contrast, dissolved oxygen supersaturation ( $120$ - $150 \%$ ) was recorded in the surface layers ( $0$ - $1.5$  m) in August and September. Surface water pH was  $7.5$ - $8$  in May and June, about  $9$  in July, and  $9.5$ - $10.5$  in August and September (Figure 4). There were, however, vertical pH and DO differences despite small vertical temperature gradients (Figure 5).

## Discussion

Conditions in Lake Österträsk have changed markedly during the last decades. The water level was lowered several times between 1930 and 1970 (Storberg 1980). There was a decline

of the reed belts which can be judged by old photographs. Cedercreutz (1934, 1947) reported 11 species of aquatic plants but no *Myriophyllum* species in the early 20<sup>th</sup> century. *Nitella flexilis* (L.) C.A. Agardh was recorded by Cedercreutz (1934), but it was not observed in 2006. No extreme pH, nor oxygen supersaturation or depletion, were reported before the watermilfoil invasion. On 22 August 1962, surface pH was 7.5 and dissolved oxygen at 3 m exceeded 90 % saturation (Sundblom and Moliis 1962). Carlsson (2001) recorded pH 8.3 in July 1994. On 13 July 1999, when *M. sibiricum* was present, pH reached 9.1 (Lindholm and Hägg 2001). Due to the massive growth of watermilfoil (and thus increased decaying plant material) most sandy bottom areas have become muddy and oxygen deprived.

The study did not provide any simple solution to lake restoration. The watermilfoil biomass of Lake Österträsk is large. The plants are tall and flexible and difficult to harvest. Due to extensive branching, extensive fragmentation, as well as turion formation from each branch tip, there would certainly always be a rich inoculum of *M. sibiricum* left after removal efforts.

Watermilfoil invasion is a new environmental problem in Åland. To our knowledge, *Myriophyllum sibiricum* now occurs in three Åland lakes. The source of *M. sibiricum* in the lakes is unknown, but it occurs sporadically in brackish water archipelago of SW Finland. Certainly, many potential invasion routes exist. It seems that, once established in a lake, *M. sibiricum* creates conditions favourable for itself while suppressing other macrophyte species.

## Acknowledgements

This study was supported by the parish of Saltvik, Societas pro Fauna et Flora Fennica, and Maa- ja Vesitekniikan Tuki ry. We also want to thank Berit and Roine Johansson, and Husö Biological Station (Åbo Akademi University).

## References

- Carlsson (2001) Freshwater snail communities and lake classification. An example from the Åland Islands, southwestern Finland. *Limnologica* 31: 129-138
- Carignan R, Kalff J (1982) Phosphorus release by submerged macrophytes: the significance to epiphyton and phytoplankton. *Limnology and Oceanography* 27: 419-427, <http://dx.doi.org/10.4319/lo.1982.27.3.0419>
- Cedercreutz C (1934) Die Algenflora und Algenvegetation auf Åland. *Acta Botanica Fennica* 15: 1-120
- Cedercreutz C (1947) Die Gefäßpflanzenvegetation der Seen auf Åland. *Acta Botanica Fennica* 38: 1-77
- Lindholm T (1978) Bioassay and in situ studies on productivity in a coastal meromictic lake. *Verhandlungen der Internationalen Vereinigung für Theoretische und Angewandte Limnologie* 20: 891-894
- Lindholm T (1991) Från havsvik till insjö. Miljöförlaget, Helsingfors
- Lindholm T, Fröjdö EM (1996) Vertical gradients of a reed belt environment studied by close-interval sampling. *Archiv für Hydrobiologie* 137: 177-186
- Lindholm T, Hägg Å (2001) Saltviks insjöar. Vatten- och miljönämnden, Saltviks kommun
- Smith CS, Adams MS (1986) Phosphorus transfer from sediments by *Myriophyllum spicatum*. *Limnology and Oceanography* 31: 1312-1321, <http://dx.doi.org/10.4319/lo.1986.31.6.1312>
- Storberg KE (1980) Förekomst och fångst av flodkräfta på Åland åren 1976-1978. *Meddelanden från Husö biologiska station* 22: 33-104
- Sundblom NO, Moliis B (1962) Fortsatta limnologiska undersökningar av åländska insjöar. *Meddelanden från Husö biologiska station* 4: 1-27
- Wetzel RG (2001) *Limnology. Lake and River Ecosystems*. Elsevier Academic Press, San Diego