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Erosion and Archaeological Heritage Protection in Lake Constance and Lake Zurich: The Interreg IV Project 'Erosion und Denkmalschutz am Bodensee und Zürichsee'

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Lake Constance and Lake Zürich contain important archaeological cultural assets. Above all the so-called pile dwellings of the fifth to the first millennium BC are widespread in the shallow water areas of the lakes, and in 2011 a total of twenty of these sites were included into the inscription of 'Prehistoric Pile Dwellings around the Alps' on the UNESCO World Heritage List. However, construction in harbours and along the lakeshore, shipping traffic, and recreational facilities as well as erosion processes all considerably endanger the stability of the underwater cultural assets. Since the 1980s the authorities concerned with the preservation of archaeological heritage in Baden-Württemberg and the cantons of Thurgau and Zürich have developed working techniques for the preservation of these special underwater cultural assets. Numerous questions about the causes of erosion, the technical installation and the effectivity of protective measures against erosion and the ecological tolerance of such measures, however, remain open.

At this point the Interreg IV project 'Erosion and Archaeological Heritage Protection on Lake Constance and Lake Zürich', started in conjunction with various institutes concerned with lake research. Within the framework of this project the technical methods of mapping and surveillance of the site as a basis of an archaeological monitoring were refined and extended and measures for the integration of protection against erosion were intensified and checked. From the natural scientific point of view, the essential topics for a long-term reduction of anthropogenic-increased erosion are a reduction of ship-induced waves.

KEYWORDS pile-dwelling sites, erosion, protective installations, archaeological monitoring, erosion markers

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Internationally renowned prehistoric sources

Pile dwellings from the prehistoric times are a particular phenomenon of the pre-Alpine region. In the Neolithic and Bronze Ages, and in isolated cases into the Iron Age, settlements were not only built on dry land but also in wetlands — in the shallow water zones of the larger and smaller lakes, on moorlands and less often on the floodplains of rivers. At these sites organic materials, in addition to the many other finds, remain preserved thanks to the ideal preservation conditions in the airtight and continuously waterlogged surroundings. Timber for construction, food remains, stockpiles, wooden tools, everyday objects and even pieces of clothing allow astonishingly vivid and multi-faceted insights into the lives of the people who established their villages there thousands of years ago.

Due to the diversity of the surviving materials the pile dwellings supply precise and detailed perceptions of the world of Europe's early farmers — their everyday lives, agriculture, animal husbandry and technological innovations. The possibilities of exact dating of the surviving wooden architectural elements using dendrochronology allow the history of the development of individual settlements to be traced and in ideal cases even the development of settlements in whole regions over a very long time span. The pile dwellings, therefore, constitute extraordinary archaeological sources for prehistoric settlements (Suter and Schlichtherle, 2009; Natter and Schlichtherle, 2011; Hafner et al., 2006).

Since June 2011, the prehistoric pile dwellings around the Alps have been accredited, by virtue of their unique preservation conditions, as UNESCO World Heritage Sites and inscribed on the list. In six Alpine countries, Switzerland, Germany, Austria, Slovenia, Italy, and France, 850 to 1000 wetland sites from between 5000 and 500 BC are registered (Figure 1). One hundred and eleven stations have been inscribed on the World Heritage List as representative for all the sites.

In addition to the pile dwellings other monuments remain conserved in the pre-Alpine lakes. Shipwreck remains can be found on the lakebeds and to some extent in the shallow water zones. Narrow areas of moorlands and the outflows of lakes were favoured places for crossings and it is here that the remains of crossings from the Neolithic Age to the Bronze Age are concentrated. Constructions from historical times still remain unresearched in the waters.

Dangers and strategies for the protection of underwater monuments

As long as organic materials always remain covered by water and sediment, the state of preservation, archaeologically speaking, is excellent in terms of tool marks and other archaeological information. The long-term maintenance of moorland and underwater monuments, however, is the cause of great concern as the conditions have deteriorated considerably in recent decades through agricultural usage, the drainage of wetlands and the growing pressures on resources along the lakeshores. In particular complex erosion processes increasingly threaten the lake dwellings on the shores of the pre-Alpine lakes. In the course of such erosion processes sand and lake marl sediment (Seekreide) are swept away from the shallow water zones and deposited in the deeper areas or at other shoreline sectors. A large number of pile dwellings have lost their protective covering and are being destroyed piece by piece. Many of the

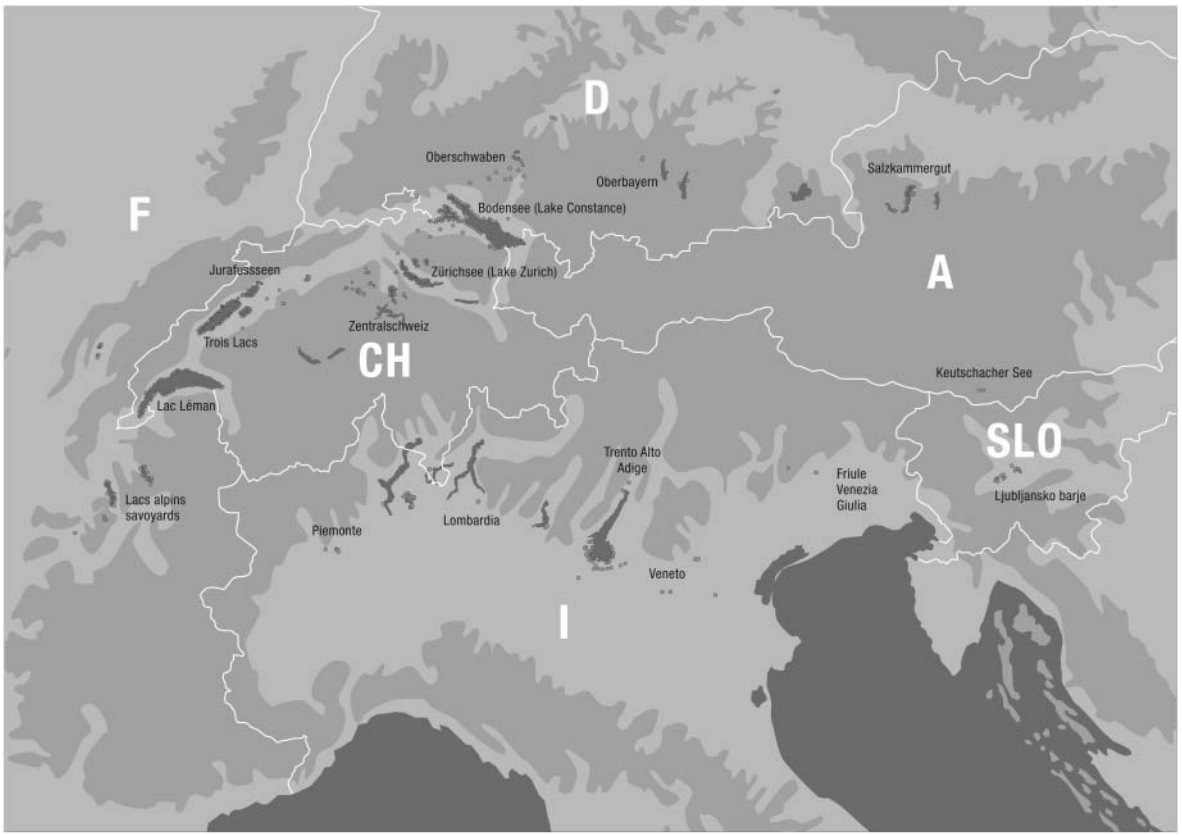

FIGURE 1 Around 1000 moorland and lake dwellings are known in the Alpine countries of Switzerland, Germany, Austria, Slovenia, Italy, and France. Of these, 111 have been inscribed on the UNESCO World Heritage List. Twenty-four of these can be found between Lake Constance and Lake Zürich. *Graphics: A. Mathis, AM Gestalten*

FIGURE 2 Sipplingen-Osthafen (D-Bodenseekreis): erosion rim in Sipplingen Bay. The waves continuously wash free new timber structures. Every year cultural layers disappear. *RPS/LAD, M. Kinsky*

sites, preserved for thousands of years in sediment under water, have in recent decades been totally or partially destroyed (Figure 2). The development of an effective protective strategy is thus an urgent necessity and an important task for the proper authorities.

Erosion on the shorelines of the lakes is caused by a number of different factors. Shipping traffic, shoreline constructions, and construction in the lakes all cause an increase in wave energy but also a reduction in protective aquatic plants, lower mean water levels, and an increase in certain waterfowl are further factors. The impact of individual factors, however, was until recently unknown. On Lake Constance and Lake Zürich a multi-disciplinary and transnational project was conceived in order to track the causes and the course of destructive erosion processes, to optimize and continue to develop protective measures for the pile dwellings, to introduce long-term measures for monitoring the lake dwellings while at the same time to inform the public about the importance of and the dangers to the pile dwellings. This was enabled within the framework of the Interreg IV programme 'Alpenrhein — Bodensee — Hochrhein' (ABH) sponsored by the European Union and the participating Swiss cantons within the programme region. The project 'Erosion and Archaeological Heritage Protection in Lake Constance and Lake Zurich' is supported jointly by the Landesamt für Denkmalpflege in the Regierungspräsidium Stuttgart, the Institut für Seenforschung, Baden-Württemberg, the Amt for Archaeology of the Canton of Thurgau, the Kantonsarchäologie Zürich, and the Vorarlberg Museum and carried out with the cooperation of the Limnologische Institut of the University of Constance

and the Institute for Lake Research of the Eidgenössischen Technischen Hochschulen (EAWAG). In total 1.8 million Euros, including subsidies, have been made available from 2008 to 2011. The objective was to develop courses of action for the protection of pile dwellings and other underwater monuments.

The pile dwellings on Lake Constance and Lake Zurich are at the centre of the project. Between Lake Constance and Lake Zurich there are 192 known lake dwelling settlements, around 20 per cent of all known settlement sites. Most of them are found on the shore areas of the lakes. Only 1–5 per cent of them have been extensively researched. A far greater part of the sites are acutely threatened by erosion. A systematic excavation of all the threatened areas is impossible, particularly as excavations under water are very complex and costly and also not preferable as the scientific potential of the find site is lost. On numerous occasions threatened lake dwelling sites have been protected in conjunction with native conservation authorities. Thereby, as a rule, unnatural lakeshore constructions were removed and natural embankment slopes were restored by covering the shore sections in question with gravel (Schlichtherle, 2001: 128). Many sections of the shore, however, particularly those in the direct vicinity of towns or villages, have not yet been renatured or are unsuited to this. The excavation of such threatened sectors, including the follow-up costs, would be at least ten to fifteen times more expensive than a protective covering (Eberschweiler et al., 2006: 36).

For this reason protective installations have been introduced now for some twenty-five years, by the responsible bodies, for settlements that are particularly threatened by erosion. As one of the first measures under the auspices of the Landesdenkmalamtes Baden-Württemberg, (now the Landesamt für Denkmalpflege in the Regierungspräsidium Stuttgart) the lake dwelling in the bay of Wangen on the western shore of Lake Constance was completely sealed, in a number of stages between 1986 and 1995, by a 10,000 sq. m layer consisting of geotextile and gravel (Schlichtherle, 1996). Further gravel layers followed both on the German and Swiss shores of Lake Constance. Different variations (geotextile strips fixed to the lakebed, gravel coverings with complete or partial underlay of geotextiles, gravel covering without a geotextile underlay) were employed as protection against erosion. Most of the geotextiles used were made of synthetic materials and more unusually coconut matting. The depth of the gravel covering was on average 20–30 cm and was especially chosen so that the archaeological layers would not be damaged by the (Schlichtherle, 2001: 129; Brem et al., 2001: 21; Hafner and Schlichtherle, 2008: 112; Köninger and Schlichtherle, in press). In western Switzerland similar methods were used, particularly on Lake Bienne (Hafner, 2006). The application methods were continuously improved and a special floating vessel was developed in order to accomplish the task cheaply and efficiently.

Despite the evident success of the covering measures there are still a number of questions as to their durability and the best possible execution. The initial misgivings that the currents prevailing on the lakebed, for example during storms, could wash away the gravel layer leaving the geotextile exposed, proved unfounded (Hafner and Schlichtherle, 2008: 113). However, empirical data were missing as to the ideal application of the gravel mixture and the different geotextiles as well as the ecological implications of the covering. An important aspect of the Interreg IV project is, therefore, the monitoring of protective installations employed up to now and also their future development.

Four shore sections on the north and south shores of Lake Constance, off the villages of Unteruhldingen, Sipplingen, Litzelstetten, and Steckborn, each with distinctive erosion dynamics, were selected in order to develop new methods of effective protection against erosion. Surfaces were covered with different mixtures of gravel with differing stone sizes depending on the exposure of the shoreline area concerned in order to investigate how the gravel layers with varying thicknesses responded to the wash of the waves. A special boat designed and constructed for the purpose of transporting and depositing the gravel allowed individual loads of gravel to be deposited precisely to the last centimetre. This accuracy allowed a series of experiments with lattice structured gravel layers that are an important component of the Interreg IV project (Figure 3). As a variation on gravel coverings for entire areas, here over a total area of 3685 sq. m, only 5 m strips were covered with gravel. Between them were two larger rectangles of 32 × 26 m and five smaller squares of 7.5 × 7.5 m free of gravel. The aim was to find out whether the grids were any good as sediment traps and whether fine sediment was deposited in the inner, gravel-free areas after storms and thus whether a semi-natural protection against erosion could be established. If the experiment was a success then the amount of gravel required for coating areas of the lakebed could be greatly reduced leading to a considerable reduction in costs. Up until now on Lake Constance these measures have covered diverse areas of severely threatened lake dwellings and thus preserved archaeological resources for the future. They cover, at the moment, a total area of over 3 hectares (Figure 4).

Controls of the existing protective covering show that the gravel structures have largely remained *in situ*. A more detailed look, however, revealed something

FIGURE 3 Arial view of the lattice-structured gravel covering in Sipplingen Bay.
Photograph RPS/LAD, O. Braasch

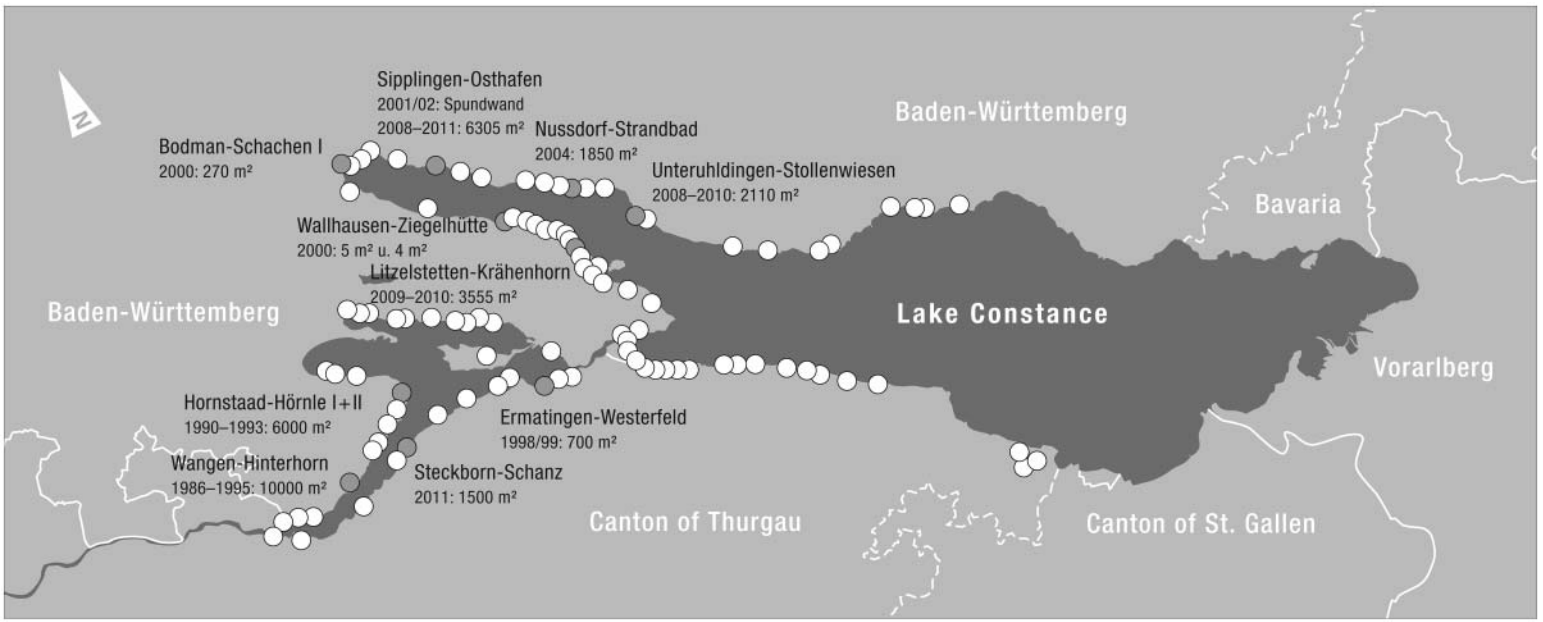

FIGURE 4 Protective measures against erosion for lake dwellings on Lake Constance as of 2011. White circles: the lake dwelling sites of Lake Constance; grey circles: lake dwellings with protective covering, representation of protected area in square metres.
Graphics: A. Mathis, AM Gestalten

unexpected. Swans combing through the cultural layers of the settlements for food have proven to be a previously underestimated destructive factor not only for the pile-dwelling settlements but also for the protective covering. When searching for food they are capable of digging holes in 25 cm thick layers of gravel. For this reason a higher proportion of coarser, larger pieces of gravel and the insertion of a geotextile underlay are important for durability of the protective covering.

The basic objective is an optimizing of erosion protection whilst at the same time blending in with the ecology of the shallow water zones and causing as little disruption as possible. This is why the accompanying ecological investigations documenting the repercussions of the measures on the lakebed as a biosphere were an important component of the Interreg IV project. They were conducted by the Arbeitsgruppe Bodenseeufer (AGBU). Sediment, fauna, and flora of the lakebed were extensively recorded and compared before and after the adoption of the protective measures. Additionally, unaffected reference areas were included in the studies. It would appear that the latticed structured gravel covering is ecologically more compatible than the blanket covering of individual sections (Ostendorp et al., in press). The effectiveness of the gravel covering, however, could not be tested within the framework of a three-year project and further observations are desirable both regarding the effectiveness of the gravel covering and the long-term development of the ecological circumstances.

Archaeological monitoring on Lake Zurich and Lake Constance

Another important objective of the project was to establish or rather extend the basis for a long-term, systematic monitoring system for the lake settlements. Since the beginnings of underwater archaeological research in the 1980s, divers have made observations that the appearance of individual sites has changed significantly. Settlement layers exposed on the lakebed and pile tips poking further out of the lakebed than previously point to sediment displacements. Although corresponding observations were mentioned in reports, initially they were not systematically quantified. In the 1990s wooden stakes, amongst other things, were placed at endangered stations in the canton of Zürich to monitor erosion. Here threatened areas, with cultural layers exposed on the lakebed, are often situated at the junction of the flat shallow water zones and the relatively steep slopes to the depths. In this situation sets of measuring stakes and floating lines have proven to be simple technical resources for monitoring erosion (Figure 5). To this end lines and measuring tapes were attached to the stakes above the lakebed. Monitoring is carried out by measuring the distance between the line and the lakebed and indicates the rate of erosion. Corresponding dives are conducted, as a general rule, every five years, but depending on the situation or the findings they can also be undertaken at shorter intervals. Almost a quarter of the stations on Lake Zürich are today furnished with equipment for monitoring erosion (Eberschweiler, in press; Scherer, T., pers. comm.).

On Lake Constance erosion markers have increasingly been installed only since the beginning of the Interreg IV project. Only 19 erosion markers existed at 14 stations until 2007. In the meantime 30 settlement areas — more than a third of all the known pile-dwelling sites on Lake Constance — have been supplied with 176 erosion markers and thus a representative cross-section is in place for a standard monitoring of pile dwellings on the lake.

FIGURE 5 Reference posts for monitoring erosion on Greifensee (Canton of Zürich). The tape measure and lines attached to the stake for monitoring purposes are easily recognizable. *Photograph Amt für Städtebau Zürich — Unterwasserarchäologie*

The erosion markers are placed by research divers in a number of alignments spread around the settlement areas and measured by GPS. Depending on the predetermined situation — deep or shallow water, close to the shore, strong or weak currents — different variations are deployed, for example oak stakes, PVC rods, and plastic or metal chains, and driven into the lakebed. In the following years the markers should be checked at regular intervals and readings taken. The aim is to establish tailored and durable reference points for the respective situations.

The erosion markers are, however, only a part of the monitoring process. Another important point is to establish whether archaeological occupation layers are exposed on the lakebed or embedded in sediment. For a systematic determination of the status of selected settlements, all the available archaeological, geological, topographical, sedimentological data and any information relevant to monument preservation are compiled and transferred to surface plans. Here a diversity of data sources becomes integrated. In the course of a project, a series of technical procedures were also tested, such as various echo sounding systems, terrain scans and bathymetric recordings, for the logging of erosion and accumulation processes. However, pinpoint accuracy in recording the lakebed, especially in the shallow water zones, has mostly proven to be problematic.

Ideally, as a result of archaeological monitoring, development prognoses can be made for individual sections of shore or threatened sites. If necessary, areas of lake

settlements that are imminently endangered have to be selectively protected or rescue excavations have to be initiated. In any case further monitoring at regular intervals is needed.

Research into the causes and the progression of erosion

The natural scientific investigations into the causes and progression of erosion have been very extensive and used a variety of forms that included documentation of the lakebed using modern hydroacoustic procedures, analyses of sediment cores, long-term measurements of wave energy at selected stations, practical experiments on sediment transportation in the shallows, laboratory experiments on the erodibility of natural sediment, and the development of 2D and 3D models of sediment transportation in the shallows.

At this point the concluding book can only be referred to as it is due to be published in 2012 (Brem et al., in press). The most important factors for the energy input in the shallow water zones and the transformations on the lakebed resulting from this, are the wind and waves. Experiments by Hofmann et al. (in press), that there are clear differences between wind and the wash from shipping. Depending on the exposure of the site the energy input from the wash from shipping can amount to up to 50 per cent and thus has a large share in the continuous mobilization of fine particles (Hofmann et al., in press). A long-term objective has to be to reroute shipping traffic away from sensitive locations.

Raising the awareness of the public and the decision makers

A further aim of the project was to inform the public about the importance of and the dangers to pile dwellings in the form of an accompanying exhibition. The exhibition 'The Lake Recalls . . . Underwater Archaeology and Lake Research', developed together within the project and implemented by the Voralberg Museum, has in the meantime been displayed in twenty-three communities in south-west Germany and Switzerland, and contributed to directly informing the public. In addition to being displayed in museums, the locations included selected authorities that are concerned with other aspects of the lakeshore, with foyers available with the corresponding space and frequented by the public. In this way not only were the broad public made aware but also the administrative and political decision makers were reached (Heumüller et al., in press).

Conclusions

The themes covered within the framework of the project represent an important basis for the future management of the UNESCO World Heritage Sites. The concluding book, due to be published in 2012 (Brem et al., in press), contains a series of related essays and case studies from a total of twenty-six authors. Particular value is placed on the formulation of courses of action. Various aspects of the tasks that have already begun, particularly the monitoring of the sites and the monitoring and development of new protective measures can be implemented as part of the accompanying measures for the UNESCO World Heritage.

Further information about the project can be found at: <http://www.der-see-erzaehlt.eu/> and <http://www.erosion-und-denkmalschutz-bodensee-zuerichsee.eu/>

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