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Protection and support of littoral macrophyte stands by breakwaters on differently exposed shores of the Lipno reservoir

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Abstract

In reservoirs with wide water level fluctuation, littoral macrophyte stands are often absent on the erosion exposed shores. The poorly developed aquatic ecosystem of these sites/habitats indicates a low ecological potential in the sense of the EU Water Framework Directive. The aim of this study was to (1) describe the littoral macrophyte vegetation and their habitats on differently erosion-exposed shores of the Lipno reservoir, (2) assess factors that impair the vegetation development, and (3) verify the positive effect of simple wooden breakwaters on this vegetation. Three breakwaters were installed in the eulittoral zone in localities with homogeneous morphology but different fetch length and light conditions. Changes in littoral macrophyte vegetation under breakwater treatment were evaluated in 2006–2011. Species composition, distribution, and cover, as well as water level fluctuations and sediment structure were assessed at the breakwater and control sites. The results showed that simple breakwaters can be effective only if basic requirements for the growth of littoral macrophytes are met, i.e., the presence of nutrients in the substrate and sufficient light without shading by trees. This type of breakwaters was ineffective in heavily erosion-exposed areas with largely degraded substrate. At such sites, it is necessary to consider whether feasible would not be protection by more sophisticated breakwaters preventing losses of fine particles from the substrate, combined with addition of nutrient-rich substrate and planted macrophytes.

Key words: breakwater structure, shoreline erosion, littoral vegetation, water level fluctuation, wave activity

Introduction

The presence of well-developed littoral vegetation influences positively the aquatic ecosystem and water quality (Carpenter & Londge 1986, Just et al. 2003, Moss 2008). Macrophytes as primary producers supply food to the first consumers in trophic chains (Gross et al. 2001), provide habitats and refuges for periphyton, zooplankton, other invertebrate species, and vertebrates, such as fish (Balon 1975, Aarts & Nienhuis 2003) and frogs (Strayer & Findlay 2010, Bornette & Puijalon 2011). They play an important role in biochemical cycles, e.g., by storing nutrients in their biomass and influencing food webs of aquatic ecosystems (Jeppesen et al. 1997). The importance of littoral macrophytes in the aquatic ecosystem is also reflected by the requirement of the EU Water Framework Directive (Directive 2000/60/EC) for their presence at all suitable sites in the littoral of lakes and reservoirs so that their ecological status or potential can be positively evaluated.

Man-made lakes are used for different purposes, such as hydroelectricity, water storage, flow augmentation, irrigation, flood protection, fish production and recreation. Many of these uses may generate water level fluctuations, shift the transition zone between land and water, and accelerate erosive processes along the shoreline. Erosion-exposed areas of water bodies have usually steeply sloping shores with a large fetch length (Moss 2008, Krolová et al. 2012). At these sites, the growth of littoral macrophytes and vegetation development are prevented by unfavourable conditions induced by wave action (Weisner 1987, Weisner et al. 1997), frost and ice phenomena (Nilsson 1981, Björk 1994), bottom degradation (Madsen et al. 1996, 2006, Nordstrom & Jackson 2012) sediment re-suspension or reduced water transparency (Kalff 2002).

To mitigate erosive processes along the shoreline, anti-erosion barriers (breakwaters) from wooden structures, large stones (McComas 2003) or planted trees (Šlezingr 2007, Míča & Šlezingr 2008) have been used. These measures have usually little supporting effect on littoral macrophyte vegetation even if erosion has been diminished. The reason is persisting poor nutrition of the plants due to the degraded substrate at the erosion-damaged shores. For restoration of macrophyte stands at such sites, transplanting of native macrophytes together with addition of natural sediment (Hermann et al. 1993, Jansen 1993, Ostendorp et al. 1995) or a nutrient-rich substrate (Iseli 1993, Zhen 2002) was often needed after the shores had been protected against erosion.

The aim of this study was (a) to investigate factors controlling littoral vegetation development on erosion-exposed sites on the shore of a reservoir with fluctuating water level, (b) to test if simple woody breakwaters can be effective in protection of the shore against erosion, and (c) under which conditions these breakwaters can support littoral macrophyte vegetation development. In erosion-exposed areas of water bodies, the breakwaters were supposed to reduce wave activity and consequently support the growth and reproduction of macrophytes.

Methods

Study area

The Lipno reservoir (Fig. 1) is a large dam impoundment situated in the upper reaches of the Vltava River in the foothills of the Bohemian Forest (= Šumava Mts.) (coordinates of dam: 48°38'00"N, 14°14'15"E; surface area: 48 km^2; volume: 306 mil. m^3; mean water residence time: 0.6 year; elevation of maximum water level: 725.6 m a.s.l.). The reservoir was built as the uppermost part of the Vltava cascade of hydropower reservoirs and was first filled in 1960. The major purposes of the reservoir include hydroelectricity generation, flow maintenance, and flood control, but the reservoir is also largely used for recreation and angling. The reservoir is operated within an annual cycle of filling and emptying. The maximum reservoir pool is in the spring; during the winter period the water level of the pool is intentionally lowered to increase the flood control capacity before the snow melt; in the summer and autumn months, the water level depends on flow conditions: the water level is almost stable in years of high flow conditions but large drops in water level (up to >3 m) are common in years of subnormal flow (Fig. 2).

In the Lipno reservoir, littoral macrophytes occur only in the eulittoral which is delimited by the range of water level fluctuations and has a characteristic macrophyte vegetation zonation. The shore protected against erosion can be divided into three zones: (i) upper eulittoral in the range of 724.3–725.6 m (flooded during <20% of time during 2005–2011) that hosts a dense hydrophilous vegetation of grasses and sedges; (ii) middle eulittoral in the range of 723.9–724.3 m (flooded 25–50% of time), with a low-density cover of a community

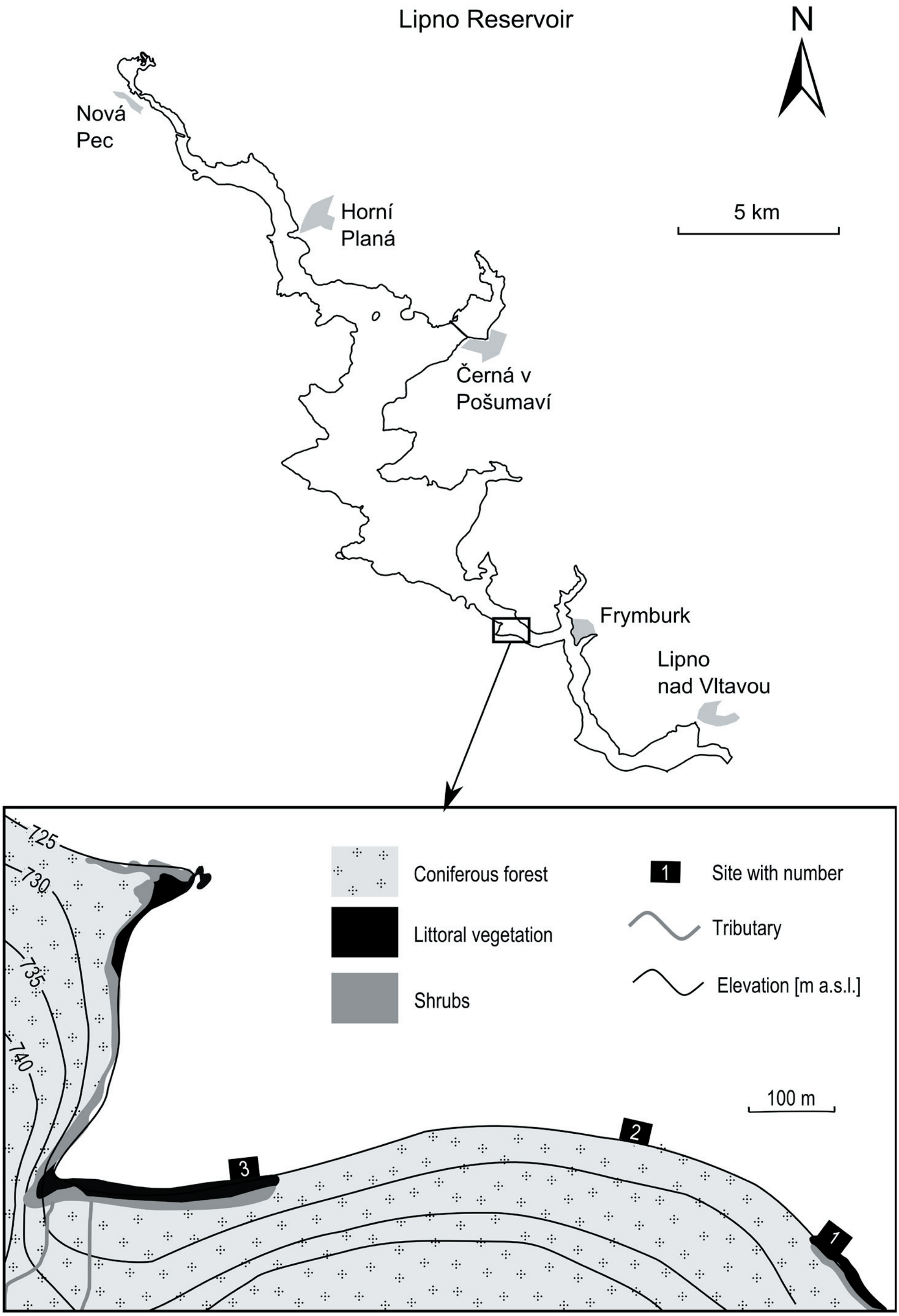

Fig. 1. Situation drawings of the Lipno reservoir and the study sites.

Table 1. Morphology characteristics of the study sites: geographic coordinates (WGS84; N, latitude; E, longitude), elevation (m a.s.l.), fetch length of wind action, height of erosion step (HES), shore slope, areas of breakwater protected, and control areas.

Site	Coordinates		Elevation (m)		Fetch length (km)	HES (cm)	Slope (°)	Breakwater area (m²)	Control area (m²)
	N	E	min	max					
1	48°39'27"	14°08'37"	724.2	724.5	2.5	10	4.4	54	50
2	48°39'31"	14°08'26"	723.9	724.4	8.5	30	5.7	53	69
3	48°39'29"	14°08'04"	723.6	724.0	1.0	5	4.6	57	54

of perennial and annual emerged species, amphibious species and bare bottom species; (iii) lower eulittoral in the range of 723.5–723.9 m (flooded 50–75% of time), with sporadic occurrence of bare bottom macrophyte species (Krolová et al. 2013). This zonation of macrophytes exists also on the erosion-exposed shores, but there the dense vegetation of the upper eulittoral recedes to the uppermost margin of the reservoir (725.6 m) and the communities of the middle and lower eulittoral zones are much rarer, species-poorer and covering smaller areas (Krolová et al. 2012, 2013).

Breakwaters

During 2006–2011, breakwaters were installed along the erosion-exposed shore of the Lipno reservoir nearby the Frýdava village in three locations with similar morphology but largely differing in fetch length and, hence, differently exposed to erosion and with different conditions for littoral vegetation development (Fig. 1, Table 1). The breakwaters were installed within the eulittoral but at different elevations according to the expected highest potential for protection and support of littoral vegetation (elevations at Sites 1, 2, and 3 corresponded to the upper, middle, and lower-to-middle eulittoral, respectively; cf. Table 1). The construction of the breakwaters consisted of wooden poles (diameter 10 cm, length 150 cm) that were closely spaced (distances 10 cm) and fixed to the bottom. The final length (ca. 15 m) and shape of each breakwater was inferred from the site-specific activity of waves. The construction of the breakwater at Site 1 was modified by adding a 30-cm stripe of non-woven geo-textile in October 2009 in order to stop continued losses of fine particles from the substrate. Two monitoring areas were located and marked with fixed points on either site – a breakwater protected area behind the breakwater and a control area of a similar size and vegetation cover next to each breakwater protected area.

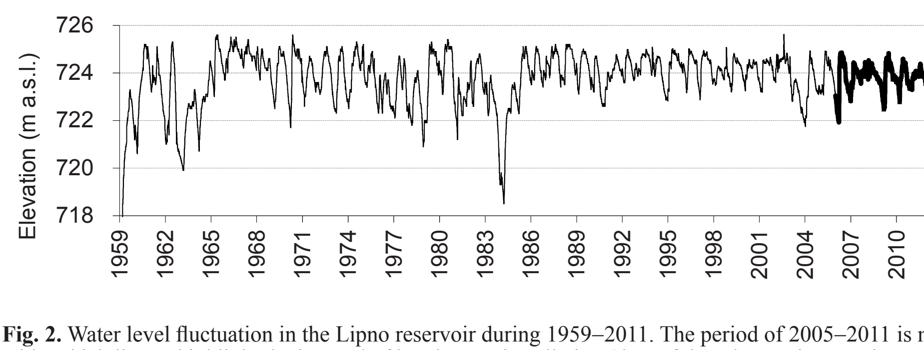

Fig. 2. Water level fluctuation in the Lipno reservoir during 1959–2011. The period of 2005–2011 is marked with a thick line to highlight the interval of breakwater installation (data of the Vltava River Basin Authority, State Enterprise).

Characteristics of the littoral vegetation

Littoral macrophyte vegetation was examined in the autumn at the beginning and the end of the study period 2006–2011. Species composition, plant cover of individual species and total vegetation cover were quantified within each monitoring area and, in addition, qualitative descriptions were made of the vegetation both above and below the breakwater area. The plant cover of individual species was determined using the Braun-Blanquet combined abundance-dominance scales (Dierschke 1994), with its category 2 being split into subcategories 2a and 2b. The final scale is: r (rare), + (cover negligible), 1 (<5%), 2a (5–15%), 2b (15–25%), 3 (25–50%), 4 (50–75%), 5 (75–100%). Names of vascular plants were unified according to Kubát et al. (2002).

Substrate structure

Five samples of substrate (0.5 l) were taken from the surface (0 to 10 cm) layer of the bottom in each breakwater-protected and control area. Sampling and samples analysis were performed in 2006 and 2011. Substrate particle size, determined by dry sieve and wet sedimentation methods (Brady & Weil 2002), was divided into three categories: gravel (>2 mm; dry sieve); sand (0.06–2 mm; sedimentation); silt and clay (<0.06 mm; sedimentation).

Statistical analysis

Changes in selected characteristics (substrate particle size distribution, vegetation cover values in 1-m^2 squares of the monitoring areas, flooding regime) of the breakwater-protected and control areas on each site between 2006 (before the installation of breakwaters) and 2011 (shore protected by breakwaters for five years) were tested by repeated measures ANOVA. The data on the substrate particle size distribution and vegetation cover were logarithmically transformed to ensure normality. The analyses were performed in STATISTICA 10.0 (StatSoft, Inc., USA).

Results

Effects of breakwaters on littoral vegetation

In general, littoral macrophyte vegetation of the studied sites consisted of six species. Quantitative changes in the vegetation characteristics prior (autumn 2006) and after (autumn 2011) installation of the breakwaters are shown in Table 2 and Fig. 3.

Site 1

In 2006 (prior to the installation of the breakwater), a dense cover of *Phalaris arundinacea* and *Carex acuta* with *Salix* spp. bushes consisting of young individuals only was present above the level of 724.7 m. In the upper eulittoral zone, where the breakwater and control monitoring areas were located, we observed markedly eroded substrate and a low-cover macrophyte vegetation of clusters of *Phalaris arundinacea* and solitary seedlings of *Salix* spp. and *Taraxacum* spp. (Table 2, Fig. 3). A zone with a sparse cover of *Eleocharis acicularis* was present below the breakwater in the middle eulittoral.

In 2011, we observed a significant ($F = 4.3$, $df = 1$, $p = 0.045$) increase in total area of vegetation in the breakwater-protected area, mainly caused by an expansion of *Phalaris arundinacea* (Table 2, Fig. 3). We also recorded an increase in the number of species, with two new low-cover species, namely *Carex acuta* and *Equisetum fluviatile.* The zone of *Eleocharis acicularis* below the breakwater was not recorded.

Table 2. Macrophytes at localities of breakwaters and control areas between 2006 and 2011. Legend: B – breakwater protected area; C – control area; Group – functional group according to habitat preference (T – hydrophilous terrestrial, E – emergent, A – amphibious, Sh – shrub).

		Site 1				Site 2				Site 3			
		B		C		B		C		B		C	
Year		2006	2011	2006	2011	2006	2011	2006	2011	2006	2011	2006	2011
Total area of littoral vegetation (m^2)		16	23	4	2	0.5	0.02	0.5	0.02	57	57	54	54
Area of emergent species (m^2)		16	23	4	0.2	0.5	0.02	0.5	0.02	7	19	11	26
Total cover of littoral vegetation (%)		35	60	30	30	3	5	3	1	45	60	45	55
Cover of emergent species (%)		25	50	30	30	3	3	3	1	30	40	35	35
Number of species		3	5	2	3	1	2	1	1	3	3	2	2
Species	**Group**	**Cover of species by Braun-Blanquet scale**											
Carex acuta L.	E	–	1	–	1	–	–	–	–	1	–	2a	–
Eleocharis acicularis (L.) R. et Sch.	A	–	–	–	–	–	1	–	–	2b	2b	2a	2a
Equisetum fluviatile L.	E	–	+	–	–	–	–	–	–	–	–	–	–
Phalaris arundinacea (L.) Roth.	E	2a	2b	2a	2a	1	1	1	1	2b	3	2b	3
Salix spp.	Sh	+	+	+	+	–	–	–	–	–	–	–	–
Taraxacum spp.	T	1	1	–	–	–	–	–	–	–	–	–	–

The character of the littoral vegetation, their areas and cover were not significantly changed in the control area in 2011. Similar to the breakwater-protected area, the species number increased when a small plant stand of *Carex acuta* appeared in 2011 (Fig. 3).

Site 2

The littoral macrophyte vegetation was sparse at this site both in the middle eulittoral, where the breakwater-protected and control areas were situated, and also in the upper eulittoral, apparently in connection with the shading by a ca. 20 m high forest stand on the shore that was composed of *Picea abies*, *Betula pendula*, *Alnus glutinosa*, and *Salix* spp. Trees and shrubs of this forest stand were rooted above the erosion step (724.9−725.20 m), with their branches hanging above the eulittoral zone. In 2006, the characteristics of littoral macrophyte vegetation were the same both in the breakwater-protected and the control area (Table 2, Fig. 3).

In 2011, we observed only tiny and insignificant changes in the total areas and cover densities of littoral macrophyte vegetation or emerged species both in the breakwater-protected and control areas. An increase of species number occurred in the breakwater-protected area where *Eleocharis acicularis* established a narrow (ca. 10 cm wide) and thin strip across the study area parallel with the contour of 724.3 m (Table 2, Fig. 3).

Site 3

In 2006, the macrophyte vegetation in the breakwater protected and control areas (that were situated in the middle and lower eulittoral at this site) consisted of clusters of *Phalaris arundinacea* at their upper margin and *Eleocharis acicularis* at lower elevations (Table 2, Fig. 3). The upper eulittoral above the study areas was overgrown by a dense community of dominant *Phalaris arundinacea* and *Carex acuta,* with bushes of *Salix* spp. above the elevation of 724.2 m.

In 2011, the character of the littoral macrophyte vegetation changed markedly both in the breakwater-protected and control areas. The cover of emergent macrophyte species represented by *Phalaris arundinacea* significantly increased ($F = 12.36$, $df = 1$, $p = 0.0016$; Fig. 3) in contrary to that of *Eleocharis acicularis* (amphibious species) that did not change. Interestingly, the species number decreased as *Carex acuta* disappeared from both study areas.

Flooding and water level fluctuation

The flooding regime at the three sites was different ($F = 173$, $df = 6$, $p < 0.0001$) as a result of their location at different elevations (Table 1, Fig. 4). From comparing the hydrological regime of the study sites, it is evident that flooding periods prolonged from Site 1 to Site 3. All three sites were flooded at least each spring-time.

Character of substrate

The results of the particle size analysis of substrate samples from the study sites are presented in Fig. 5. The substrate at Sites 1 and 2 was heavily degraded as indicated by the almost missing silt and clay fraction (<0.06 mm) and the predominance of the gravel and sand fractions. The sand fraction was largest also at Site 3 but the substrate here contained also ca. 15% of the silt and clay fractions. The sand fraction (0.06–2 mm) was accumulated ($F = 12.308$, $df = 1$, $p = 0.004$) also at Site 1 protected by the breakwater during the observation. No significant changes in substrate structure occurred when the locality was protected by the breakwater.

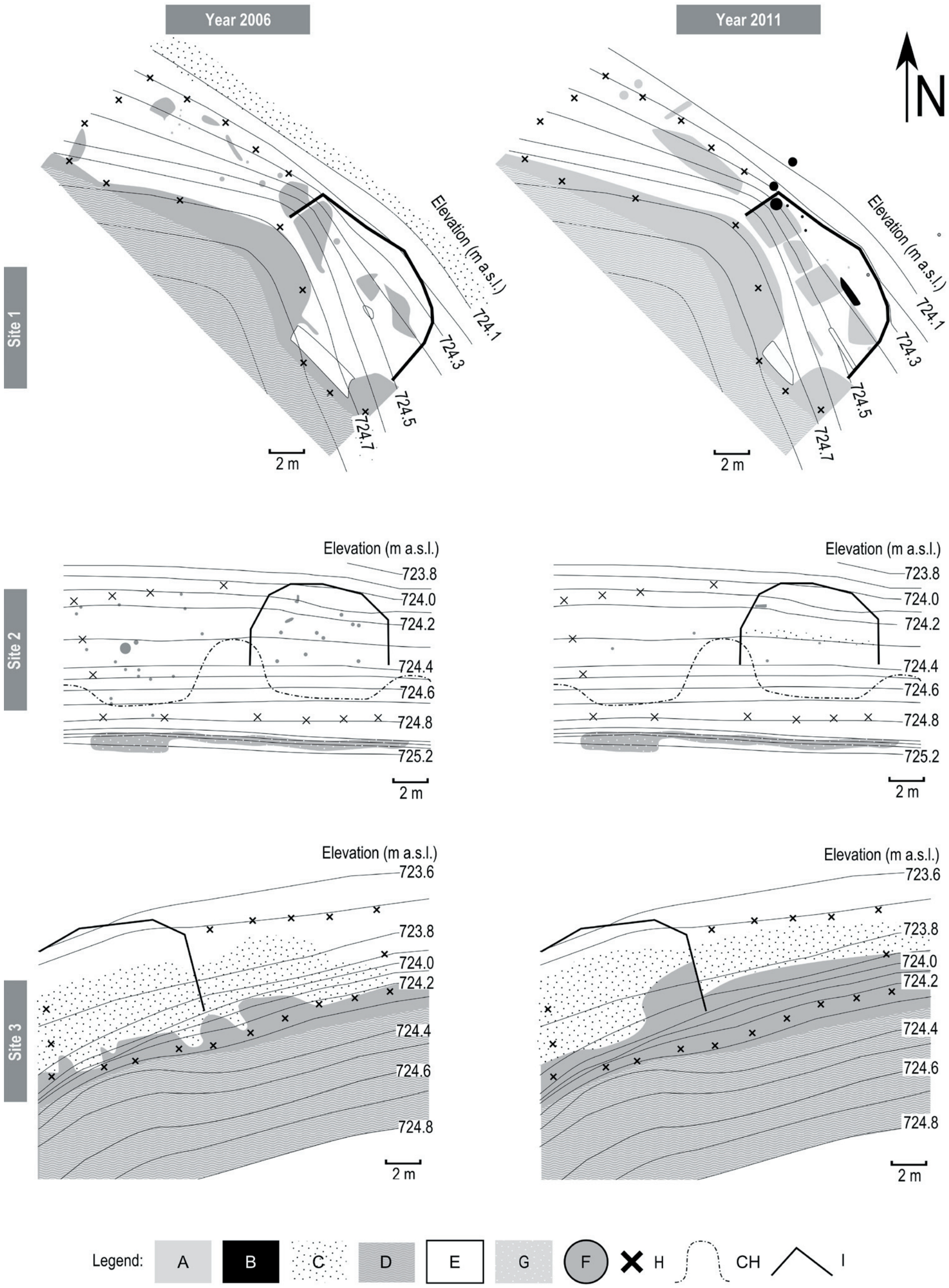

Fig. 3. Maps of littoral vegetation at the study sites in 2006 and 2011. Legend: A – *Phalaris arundinacea*, B – *Carex acuta*, C – *Eleocharis acicularis*, D – *Phalaris arundinacea*, *Carex acuta* and *Salix* spp., E – *Taraxacum* spp., F – *Equisetum fluviatile*, G – *Phalaris arundinacea* and terrestrial species, H – location points of monitored areas, CH – shading of locality, I – breakwaters.

Ice phenomena participated in erosive degradation of the substrate as much as wave action. An example of such an event was observed in the lower zone at Site 1 in the spring of 2009 (Fig. 6). The preceding winter period was relatively dry and cold, with a 2-month period of continuous frosts (from the end of December till the beginning of March). The water level in the reservoir was gradually lowered (by ca. 2 m) until the snow and ice melt in early April. The soil that had frozen during the drawdown became unstable in the melt period and an erosion furrow approximately 1.5–2 m wide, 30 cm deep and at least 1 km long was formed along the shoreline.

Discussion

Littoral vegetation at the study sites

The development of macrophytes at the study sites corresponded mainly to the gradient of erosion incidence that was largest at Site 2, intermediate at Site 1, and smallest at Site 3,

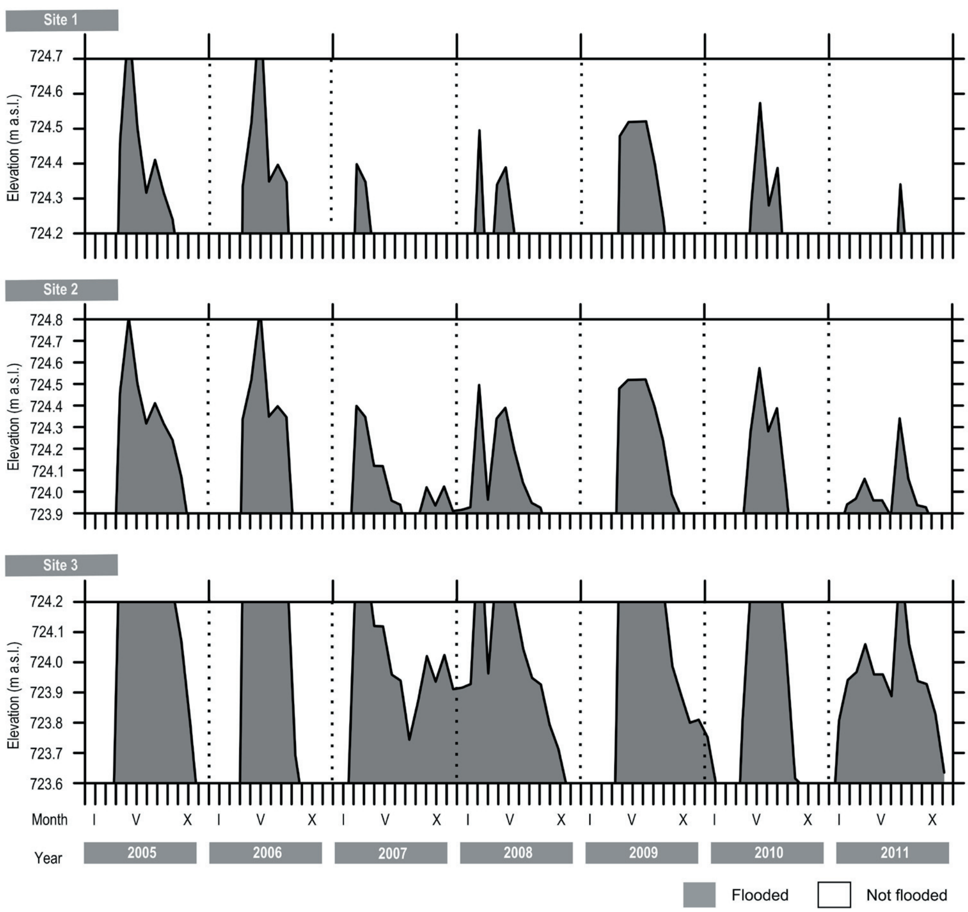

Fig. 4. Water level fluctuations at the study sites during 2005–2011. Daily data of water level in the Lipno reservoir were provided by the Vltava River Basin Authorities, State Enterprise.

being also influenced by shading by trees that was distinct especially at Site 2. These factors were reflected in the zonation of macrophytes formed under the influence of water level fluctuations on the shores of the Lipno reservoir. The typical zonation of macrophytes with three zones in the eulittoral (Krolová et al. 2013) was developed only at the least erosion--exposed Site 3. Strong erosion hindered the growth of littoral vegetation at Sites 1 and 2. At Site 1, the zone with emergent species (*Phalaris arundinacea*, *Carex acuta*) and shrubs

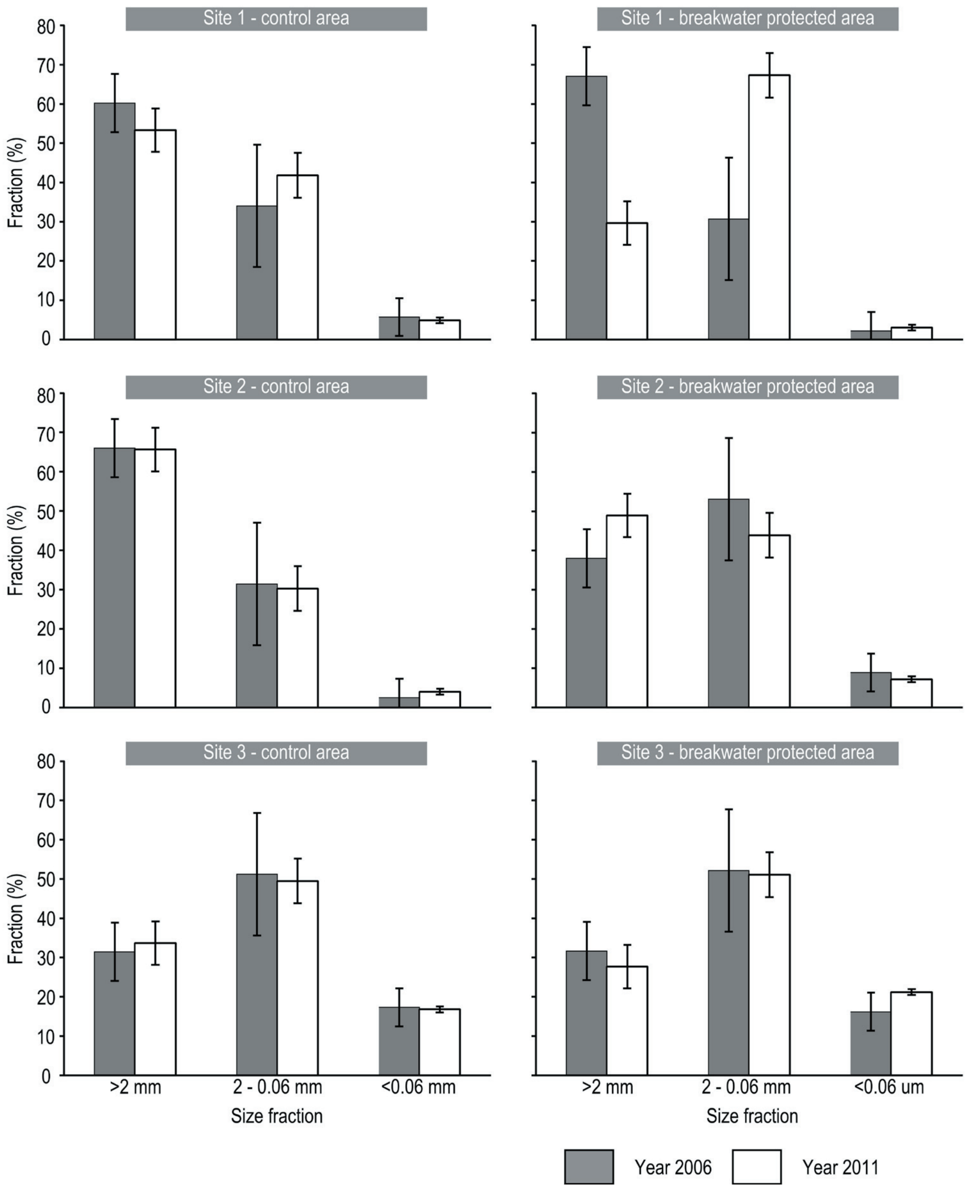

Fig. 5. Comparison of particle size fractions in the substrate at the study sites.

(*Salix* spp.), typical of the upper eulittoral, was shifted by 0.5 m upwards compared to the typical zonation (above the erosion step at elevations of 724.7–724.8 m). Littoral macrophyte vegetation was almost absent at the elevations of the middle and lower eulittoral sub-zones. At Site 2, the erosion step was even higher (at the elevation of 724.9–725.2 m) and littoral vegetation of the upper eulittoral sub-zone was not present, apparently due to shading by trees and shrubs (Fig. 3; Lellák & Kubíček 1992).

The combination of two factors, namely water level fluctuation and wave action, leads to erosion and losses of fine particles from the substrate in the eulittoral and supports the occurrence of macrophytes that are adapted to these conditions (periodical flooding and small nutrient content in the substrate). The emergent *Phalaris arundinacea* was typical of this zone at elevations of ca. 723.8–725.6 m. This species does not spread to lower elevations, apparently because it does not survive long-time flooding (Rice & Pinkerton 1993, Lavergne & Molofsky 2004, Krolová et al. 2013). *P. arundinacea* is also known for its mechanical resistance in habitats that are highly eroded, for example, along river banks where mechanical effects of water flow are high (Grime et al. 1988).

Fig. 6. Bottom damage after ice melt during a drop of water level in the eulittoral zone of the Lipno reservoir near Site 1 in spring 2009.

Another species, widespread at the monitored sites, was *Eleocharis acicularis* that was frequently present down to elevation of ca. 723.4 m on erosion-exposed shores of the Lipno reservoir (Krolová et al. 2010). This species is resistant to water level fluctuations, undiscerning as for the quality of substrate and has a very good regeneration ability after damage (Duras et al. 2007). This species is typical of reservoirs with wide water level fluctuations and was also observed, for example, in the reservoirs Lučina, Žlutice, Klíčava, Karhov (Duras et al. 2007), and Nýrsko (Hejzlar et al. 2005, Štěrba 2006).

Efficiency of breakwaters

The breakwaters efficiency in terms of recovery of degraded substrate and support to macrophyte growth was not high. Some effect could be recognised only at Site 1. Not verified was our assumption that the amendment of a breakwater with a stripe of geo-textile would increase retention of fine particles and thus increase nutrient content in the substrate. The results of substrate analysis showed (Fig. 5) that the content of nutrient-rich silt and clay particles <0.06 mm (Brady & Weil 2002) remained unchanged and the littoral vegetation consisted of species with a small demand for nutrients. We ascribe the recorded significant increase in total vegetation cover mainly to the mechanical protection from the effects of wave action (Bornette & Puijalon 2011) in conjunction with less frequent flooding of the area in recent years (Fig. 4). It can be assumed that if a breakwater was supplemented by nutrient-rich substrate, littoral vegetation would spread more, like in the cases described in other studies (e.g., Iseli 1993, Ostendorp et al. 1995, Zhen 2002).

The low efficiency of the breakwater at Site 2 can be explained mainly by the substrate being heavily degraded due to the strong erosion activity of waves and water level fluctuations (Björk et al. 1972, Coops & Hosper 2002, Vilmundardóttir et al. 2010). The almost entire absence of macrophytes was influenced by both nutrient limitation and shading of the locality by trees. The presence of *Eleocharis acicularis* should be considered most probably as an episodic event. Its low vegetation cover in the line parallel with the contour of 724.5 m suggests that this species may have been brought there from other nearby localities shortly before the survey.

Site 3 was vegetated by littoral macrophytes already at the start of our study, apparently because this shore is relatively well protected against wave action (with a short fetch length; see Table 1 and Fig. 1). Another favourable characteristic of this site with respect to macrophyte growth is its location in a valley where the soil is moistened by seepage of groundwater at many sites. The simple breakwater does not bring much benefit to this area because its macrophytes are not exposed to a strong wave action and their presence is probably predominantly regulated by water level fluctuations with alternating flooding and drying of the site.

Erosion, shading and suitable placement of breakwaters

The recorded results show that the development of littoral vegetation is influenced by a combination of factors and their interactions. It is obvious that erosion is the main factor limiting the development of littoral macrophytes at Sites 1 and 2 because their substrate does not contain fine particles rich in nutrients (Fig. 5) necessary for the development of macrophytes (Madsen et al. 1996, van Geest et al. 2003, Furey et al. 2004). Erosion and degradation of substrate are primarily dependent on the exposure of a locality to wave action (fetch length and wind direction; Vilmundardóttir et al. 2010). For example, the calculated heights of waves at Sites 1, 2 and 3 according to the Czech national standard ČSN 75 0255 (1988) at 20 $m.s^{-1}$ wind speed (such a wind speed occurs once every 10 years according to the 1994–2011 data set from the nearby weather station of the Czech Hydrometeorological Institute at Černá v Pošumaví) are 0.9, 1.5 and 0.8 m, respectively, while they are only 0.4, 0.6 and 0.2 m at 10 m.s^{-1} wind speed (with an average occurrence of 2 days per year), and 0.2, 0.3 and 0.1 m at 5 m.s^{-1} wind speed (on ca. 30 days per year). The differences between the calculated wave heights correspond well with the position of the erosion step at each locality, e.g., the erosion step is by 0.3 m higher at the most erosion-exposed Site 2 than it is at the less exposed Site 1.

Water level fluctuations are another factor important for the erosion of shores (Björk et al. 1972, Coops & Hosper 2002). Shore erosion is a long-term process and results from the entire reservoir history. It is evident from Fig. 2 that, from the 1960s to 1980s, the reservoir was exposed to even wider water level fluctuations than in the past decades and also the seasonal maxima of water level were higher. Hence, the erosion of the shoreline apparently reached higher elevations during that period and the current state of the reservoir shores is the consequence.

The construction of simple breakwaters has no effect on the conditions with a combination of multiple unsuitable factors, e.g., exposure of a locality to a long fetch length together with shading by trees and shrubs (like at Site 2). In such a case, support to the development of littoral vegetation is very difficult to achieve. Conversely, localities that contain eroded substrate but are not highly exposed to erosion, have good light conditions, and also host developed littoral vegetation in the upper eulittoral (like at Site 1) can have a great potential for successful support to littoral macrophyte vegetation by using simple erosion protection measures. However, breakwaters should be always designed to prevent the washing out of fine particles from the substrate, as was our pile breakwater amended with geo-textile (at Site 1).

Correct location of breakwaters at a suitable elevation in relation to the range of water level fluctuations in a reservoir is of a great importance in our opinion. The development of seasonally flooded vegetation in the middle eulittoral is valuable for the aquatic ecosystem (Carpenter & Lodge 1986, Krolová et al. 2013); therefore the protection of and support to macrophytes in this zone should be preferred. This zone is flooded in the Lipno reservoir for 20–50% of the time. The frequent occurrence of the flood line within this zone greatly increases the probability of heavy erosion events due to strong winds that occur with low frequencies but have critical consequences for shore erosion. A breakwater in the middle eulittoral can also protect the upper eulittoral. On the other hand, it would be not very sensible to locate breakwaters in the lower eulittoral, mainly because the growth of macrophytes here does not primarily respond to erosion but to water level fluctuations.

Conclusions

The development of littoral macrophytes on the erosion exposed shores in the Lipno reservoir is limited by the erosive effects of wave action and ice phenomena interacting with water level fluctuation caused by the reservoir management.

Mechanical protection of macrophytes in the eulittoral zone by a simple breakwater can be effective at locations where basic conditions for the development of littoral vegetation are met, such as the presence of a substrate with sufficient nutrient contents, good light conditions without shading (for example by trees and shrubs), and a correct locating of the breakwater within the eulittoral zone (especially in the middle eulittoral that has the greatest functional significance for the aquatic ecosystem).

The use of a simple breakwater in areas highly exposed to wave action with a substrate strongly degraded due to long-lasting erosion and with tree shading is not suitable. In erosion exposed places, it is necessary to consider whether the protection by more advanced breakwaters preventing losses of fine particles from the substrate and addition of nutrient--rich substrate and planting of macrophytes would help, or whether it would be better to leave these exposed areas without littoral vegetation and adopt only mechanical protection of shores.

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