First publ. in: International Journal of Ecohydrology & Hydrobiology 4 (2004), 4, pp. 379-395

Assessment of human pressures and their hydromorphological impacts on lakeshores in Europe

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Abstract

Europe has a large number of lakes, many of them lie in densely settled areas. For instance, Germany has 1073 lakes with a surface area greater than 0.5 km^2, surrounded by lakeshore habitats of appr. 11 000 km. The lakeshore habitats are of outstanding significance for biodiversity, ecosystem function as well as a variety of human uses.

In this paper we give an operational definition of the lakeshore zone (i.e. the littoral zone, the shoreline and the riparian zone). We list significant human pressures directly on the lakeshores or coming from the catchment, and we describe the most important impacts resulting from such pressures. For illustration, we present some examples (eutrophication, morphological modications, hydrological changes) from Lake Constance. Generally, many of these pressures are related to changes to the hydrological regime of the lake and/or to morphological modifications of the shore zone, but knowledge about the links between pressures and specific impacts is poor.

We briefly discuss four approaches, which have recently been developed to assess the hydromorphological quality of lakeshores. These procedures are designed to fulfil the requirements of the European Water Framework Directive (WFD), as well as the requirements of regional planning and nature conservation.

Key words: European Water Framework Directive, Lakeshore Habitat Survey, ecotone, littoral, riparian zone, human pressures, sustainable use.

1. Introduction

About 0.5 % of the earth's surface is covered with lakes with surface areas range from 0.01 km^2 (by definition) to 374 400 km^2 (Caspian Sea). Three out of the 25 largest lakes in the world lie in Europe. The largest of them is Lake Ladoga at 18 400 km^2. There are estimated to be about 8.5 10^6 lakes in the world (Meybeck 1995), and in Europe more than 5 10^5 natural lakes (Kristiansen, Hansen 1994).

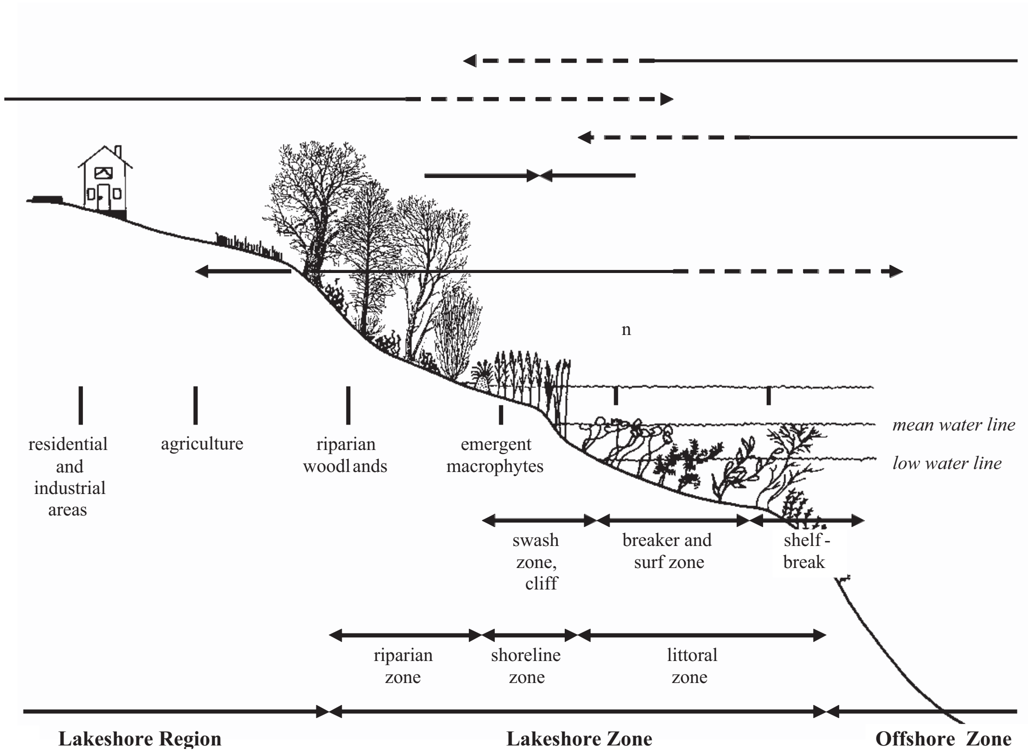

Fig. 1. The lakeshore zone: definitions, zonation of vegetation and wave action, interests and responsibilities

Presently, the total length of the shoreline and the area covered by lakeshore ecotones in Europe are unknown. Estimates can be made by taking the scaling behaviour of the area and perimeter of the lakes into account. It is well known, that the number of lakes inversely scales with lake area (Mandelbrot 1977; Meybeck 1995). Using the database of German lakes (Nixdorf *et al.* 2004) such an analysis, combining the area dependence of shore length and the size distribution, is possible on this regional scale. Using the information available for 1073 lakes with an area greater than 0.5 km^2, including lakes of natural and artificial origin, models for the number of lakes of a certain size class and their shore length suggest that the total shoreline length of lakes in Germany is approximately 11 000 km, with 6000 km for natural lakes larger than 0.5 km^2. These figures underline the outstanding significance of the lakeshore zone as a transitional habitat between land and water.

Natural lakes are not spread evenly over Europe but are concentrated in 'lake landscapes' according to geomorphology and landscape history (Embleton 1984). The majority of lakes are bound to the glacial landscapes of northern Europe and around higher mountain ranges. In central Europe many lakes are situated in densely settled areas with intense agriculture and high industrial production. These have heavy tourist demand for natural-looking sceneries with elevated standards of comfort and leisure facilities. Hence, European lakeshores are not only centres of biodiversity, but they also attract human pressures of several kinds, and they are the focus of diverging stakeholder interests, and powers and responsibilities of authorities, which often interact and compete with each other.

On the 22nd of December, 2000, the "*Directive 2000/60/EC of the European Parliament and of the Council establishing a framework for Community action in the field of water policy*" (WFD) came into force. In contrast to most European directives concerning water pollution control and management, which up until this point have been very limited in scope, this directive takes a wide view of water and water body management. Its objective is to prevent the further deterioration of the condition of water bodies, and that all more or less strongly impaired and disturbed water bodies achieve the "good" status within a certain timeframe. The term 'water body' comprises not only the permanently submerged littoral zone of lakes, but also the temporarily flooded shoreline zone and the wetlands of the emersed riparian zone, which depend on the hydrological regime of the lake. Hence, the WFD provides important momentum for the development of ecologically based lakeshore quality assessment schemes in EU member states and other countries.

Lakeshores are transitional habitats (ecotones), which connect terrestrial with the pelagic habitats of lakes[1] (Naiman *et al.* 1989; Naiman, Decamps 1997). Natural lakeshores[2] differ greatly in their physical appearance, depending on bedrock geology, mode of formation, age, depth, shape and surface area of the lake, significant geomorphological forces like slope processes, delta sedimentation, wave action and currents, prevailing type of sediment input and budget, vegetation, and water level changes in the lake.

In the lakeshore zone terrestrial habitats are closely linked together with semiaquatic and lacustrine habitats, giving rise to hydrological gradients and a high habitat diversity. Table I shows that the lakeshore zone, when compared with the pelagic water body, is characterised by a high lateral patchiness, a medium frequency of disturbance, and by an array of physical, chemical and biotic changes which are related with the cross-shore hydrological and morphological gradient.

Lakeshores may have many functions in ecology, species and habitat protection, water protection, human settlement and welfare, culture and monument preservation, recreation, fishing and tourism (Table II). A considerable direct (e.g. tourism and leisure businesses, rental income, real-estate prices) or indirect creation of economic value (e.g. drinking water supply of big cities and industrial regions) is behind these, with negative impacts on natural values. Population density in the lake's surroundings is the most prominent influence on these functions.

In this paper we outline the significance of the lakeshore zone for ecosystem functions and for humans. We list significant human pressures on the lakeshores and tentatively describe the most important impacts resulting from such pressures, and, we present some examples from Lake Constance. Finally, we discuss four lakeshore quality assessment schemes, which are currently being developed and tested in the field, and which may be used to more effectively co-ordinate different claims, under the guiding principle of sustainable use.

2. Pressures and impacts

In densely settled regions of Europe only a small fraction of the total shoreline is in a more or less natural state. Together with the input of gaseous pollutants (Howells 1990; Norton *et al.* 1990; Patrick *et al.* 1996; Schindler 1999; Roelofs 2002), urban waste water and nutrient loaded seepage from farm land (Uunk 1991; FAO 1993, Ongley 1996) an array of hydrological and morphological modifications have disrupted the ecological integrity of lakeshores.

Generally, the 'natural state' of a lakeshore section can be defined as a "state in the present or in the past, corresponding to very low human pressure, without the effects of major industrialisation, urbanisation and intensification of agriculture, and with only very minor modification of physico-chemistry, hydromorphology and biology." (CIS WG2.3 2003). In central Europe such conditions presumably prevailed during the first half of the 19th century. Today, direct human pressures on the lakeshore zone and more indirect pressures coming from the catchment give rise to impacts on the biota on both sides of the shoreline (Table III).

Up until now, the eutrophication of the littoral zone has been the focus of lakeshore quality assessment and water protection and management (s. Examples from Lake Constance, Eutrophication chapter). Table III demonstrates, however, that there are many other impacts, mainly due to hydrological modification in the catchment or at the outflow of the lake, or morphological impacts in the lakeshore zone itself. This tentative overview of the effects of human activities on the lakeshore ecosystem provides some insight into the 'driving forces', that is the pathways and mechanisms that finally give rise to a deterioration of lakeshore habitats, biota and ecosystem function:

- Lakeshore ecosystems are influenced not only by direct pressures (i.e. pressures within the lakeshore zone, as defined above) but also by remote pressures from elsewhere in the catchment area of the lake or even outside the catchment.

[1] A lake may be defined as a natural depression in inland bedrocks which is filled with water (inland lake basin), and where (i) the water body is nearly or completely surrounded by an edge (i.e. shoreline), (ii) the inflow(river water, precipitation, ground water, intrusive sea water)-to volume ratio is low so that a considerable amount of particulate matter is captured by sedimentation, (iii) the water level is the same in every place, except for very short periods (flood waves, surface waves, seiches), and where (iv) a free water body exists, the condition of which is not permanently influenced by its solid surroundings (sediment, soil, peat, bedrock), i.e. pelagic water body (Hutchinson 1957; Wetzel 2001, Kuusisto, Hyvärinen 2000 cited in Bragg 2003). Due to criterion (iv) very shallow lakes are not included, since otherwise the whole lake would be classified as a lakeshore (see below). For practical reasons one may delimit lakes to water bodies greater than 0.01 km^2 surface area so that ponds and pools are excluded.

[2] The lakeshore zone consists of three concentric belts, the littoral belt, the shoreline, and the riparian belt (Fig. 1). The landside border of the lakeshore zone is where, in a natural state, (i) no influence of high water level (i.e. with a return period of 25 years) on the morphology, hydrology substrate and biota occurs, and where (ii) no direct influence from the landside part to morphology, substrate and biota in the shore line or in the littoral is discernible (Ostendorp 2004b). The lakeside border is the maximum depth where one of the following criteria is met: (i) maximum depth of rooted or attached macrophytes stands (i.e. vascular plants, mosses or macro-algae like stoneworts) under natural trophic conditions of the water body, or (ii) depth where deep water waves change to shallow water waves indicated by shoaling and refraction. The lakeshore region may be defined as to include a belt landward of the lakeshore zone in which significant pressures and impacts to the lakeshore arise.

Table I. Generalised view of characteristic features of the littoral zone in contrast to the pelagic water body.

forms and life history traits	(plankton, nekton)	phytes, epiphytic and epilithic orga-nisms, plankton, nekton, water fowl, etc.)
structural diversity	nearly absent	medium (bedrock, sediment, soil, litter surface, plant surface)
gradients	vertical (PAR)	vertical, cross-shore, long-shore (PAR, wave movement, sediment texture)
food web	dominated by grazers; without C_{org} accumulation	dominated by detrivores; often with C_{org} accumulation

- The impacts of human activities within and outside the catchment are related to air-borne pollutants like acid deposition (mainly from NO_x, NH_3, and SO_x emissions) and to climate change (emission of green house gases, like CO_2 and CH_4). Impacts that arise only from within-catchment activities are connected to (i) dissolved or adsorbed chemicals discharged into the lake (nutrients, heavy metals, pesticides and other xenobiotic compounds, pharmaceutical residues), and to (ii) changes in the hydrological regime (i.e. the mean water level, the level and frequencies of extreme water levels, and the yearly course of the water level), that derive from various engineered measures in context with agriculture, urban water supply, power gen-

Table II. Socio-economic and cultural significance of the lakeshore zone.

aesthetic value as a scenic landscape	resident population, day-trippers and tourists, touristic business, private land owners, shareholder interests
transport	public transport traffic, recreational boat traffic
private and public space for leisure, recreational and touristic activities	bathing, surfing, boating, aquatic sports, walking, celebrating public festivals and private parties, sport fishing
private and public space for infrastructure and enterprises (recreation, tourism, business, etc.),	baths and beaches, lakeside promenades and parks, restaurants and hotels, camping and caravan sites, harbours and landing places, marinas; shareholder interests
traditional trades and sources of income	professional fisheries, traditional handicrafts
sites of ancient monuments, and cultural layers of prehistoric settlements	historical science, archaeology, preservation of heritage (serving legal obligations); visitors, touristic business
species protection	phanerogams, invertebrates (e.g. beetles, butterflies, dragonflies), fish, birds, mammals; biodiversity; nature lovers and bird-watchers; tourist guides
habitat protection	riparian woodlands, extensively cultivated wet meadows, reedbelts, submerged vegetation; nature conservation authorities (serving legal obligations)
land-water inface and buffer zone	wetland vegetation, esp. reedbelts; water fowl (shelter from disturbance); control of non-point sources of nutrients (water protection management)

eration and navigation. These pressures, and the many impacts that result from them, are generic, at least for densely settled parts of Europe, and not very lake specific.

- Direct pressures on the lakeshore zone are centred around (i) changes in the hydrological regime of a lake due to threshold manipulations, or weirs in the outflow for several purposes (agricultural drainage, flood control, hydropower generation, etc.), (ii) morphological modifications in context with recreational uses, urbanisation and industrialisation, traffic and transport, sand and gravel extraction, boating and navigation. The direct input of nutrients plays a minor role, since the lakeshore zone is often not suitable for highly productive agriculture. Pollution from oil, fuel and other hazardous chemicals may occur in the vicinity of harbours and industrial plants or as a consequence of accidents during the transport and re-loading of such chemicals. One may regard these pressures to be lake specific or site specific. However, in regions with a comparable economic and population development, most lakes tend to be subjected to the same pressures at similar intensities. This is, for instance, the case for lakes in the northern alpine forelands between Lac du Bourget (France) and Lake Wallersee (Austria) which lie in densely settled landscapes with productive agriculture, a high level of economic development and a high touristic and recreational value. Hence, these pressures are generic when regarded on a landscape basis.

The knowledge basis differs greatly depending on the type of pressure and impact. With respect to the eutrophication of lakes we have a sound understanding of the relationships between catchment population density, agricultural practice and land use intensity, nutrient discharge from point and non-point sources, and the effects of nutrient enhancement on several compartments of the lake ecosystem, including littoral biocoenoses (e.g. Harper 1992; Sutcliffe, Jones 1992; Pieczyńska 1993; Tamminen, Kuosa 1998). However, the knowledge regarding hydrological changes and morphological modifications on the shore zone is fragmentary and in many fields restricted to problems and questions, for which engineering models and solutions exist (e.g. discharge manipulation and water table fluctuations, waves and littoral currents around inshore constructions, shore profile, sediment texture and erosion control). We have, for instance, a poor understanding of the consequences of specific constructions and human activities in the shore zone for habitat fragmentation and habitat suitability for macroinvertebrates, littoral fish communities and water fowl, for minimum population size of endangered species, vulnerability to alien aggressive species, microbial activity and organic matter mineralisation, and for the relation between stability, resilience and progressive development of lakeshore ecosystems. Finally, there are no convincing concepts of sustainability and wise use with respect to lakeshores in densely settled regions.

Hence, the overview given in Table III is more tentative than a summary of existing knowledge in this field.

3. Examples from Lake Constance

Lake Constance is a glacially formed lake in the north-alpine molasse basin with a surface area of 529 km^2, a shore length of 289 km and a maximum depth of 253 m, making it the largest and deepest northern pre-alpine lake. The total shore length is divided by three states (Germany, Austria, Switzerland), of which Germany (62%) and Switzerland (26%) have the largest parts. The mean width of the littoral zone is about 200 m but it can reach 1 km and more in river deltas. About 450 000 people live in the lakeshore region, and another 2 million tourists and ca. 27 million day-trippers per season come to Lake Constance for their holidays or to visit one of the many commercial events (s. Ostendorp *et al.* 2003a; Ostendorp 2004a, and the literature cited herein for references to this chapter, if not otherwise stated).

Eutrophication

Lake Constance is an important water reservoir, not only for regional agriculture (irrigation of vegetable crops and fruit-cultures), industry and households but to a greater extent for the industrial and conurbation regions some hundred of kilometres north. Presently, approximately 4.0 million people in 320 municipalities are supplied with drinking water, using a pipeline net of 1700 km length. From the end of the 1950s the high quality of the drinking water was endangered by the nutrient input from municipal and industrial wastewater, and from fertiliser application in agriculture. In 1959 a transboundary organisation (IGKB) was founded by the adjacent federal states of Germany and Austria, and the cantons of Switzerland, to formulate and to enforce common standards for water quality and wastewater treatment. Until now, 4 billion € have been invested in the sewage system and wastewater treatment plants with advanced denitrification and phosphorus precipitation technologies. The phosphorus concentration in the water column peaked around 1980 (82 μg P dm^{-3}), and decreased to approximately 12 μg P dm^{-3} at the beginning of this century. However, the nitrate concentration remained high with approximately 0.9 to 1.0 mg N dm^{-3},

Table III. Human activities (driving forces) and pressures in the catchment area (A) and in the immediate lakeshore zone (B), and potential impacts on hydrology, morphology and biota of lakeshores.

water suppl navigation (riv flood defen	▪ dam plants, weirs, reservoirs (hydro-power generation, water supply, flow regulation) ▪ flood protection embankments, flood plain damming, straightening of river channels ▪ extraction of sand and gravel from stream beds	unfavourable conditions for sessile plants and animals in the littoral zone ⇒ increase in severity of flood waves, higher water level amplitudes (helophytes, macrophytes) ⇒ sediment deficit in the shore zone; bank erosion
water engineering of agricultural land	▪ drainage of hydric soils (nutrient mineralisation) ▪ abstraction of water (irrigation)	⇒ eutrophication ⇒ lowering of water level, change in hydrological regime (bank erosion, helophytes, macrophytes)
productive agriculture and stock-farming	▪ soil erosion and solid matter inflow ▪ inflow of dissolved and particulate nutrients from non-point sources (via soil erosion, surface run-off) ▪ input of pesticides and other agro-chemicals (via soil erosion, surface flow) ▪ cattle grazing	⇒ silting up (riparian wetlands, helophytes) ⇒ eutrophication (riparian wetlands, helophytes, macrophytes, benthic algae) ⇒ toxic effects ⇒ trampling and grazing (riparian wetlands, helophytes)
road building, railway lines	▪ direct destruction of habitats ▪ land fill-up, shore enforcement ▪ release of hazardous substances on background levels (gas, oil) or by accident (various chemicals)	⇒ loss in total area of habitats ⇒ fragmentation and disintegration of lakeshore zonation and hydroseres ⇒ modification of wave characteristics, erosive forces and longshore transport of sediment matter ⇒ toxic effects and mechanical damage during decontamination (riparian wetlands, helophytes)

indicating the continuous significance of fertiliser application in agriculture for the nutrient budget of Lake Constance.

Besides phytoplankton, zooplankton, fish populations and professional fisheries, the littoral biocoenoses were affected by the eutrophication of the pelagic water body. The abundance of Charophyceae species and some broad-leaved *Potamogeton* species decreased. During summer the submerged macrophytes were overgrown with filamentous algae so that swimming and boating were hindered (Fig. 2). Clumps of algae and macrophytes were washed against the waterside reed belt, causing considerable mechanical damage to the culms. The endemic Littorelletea-vegetation on nutrient poor gravel shores suffered from the enhanced nutrient availability, since its habitats were overgrown by benthic algae and by competitive grasses and sedges.

When the water purification measures became effective, and phosphorus levels dropped in the 1990s the Charophyceae vegetation recovered. Some species, which had disappeared during the eutrophication phase, were re-discovered (Fig. 3) (Schmieder 1998). The abundance of filamentous algae was reduced (Schmieder, Pier 2000) so that the lakeside reed front recovered and could spread again.

Table III. continuation

B – immediate lakeshore zone		
human activities in the catchment area	**pressures**	**important impacts**
urbanisation and industrialisation	▪ land reclamation and erosion defence constructions ▪ long-shore and cross-shore constructions ▪ modification of the cross-shore profile ▪ waste disposal, contaminated landfills ▪ marinas, landing places, harbours, loading bridges; housing and commercials estates, sealing of the ground ▪ urban drainage, storm water and emergency overflows, inflow of untreated/treated sewage	⇒ direct destruction and isolation of habitats ⇒ sediment loss from the shallow water zone due to the increase of wave energy reflection ⇒ erosion of unprotected shorelines due to increase in longshore current velocities ⇒ erosion or silting up of organic matter; hygienical problems (e.g. fecal bacteria) ⇒ deleterious effects on the biota due to the non-point inflow of hazardous chemicals ⇒ direct destruction of habitats ⇒ decomposable organic matter, oxygen deficits, nutrient inflow
peat, sand and gravel extraction	▪ onshore pits, bedload dredging in river delta channels ▪ sublacustrine dredging of landing places and harbour channels	⇒ enhancement of wave energy to the shore, sediment matter deficits in the shorezone ⇒ sediment erosion from neighboring areas and silting
water sup-ply	▪ water abstraction for irrigation, industrial and municipal water supply	⇒ modification of the mean water level and its yearly course
water level management for flood protection, soil amelioration and drainage, hydro-power generation	▪ outflow damming, weirs ▪ outflow dredging ▪ artificial water level management	⇒ modification of the water level (mean, max, min, yearly course) ⇒ modification of habitat suitability for riparian trees and bushes, wetland and littoral plant species, fish, water fowl, etc.
recreation	▪ camping places, bathing beaches ▪ boating, surfing ▪ buoy fields, landing places, jetties and platforms	⇒ direct destruction of habitats ⇒ disturbance of breeding birds and waterfowl ⇒ modification of habitat suitability (e.g. for fish)
navigation	▪ shore development and infrastructure (harbours, facilities, marinas) ▪ maintenance (e.g. dredging of harbours) ▪ introduction of aggressive alien species ▪ contamination with hazardous chemicals (anti-fouling paintings, oil and fuel spill)	⇒ direct destruction of habitats ⇒ sediment erosion from neighboring areas and silting ⇒ out-competing of native species, effects on the food web ⇒ impacts on invertebrate populations by endocrine disruption
professional and recreational fisheries	▪ selective removal of species or age classes ▪ artificial stocking of fish species ▪ introduction of alien genotypes and fish species	⇒ modification of fish population dynamics and food web ⇒ genetic mixing, extinction of local genotypes ⇒ competition with native species
hunting of water fowl	▪ disturbance of resting water fowl ▪ contamination by lead from hail-shot	⇒ disturbance of resting water fowl, reduction of body fat reserves of migrating bird ⇒ toxic effects to benthivore water fowl

The development of water quality from oligo-/mesotrophic to highly eutrophic and back again is a common feature of many lakes in the northern alpine forelands (BUWAL 1994; Stanners, Bourdeau 1995; BLW 1996) and in other regions (Umweltbundesamt 2001; Nixon *et al.* 2003; Nixdorf *et al.* 2004; EEA 2004; see also Pieczyńska 1993). The impacts of enhanced nutrient input in the littoral zone have been documented in many scientific publications and reports from responsible authorities. One output was that submerged macrophytes, diatoms and some macroinvertebrate groups can be used as indicators for the trophic state of lakes (Lachavanne 1985; Lachavanne *et al.* 1991; Fittkau, Colling 1992; Johnson 1998; Schmieder 1998; Melzer 1999; Seele *et al.* 2000, Zintz, Böhmer 2000).

As a result, one can state that (i) eutrophication is generic for large numbers of lakes in central Europe, (ii) the causes of eutrophication and the sources of nutrient input to lakes are sci-

Fig. 2. Eutrophication in the bight of Friedrichshafen (Lake Constance-Obersee): mats of filamentous algae, mainly *Cladophora* spec., covering submerged macrophytes (*Chara* and *Potamogeton* species).

entifically fairly well understood, (iii) the consequences of eutrophication for relevant members of the littoral and shoreline biocoenoses have been well documented, (iv) competent authorities in European countries have been aware of this problem for many years, and (v) legislative measures, administrative implementation and technical means of waste water treatment have proved to be effective, at least for point source pollution (Kristensen, Hansen, 1994; Nixon *et al.* 2003). Hence, we propose that the eutrophication of lakes will not be the main challenge for water protection and management in central Europe during the next decades.

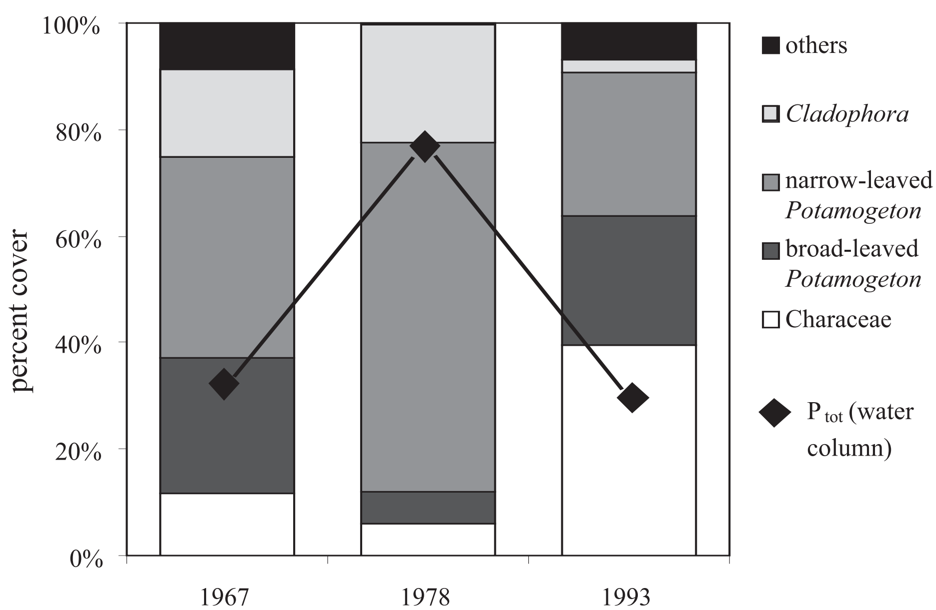

Fig. 3. Percentage of cover of different species along Lake Constance shore (Obersee and Untersee) during the eutrophication phase (1967 - 1978) and during the oligotrophication phase (1978 - 1993). P_{tot} - total phosphorus (mean concentration in the water column of Lake Constance-Obersee).

Fig. 4. Damaged shore fortifications on the eastern shore of Lake Constance near Bregenz.

Morphological modifications of the lakeshore zone

The lakeshore region of Lake Constance is a conurbation area with a mean population density of 575 persons km^{-2} (data from 2000) in 53 municipalities with direct access to the shore. The shore region is very attractive for housing, for commercial and for recreational activities, with the result that the population density in the 'second row' of municipalities (i.e. those without direct connection to the shore) is much lower (on average 270 persons km^{-2}). Between 1980 and 2000 the population increased by 63 persons km^{-2} in the 'first row' municipalities, but only by 44 persons km^{-2} in the 'second row' municipalities. Along with the high population density the percentage of land covered by estates, roads, places, etc. (19,1%) is 70% higher than the average of neighbouring federal states and cantons, whereas the percentage of woodlands is by 23% lower.

One factor in the recent development of population density, land cover, infrastructure, transport density and welfare is the attractiveness of the waterside for water sports, recreation, 'infotainment' and other kinds of leisure activities. Since the last decades of the 19th century many riparian wetlands and farmlands were transformed into private estates with direct access to the water line so that a large but unknown percentage of the total shore length of Lake Constance is privately owned for permanent housing or holiday-homes. During the holiday season, more than 27 million highly mobile and event orientated holiday-makers and day-trippers come to Lake Constance. The leisure facilities are concentrated in the shore zone: 97 harbours and jetties and 20 large buoy fields for a total of 56 900 registered recreational boats and cruise ships, and an unknown number of boats that come temporarily from other parts of Europe. In addition to this, there are approximately 73 bathing beaches, 42 camping sites and another 29 landing places for surfers.

Approximately 29% of the shoreline is covered by natural reed belts, 38% are heavily impacted by shoreline fortifications, cross shore constructions and other kinds of morphological modifications (Teiber, 2003) (Fig. 4). Presently, a great part of the natural shore zone is included in one of the 29 nature reserves, which cover a total of 53.64 km^2. The effects of shoreline modifications on littoral biocoenoses and ecosystem function have not been thoroughly investigated. Common opinion is that they cause shoreline instability and bank erosion in adjacent unprotected areas, and that they reduce the 'self purification' capacity of the littoral. For this reason, about 25 km of eroded or fortified shoreline has been rehabilitated since the 1980s, through the use of sand or gravel filling to give a more gently sloped bank (Fig. 5). Some areas have been re-vegetated by reed planting, others are open to the public for recreational uses. The ecological effects of the rehabilitation measures have not been documented.

The situation of Lake Constance shores is similar to other large lakes in densely settled areas, at least in the Swiss midlands, south Bavaria, western Austria, northern Germany and around Berlin. Common features are high pressures from overpopulation, high industrial and economic stan-

Fig. 5. Lakeshore rehabilitation works during low water period in February. Here, an eroded beach is filled up with a basement of boulders to give a break wave construction.

dards, heavy demand for waterside leisure facilities and activities by a prosperous urban population, non-environmentally friendly tourism activities and facilities, and in some cases by productive agriculture on fields and fertilised grasslands which have fallen dry, since a decrease in the lake level during or after the 19th century. Many lakeshores suffer from extended landfills, built-up areas, bank fortifications, cross-shore constructions, bank erosion, and a deterioration of fringing reed belts (Ostendorp 1989), riparian wetlands and littoral fish fauna. To our knowledge, there is no concise documentation of such damages, neither holistically nor for specific examples. Furthermore, the common understanding of the links between pressures and specific impacts is poor.

Hydrological changes

Lake Constance, aside from Lake Walensee, Switzerland, is the only large, unregulated lake in the alpine region, and variations in lake level are mainly the result of regional climate conditions. It

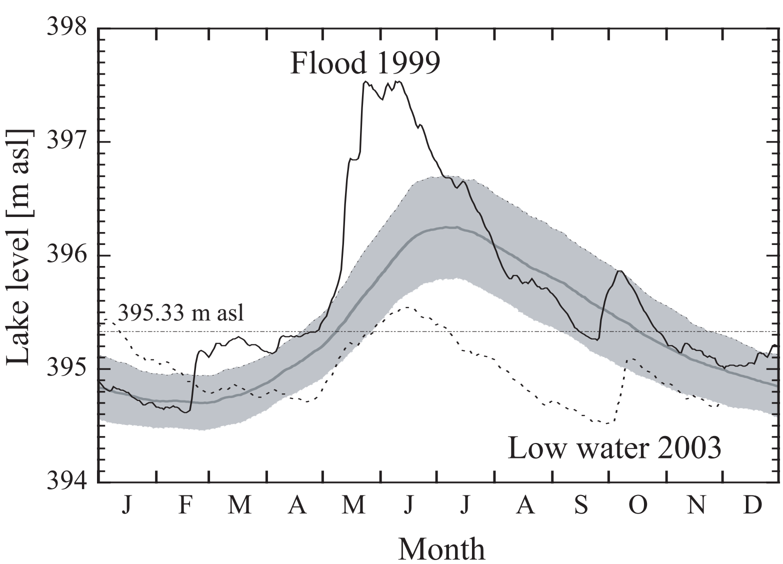

Fig. 6. Daily lake levels from Lake Constance in the extreme years 1999 (flood; black line) and 2003 (low water; dotted line), mean daily values (dark grey line), and standard deviation (grey band) for the period 1817-2003.

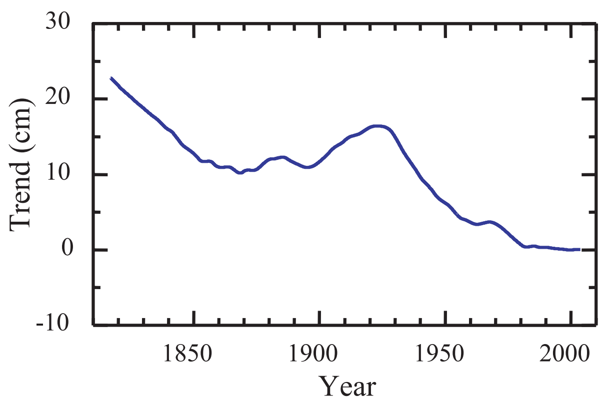

Fig. 7. Trend curve of the lake level at Konstanz for the years 1817-2003.

The yearly means of the water level show a non-linear decline, interrupted by a plateau from 1860 to 1895, followed by a short-term increase in the years up to 1925 (Fig. 7). Afterwards, a strong decrease in water level was established, which weakened during the last quarter of the 20th century.

The seasonal resolution of the trend on the basis of daily records shows a slight increase in water level during winter time of +2 mm y^{-1} or less. During summer the trend is significantly negative with a rate of -5 mm y^{-1} from July to September. (Fig. 8). This gives a mean decline of the mid-summer water of about -0.35 m in the period 1930/2002. Presumably, riparian and littoral biocoenoses must adapt to this trend with respect to their species composition and spatial extension. We do not know, however, how this happens. Maybe it happens stepwise during 'normal' years with average conditions, or maybe by qualitative changes during 'extreme' years with extraordinarily high or low water levels, which seriously disturb the former hydrosere at many places and for a long time.

receives the largest part of its water from its alpine catchment area (62.4% by area, 79.7% by water volume) and from the pre-alpine catchment area (13.3% resp. 8.6%) (Luft *et al.* 1990). The seasonal course of the lake level is mainly determined by the alpine climate. The lake level declines in winter, reaching its minimum at the end of February, when precipitation in the catchment is to a large extent stored as snow. It reaches its maximum level in June/July due to increased precipitation and snowmelt in higher altitudes (Fig. 6). Changes in precipitation and therefore run-off in the catchment area of Lake Constance directly influence extreme values and the main trend of the water level. Regular daily water gauge records started in 1816. They cover a time series of more than 187 years, making it one of the longest, continuously recorded hydrological time series.

During the last five years two extreme hydrological events happened at Lake Constance. In May and June 1999 an extreme flood occurred which caused economical damage to riparian agriculture and buildings. The flood was the third highest since 1816 with a return period of 87 years (based on detrended extreme value statistics, Jöhnk *et al.* 2004). From June to December 2003 the water level was extremely low so that large areas of the littoral platform fell dry (see Fig. 9). Although the extremely low water level recorded during September 2003 had a rank of 109 out of 187, it

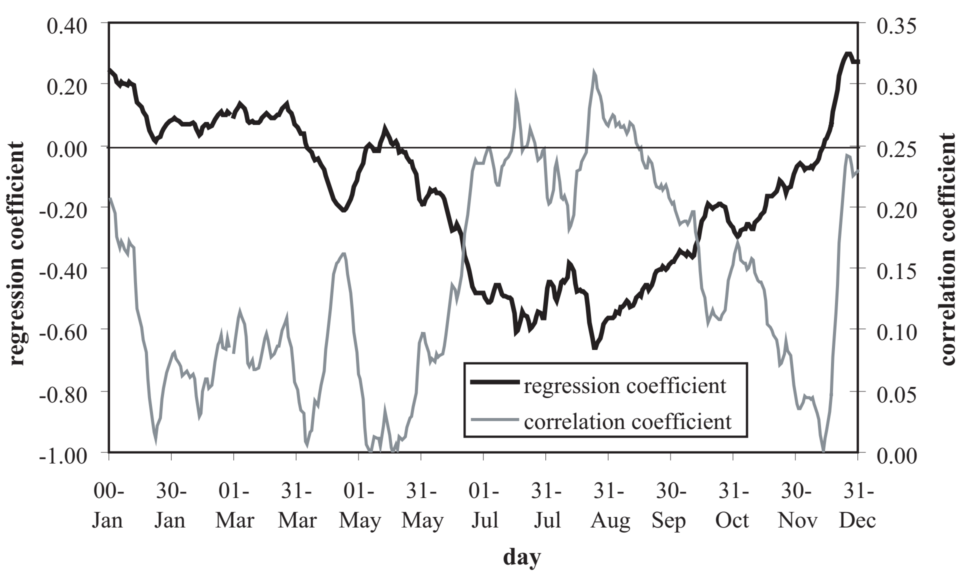

Fig. 8. Daily trend of the water level for the years 1931-2002: regressions coefficients and absolute correlations coefficients from the linear regression model on the basis of daily records; correlation coefficient greater than 0.296 are significant for P<0.10.

was by no means an extraordinary low level when based on the whole water year, but can be seen as an extremely unusual event at that specific time. Regarding the seasonality of these two events, the 1999 flood came very early in the season when the water level is normally relatively low, so that for its peak in May a return period of 4000 years was computed (Fig. 9). In comparison, in 2003 the water level was very low in May and June, and decreased continuously until October when it rose again to values within the usual range, so that maximum return periods of over 500 years occurred in September.

The consequences of the 1999 flood for the fringing reeds of Lake Constance have been extensively studied (Schmieder *et al.* 2003; Ostendorp *et al.* 2003b; Dienst *et al.* 2004): About 0.306 km^2 of aquatic *Phragmites australis* reeds bed area died back (i.e. 23% of the former area in 1998). Among the stands, which survived, the severely damaged stands were mainly composed of secondary (i.e. replacement) shoots, whereas primary and insect infested shoots dominated in less damaged stands. The development from 2000 to 2001 was characterised by an overall decrease in shoot density, a change in the composition of the shoot population in favour of flowering primary shoots, and in a recovery in culm stature. One year later the medium damaged stands showed clear signs of rehabilitation, indicated by mean culm biomass, total culm density, stand structure and standing crop.

The spatial arrangement of damage and the recovery process showed a clear relation to the ground elevation of the stands. Even severely damaged reed stands regenerated quickly, when located on high ground elevation, but stands on a low elevation level died off completely in the years following the extreme flood. This situation was comparable to the late 1960s, when approximately 40 hectares died back due to the extreme flood in 1965 (which was the 12th highest in the period 1817/2002) and the high spring water levels in the subsequent years (Ostendorp 1990; 1991). In the period between the extreme floods of 1965 and 1999, the reed areas expanded again to nearly 85% of the area before 1965. The expansion rates increased with increasing distance to the flood event of 1965. Especially in periods with series of years of low spring water level the expansion rates were high (Dienst *et al.* 2004).

At this time, the consequences of the 2003 drought are not well understood. We observed the establishment of *Typha angustifolia*, *Sagittaria sagittifolia* and other helophytes in front of the

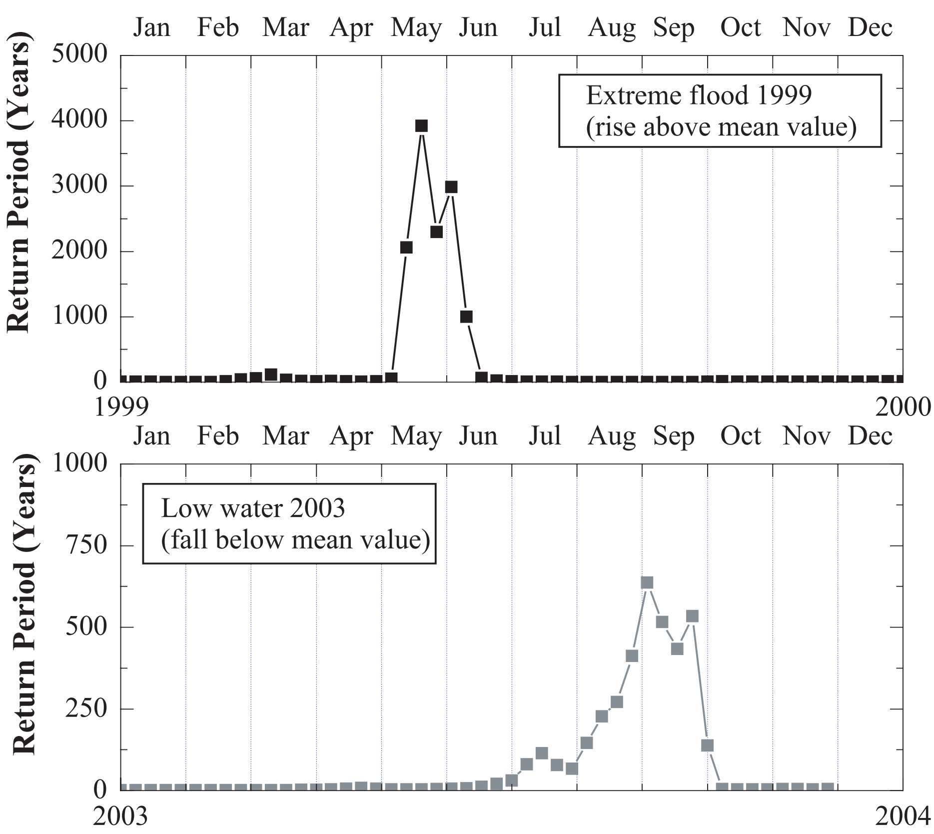

Fig. 9. Return periods for exceedance of the weekly mean value for the two extreme years 1999 (flood) and 2003 (low water).

damaged reed belt where they had never been before. The sensitive endemic species of the Littorelletea communities, which had suffered from the 1999 flood, may have profited from the low water period. Competitive grasses and sedges, however, may also have profited, so the outcome is unclear. *Phragmites* reeds may start to spread again as it was observed some years after the 1965 flood, but may be hindered from doing so by dense *Typha* belts in front.

Jöhnk *et al.* (2004) argued that the water level trends of Lake Constance and its extremes are under the control of climate change. The influence of precipitation in these distinct regional catchments on monthly lake level variations can be quantified by correlation analysis. The long-term variations in lake level and precipitation show similar patterns. The comparison of the distinct frequency (or period) bands in the periodograms of lake level, precipitation in the alpine and pre-alpine region and the index of the North Atlantic Oscillation shows that the pronounced low period bands in the range of 4 to 5 years can be attributed to regional variations in precipitation, whereas the longer period structures are more likely caused by global climatic variations. Due to climate change, precipitation on the northern side of the Alps is increasing (Quadrelli *et al.* 2001) and at the same time the temperature is rising, which shifts the snow melt to earlier periods. A clear trend towards the earlier onset of snowmelt has been found in alpine snow data during the last decades (Laternser, Schneebeli 2003). Consideration of the combined effects led to the assumption, that the occurrence of extreme floods will be earlier in future. Although the mean lake level is decreasing, this shift in occurrence time might cause problems for reed growth. Thus, we doubt that the reed areas will expand to the extent they had prior to the flood of 1965.

Climate change is a global trend, which shows significant regional modifications in and around the Alps (Beniston, Jungo 2002; Quadrelli *et al.* 2001). In the northern alpine forelands we expect an increase in winter temperature, higher precipitation in spring and an early onset of snow melting in subalpine regions (Rapp, Schönwiese 1996; Schmidli *et al.* 2002; Laternser, Schneebeli 2003). These trends may have long-term effects on the littoral biocoenoses of many lakes largely through (i) the increase in surface water temperature, which induces physical, hydrochemical and physiological effects, and (ii) change in mean water level and/or in the frequency of extremes (e.g. Straile *et al.* 2003a,b; Wallsten, Forsgren 1989). Riparian wetlands, helophyte and macrophyte vegetation may be the most affected by hydrological changes, since their community structure depends on even slight changes of the water table, but planktonic and fish communities in shallow lakes may also be affected. Presently, the understanding about possible mechanisms and the potential adaptations of littoral communities is poor.

The examples from Lake Constance demonstrate that human pressures on lakeshores can be diverse on the same stretch of land, highly complex, direct and indirect, and retardative with respect to visible impacts on habitats and biota. They also show large gaps in knowledge, especially concerning impacts from hydrological and morphological modifications.

4. Methods for lakeshore quality assessment in Europe

The many services lakeshores provide to human society exasperate important threats to riparian and littoral communities, so that, in the end, these services may be severely impeded. Such threats come from air pollution and acid depositions, from nutrient emissions and eutrophication, from land use, morphological modifications in the shoreline and inshore constructions, and from hydrological changes, either induced by man via regulation or induced indirectly by manipulation of discharge in the catchment or global air pollution and climate change. It seems that these pressures are generic to many lakes, at least to those in densely settled areas in Europe.

Along with new policies concerning sustainable use and environmentally-friendly development it is necessary to monitor the status of lakeshores in respect to their quality, comprising aspects of water quality, ecosystem structure and function, fish ecology, species protection and nature conservation, but also aspects of landscape protection, monument preservation and heritage management, and cultural and socio-economic development. Most of these aspects are, at the least, partially covered by Directives of the European Commission and Parliament, by national legislation and by international Conventions[3].

[3]The most important conventions are: Convention on Wetlands of International Importance, 1971 (Ramsar), 11 ILM, 963; Convention for the Protection of World Cultural and Natural Heritage, 1972 (World Heritage), 11 ILM, 1358; Convention on the Conservation of European Wildlife and Natural Habitats, 1979 (Berne), ETS 104; United Nations Convention on Biological Diversity 1992 (Rio), 31 ILM, 818; European Convention on the Protection of the Archaeological Heritage, 1992, ETS 143. The most important European Directives are: Directive 79/409 on the Conservation of Wild Birds, 1979, O.J. L103/1; Directive 85/337 on the Environmental Impact Assessment of Certain Public and Private Projects, 1985, O.J. L175/40 (amended by Directive 97/11, 1997, O.J. 73/5); Directive 92/43 on the Conservation of Natural Habitat and of Flora and Fauna, 1992, O.J. L206/7 (amended by Commission Decision 97/266/EC and Council Directive 97/62/EC); Directive 2000/60 (Water Framework Directive), 2000; EU Directives must be implemented by national and federal state's legislation. For a concise overview see Marsden, 2001.

Until now, there are no conclusive concepts about how these laws and conventions can be integrated and implemented in lakeshore habitat protection and development.

In this context, the European Water Framework Directive (WFD) seems to be a milestone (Chave 2001). It requires a "good" status for natural surface water bodies including their associated wetlands, i.e. the lakeshores on both sides of the water line, by 2015. It describes the methods and tools, which can be used to achieve this. The central tool to verify the achievement of "good" status, and to identify water bodies that are at risk of failing this objective is an ecological quality assessment scheme, which will form the basis of the monitoring obligations of Member States. Furthermore the WFD requires an integrated approach to include other EU legislation from the fields of species and habitat protection, and landscape planning.

The WFD and the CIS Horizontal Guidance documents do not specifically deal with the special conditions in the lakeshore zone as a transitional complex of habitats, which is directly and indirectly influenced by man, and in which many stakeholder interests and conflicts overlap. Hence, a lakeshore quality assessment scheme should also focus on aspects like nature conservancy and regional planning and development. It may subserve to some strategic targets, e.g.

- estimation of consequences from various uses,
- risk prediction of accumulating burdens,
- identification of conflicting aims,
- transparency of (implicit) evaluations,
- increasing impartiality of consideration processes,
- increasing public acceptance.

There are also some more practical reasons for a detailed and sound assessment scheme, e.g.

- regulatory consolidation of different uses,
- enforcement of restrictions by convincing argument and defence against usage claims,
- optimisation of resource utilisation,
- optimisation of habitat, species and object protection (including restoration measures),
- structuring of observation and monitoring projects.

According to the WFD, the assessment of the present status of a water body is done by comparing the measured data of a set of given quality elements (QEs) with the value these QEs have under type specific reference condition. The reference condition of a specified type of lake is materialised in a lake (or a group of lakes) where there are no human influences of any kind, and which is accordingly of 'high' status.

The QEs, which concern lake habitats and which are expected to reflect the level of anthropogenic pressures, are (WFD, Annex V, 1.1.2):

- biological components (phytoplankton, aquatic flora, benthic invertebrates, fish fauna),
- hydromorphological components (quantity and dynamics of water flow, residence time, connection to the groundwater body, lake depth variation, quantity, structure and substrate of the lake bed, structure of the lake shore),
- chemical and physio-chemical components (light transparency, temperature profile, oxygen budget, salinity, acidity, nutrient concentration as well as the concentration of specific pollutants).

The main focus is on the biological quality elements, from which the water body flora (that is the submerged macrophytes and the benthic algae), and partially also the benthic invertebrate fauna and the fish fauna, are relevant. In contrast, the hydromorphological quality elements only play a role in the "high" status since in the "good" and in the "moderate" status, the hydromorphological elements only have to be of a quality, which allows the biological quality elements to develop, in accordance with the status of the water body.

The set of QEs listed in the WFD is not particularly suited to the special conditions of the lakeshore zone. Therefore, the list needed to be extended and reformulated. It has been reformulated, with the inclusion of components from the EU Habitats Directive, and other components, which are partially beyond the legal requirements of the WFD (Ostendorp 2004b; Ostendorp *et al.* 2004).

Currently, at least three different lakeshore assessment schemes are being tested in the field. In the United Kingdom a 'Lake Habitat Survey' (LHS) protocol has been developed by Scottish Natural Heritage. The LHS goes back to main ideas and experiences collated in the United States (U.S. EPA 1998) and it is in context with the 'River Habitat Survey' in the UK and other countries (Davies, Simon 1995; Boon, Howell 1997; Jungwirth *et al.* 2000; SEPA, 2003). Another approach is being tested on 175 lakes in north-east Germany by the State Agency for Environment, Nature Protection and Geology, Mecklenburg-Vorpommern (Germany). This protocol relies mainly on the semi-quantitative evaluation of aerial photographs, thematic maps, and information from data bases of state agencies. The third method is currently developed at Lake Constance and will be tested here in near future. It is based on a provisional draft by the EAWAG (CH, Dübendorf) and it has been adopted by the International Commission for the Protection of Lake Constance (IGKB). This protocol is focused on morphological modifications, due to bank fortifications, constructions, recreation facilities, land fills and riparian land use.

All three approaches have common features, as they:

- intend to meet the formal requirements of the WFD and other EU legislation,
- focus on morphological characteristics and hydrological modifications, especially those which indicate significant human pressures, but not primarily on the biota,
- use field surveys and information from aerial photographs, maps and data bases,
- consider the riparian zone, as well as the shoreline and the littoral zone.

However, these approaches differ with respect to some practical objectives, surveying technique, portion of total shoreline surveyed, length of survey units, number of survey variables, definition of reference conditions, and aggregation procedure used to achieve a single score for each lake. Detailed information will be available in recent future, as soon as manuals and results have been published.

A more general view has been proposed by Ostendorp (2004b), which also comprises aspects such as cross-shore transect integrity and landward connectivity, the potential for dynamic development, sociocultural importance, and character and uniqueness of the landscape. The QEs may be used in an integrated way or they can be refined and reified through several levels of detail, depending on the specific aims of a study.

Lakeshore quality assessment is a fairly new field in which not so much experience exists in the EU member states. But we have good knowledge from other bioassessment and habitat assessment fields about how to structure a lakeshore quality assessment scheme, and where some of the pitfalls lie. The more complex tasks are the implementation of other EU legislation (e.g. Habitats Directive), the definition of lakeshore types and reference conditions, and a better understanding of the significance of hydrological and morphological impacts on the biota. It may not be adequate to judge from a human point of view what 'pure nature' on the lakeshore should look like, without a sound understanding of how several taxonomic groups respond to deviations from the reference conditions.

This calls for a new initiative for supplementary research.

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