6 Hydromorphological pressures in lakes

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6.1 Introduction

Hydromorphological pressures in lakes are related to the human need to control the water levels of lakes for various reasons such as production of hydropower, flood prevention, recreation, navigation, and supply of water for agricultural or human consumption. Regulation practices vary and depend on the objectives of regulation. In a typical hydropower regulation project in the northern hemisphere, water level during the summer period is increased, relative to the unregulated regime, and during the winter period, when the demand for and the price of electricity is highest, the water level is strongly lowered. Flood prevention regulation follows a similar pattern during the winter, but in summer some storage capacity is left to allow for flash flood events. When the major objective of the regulation is recreation or navigation, then regulated water levels are often more stable than natural ones. If the water level is regulated for water supply use, the water level fluctuation is more irregular and depends on the specific use of raw water.

Although hydromorphological pressures are specific to particular water bodies and their regulation regime, some generalizations can be made. Hydropower effects are typical in northern and high altitude lakes, which usually are not impacted by other pressures, whereas pressures due to regulation for navigation and recreation purposes often affect lowland lakes situated in or near densely populated areas. Morphological alterations such as dams and weirs affect mostly continuity of rivers situated downstream from the lake. On the other hand, flood protection constructions and drainage of flood plains have created embankments, which can significantly change the morphology of lowland lakes. Generally, large scale morphological alterations are more common in smaller lakes that are surrounded by agricultural and urban areas.

Hydromorphological alterations mostly affect the uppermost littoral zone, which is characterized by the presence of aquatic macrophytes, although changes in retention time can also indirectly change the trophic status of whole lake and pelagial communities too. This review focuses on the relationship between macrophytes and hydromorphological pressures, which is the most commonly known and investigated.

The Water Framework Directive (WFD) refers to the hydromorphological quality elements of lakes as hydrological regime and morphological conditions. Hydrological regime is defined as the quantity and dynamics of flow, level, residence time, and the resultant connection to groundwater. Morphological conditions are defined as lake depth variation, quantity and structure of the substrate, and both the structure and condition of the lake shore zone. Hydromorphological quality elements are only used specifically to define high status in lakes, where these elements should indicate totally, or nearly totally, undisturbed conditions. For good and moderate status levels, hydromorphological elements must only be consistent with the achievement of the values specified for the biological quality elements. Divisions between hydrological regime and morphological conditions are difficult to make, as these are often interdependent. For example, level (defined as hydrological) and depth variation (defined as morphological) are highly related. Therefore hydrological and morphological elements are treated as one in this review.

6.2 Macrophytes

Macrophytes are one of the key indicators of hydromorphological changes in lakes. Because macrophytes grow in the littoral zone they are sensitive for changes in water level fluctuation regime. A general zonation of macrophytes can be based on life-form distribution; helophytes grow in the uppermost zone and isoetids, elodeids and charids occupy deeper areas of lakes. Even small changes in the dynamics of water level fluctuation can affect the distribution and the elevation of zones. Morphological changes of the littoral zone, caused for example by dredging or embankments, significantly disturb the development of vegetation.

Annex V of the WFD outlines three macrophyte-related quality elements that need consideration in assessing the ecological status of lakes. These are (i) taxonomic composition, (ii) average macrophyte abundance, and (iii) an ecological assessment which is specific to lake type. This third requirement, for which reference communities (communities found in non impacted conditions) need to be identified, also allows for the use of different indices and pressure sensitive species in different lake types.

Taxonomic composition

In general, taxonomic composition of macrophytes is not a sensitive indicator to describe the changes in hydromorphology of lakes. However, in many studies it has been shown that macrophyte diversity is lower in lakes with fluctuating water level in North Europe (Rørslett, 1991; Hellsten, 2001) and in Canada (Hill *et al.,* 1998). However, the relationship between water level fluctuation and macrophyte diversity is not simple. An extensive literature survey of Scandinavian lakes showed that general macrophyte richness correlated mainly with draw-down of water level, but a regulation amplitude of between 1 and 3 meters supported the highest biological diversity (Rørslett, 1991). A slight increase in disturbance could even create suitable habitats for European aquatic macrophytes as noted by Murphy *et al.* (1990). A similar phenomenon was found in lakes regulated for hydropower in New Zealand, where an increase in the range of monthly water level fluctuation appears to have increased biodiversity (Riis and Hawes, 2002).

Depth variations are usually related to an artificial increase or decrease of water level. Water levels are increased to extend storage capacity of reservoirs or regulated lakes. A sudden increase of water level will initiate erosion processes, which lower biodiversity (Nilsson, 1981; Hellsten *et al.*, 1996). It should be noted that taxonomic composition is a poor indicator of water level increase, because most of the species are still present after water level increase, although abundance may differ significantly (Nilsson and Keddy, 1988; Hellsten *et al.*, 1996). Effects of raised water level also depend on ageing; after inundation shock of Swedish reservoirs species diversity was highest 30-40 years subsequent to the initiation of the regulation (Nilsson *et al.*, 1997). In most cases diversity is slightly increased after inundation due to stabilization of the shoreline.

In general, lowering of water level will lead to increased diversity, as found in several studies (Lohammar, 1949; Toivonen and Nybom, 1989; Rørslett, 1991). The main reason for increased diversity is that a newly exposed littoral zone or increased shallowness allows the sublittoral zone to cover the entire water body. Extensive lowering, which affects resuspension in the water body by allowing waves and currents to reach bottom sediments, can drastically change lake flora, as shown in several studies in the Netherlands (Scheffer, 1998). Several shallow lake studies have demonstrated a sensitive balance between different species groups (Best, 1987; Van den Berg *et al.*, 1998).

Abundance

Several studies indicate that abundance is a much more sensitive indicator for hydrological change than species composition (Nilsson and Keddy, 1988; Coops and van der Velde, 1999; Hellsten *et al.,* 1996; Hellsten, 2001). Generally, water level fluctuation affects zonation patterns, which are a function of the relative abundances of different species with different degrees of adaptation to stress caused by depth and drying (Pearsall, 1920). Therefore, changes in the amount of water level fluctuation are reflected by changes in the distribution of species (Toivonen and Lappalainen, 1980).

In addition to the range of water level fluctuation, the dynamics of the fluctuation significantly affects the abundance of macrophytes. For example, the timing and range of the spring flood clearly affects the zonation of sedge species in northern areas (Walker and Wehrhahn, 1970; Sjöberg and Danell, 1983; Hellsten, 2001). The observed increase of common reed (*Phragmites australis*) abundance in Scandinavia may be related to lowered early spring water level (Rintanen, 1996; Partanen and Hellsten, 2005). Reeds also benefit from stabilized water levels and growth periods (Coops and van der Velde, 1995; 1999). A general decline of reed beds in Mid-Europe seems, however, to be related to changes in sediment due to eutrophication (Weisner, 1991; Clevering, 1999).

Lowering of the water level while a lake is ice-covered will have significant effects, especially on large sized isoetids such as *Isoetes lacustris* and *Lobelia dortmanna*. Areas where their decline has been reported include northern Scandinavia (Quennerstedt, 1958; Rørslett, 1984; Rintanen, 1996; Hellsten, 2001) and Scotland (Smith *et al.,* 1987; Murphy *et al.,* 1990). Additional to the effect of freezing, changes in sediment quality will also significantly affect their distribution (Murphy, 2002).

Classification schemes

Very recently, as a direct response to the WFD, and because of the prior lack of suitable classification schemes, a survey methodology called the Lake Habitat Survey (LHS) was developed in the UK that directly assesses the hydromorphological elements specified in the WFD. The method is based on the EMAP guideline and its field survey method (FOML) developed in the USA. In the LHS scheme, information on physical habitat (including substrate and riparian vegetation type, but not species composition) is recorded at sampling plots around the shore, and pressures such as angling, erosion and grazing are recorded over the entire lake. Data on hydrological regime are also obtained whenever possible. Apart from the final report (Rowan *et al.,* 2004), there are no published reviews of this methodology, however this scheme has the support of the UK authorities responsible for implementing the WFD and it is intended that it will be adopted throughout the UK (J. Rowan, *pers. comm.*). It may also prove to be of use across the rest of Europe, although the relationship between the LHS score and biological status of lake is not very clear.

Apart from this new development, there are few classification schemes related to relationships between hydro-morphological factors and macrophytes. The direct response of *Isoetes lacustris* to ice penetration enables its distribution to be used for classification purposes (Rørslett, 1989; Rørslett and Johansen, 1996; Hellsten, 2001). The deepest growing areas of *I. lacustris* are also sharply limited by lack of light and therefore their growing niche is easy to predict (Rørslett, 1988). The distribution of other large isoetids such as *Isoetes echinospora*, *Lobelia dortmanna* and *Littorella uniflora* can also be used for classification purposes, because they are all responsive to ice erosion and changes in sediment structure (Rørslett, 1989; Murphy, 2002).

A classification based on strategy analysis and the division of species into stress-tolerating, ruderal and competitive categories has been effective in classifying regulated lakes in Norway (Rørslett, 1989) and in other areas (Murphy *et al.,* 1990). Ruderal species, with high resistance to disturbance, were typical in shallow water communities of regulated lakes, whereas stress-tolerating species prevailed in deeper areas.

The effects of depth changes have been generally estimated using simple calculation procedures to describe the available growth area for macrophytes. Known relationships between the deepest growth limits of bottom-rooted helophytes have produced a large number of different applications for Finnish lakes (Hellsten, 2001). Hudon (1997) developed similar relationships between average water level scenarios and areas dominated by different vegetation types in floodplain lakes of the St Lawrence River. The vegetated area of the littoral zone has also been used as an index to describe the trophic status of lakes (Leka *et al.,* 2003).

Models

The relationship between hydromorphological factors and species is usually modelled through case-dependent correlation models. For example, the effects of water level fluctuation depend essentially on the use of the lake and climate conditions. Rørslett (1989) showed in his review an analysis of 17 Norwegian regulated lakes in which the species richness (S) followed the equation:

$$S = 16.4 - 1.34\ \Delta W - 0.013\ H + 0.085\ A,$$

where ΔW = mean annual range of water level (m), H = lake altitude (m a.s.l.) and A = lake area (km^2).

Further in his analysis of 641 lakes from Norway, Sweden, Denmark and Finland, he found that lake area was the best predictor of species diversity (Rørslett, 1991). A stepwise prediction model also included hydromorphology related variables such as water level range and lake lowering with water conductivity and lake elevation values. A predictive model based on discriminant analysis and vegetation types with environmental background information was developed by Hellsten (2001). Variables in the stepwise selection were water level duration of summer, duration of frozen and non-frozen ice pressure zone, bottom substrate and relative erosion rate. The model produced good results in regulated Lake Ontojärvi, where eight types out of twelve were classified correctly. In non-regulated Lake Lentua the results were even better, where ten out of fourteen vegetation types were classified correctly. In this model, variables were more complicated and more clearly linked to increasing depth.

Heegaard *et al.* (2001) also found relatively promising results by using generalised additive model (GAM) techniques in lakes in Northern Ireland. Although the models were used in evaluating the effects of water chemistry on aquatic macrophytes, these predictive models could also be used in lakes where the water level is fluctuating.

6.3 Summary

The littoral zone is a highly varying environment and therefore the relationships between hydromorphological factors and aquatic macrophytes are often site-specific. However, the relationship between lowering of ice levels and the destruction of large isoetids is relatively clear and easy to predict in regulated hydroelectric lakes. Water level fluctuation range during the summer defines the extension of the helophyte zone which can be used as a major determinant of change.

Some of the WFD variables, such as species richness, depend on both water quality and sediment properties, therefore in nutrient-rich waters it is very difficult to find relationships between macrophytes and hydromorphological factors. Nutrient enrichment can also compensate for degradation caused by fluctuating water level. In general, the relationship between hydromorphological change and aquatic macrophytes is clearer in oligotrophic than eutrophic lowland lakes.

6.4 References

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