Erosion hazards in littoral pile dwelling sites of the UNESCO World Heritage

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1. Introduction

In the 1980s it became evident that the cultural layers and the pile fields of many prehistoric sites along Alpine lakeshores are subjected to an enduring destruction (Ramseyer & Roulière-Lambert 1996, 2006; Brem et al. 2015). Wave action and littoral erosion, occasionally in relation with shore protection works and other waterside constructions, were believed to be among the most important factors.

The outstanding prominence of the findspots was a strong motive to enrol 111 sites in the UNESCO Word Heritage List as a serial cultural heritage *Prehistoric Pile Dwellings around the Alps* (Suter & Schlichtherle 2009, UNESCO 2010/11). The status as a World Cultural Heritage implies the responsibility of the UNESCO signatory states to initiate scientific and technologic research which finally enables the responsible authorities to avert the endangerment of the prehistoric matter (UNESCO 1972, Corboud & Gowen 2016).

In the light of the above, this study was initiated in April 2015 during the *Paris 5 Conference* (Preserving Archaeological Remains in Situ; Leuzinger et al. 2016) in Kreuzlingen (Switzerland). The main objectives were (i) to concisely collate the current knowledge of the present risk situation of littoral pile dwelling monuments of getting eroded, and (ii) to identify the main causes and concomitant circumstances, in order to present a list of current initiatives of research and protection.

Based on information from the *Palafittes Database*, hosted by the *Swiss Coordination Group UNESCO Palafittes*, Basel (www. http://sites.palafittes.org), and a considerable amount of preexisting knowledge a questionary was developed and distributed to local specialists in the competent monuments authorities. The return of completed questionnaires provides the basis of the analysis presented here.

2. Methods

The *Palafittes Database* from January 2010 formed the starting point of this evaluation. The database was checked for plausibility and redundancy. It was compared with an updated (unpublished) version from April 2016 which turned out to contain the same archaeological sites for AT, CH, DE, FR, and IT. Data were taken from the updated version.

The sites were classified whether they are (i) lake littoral sites in a broader sense, or (ii) moorland sites, not belonging to an existing lake surface, or fluvial valley sites. The latter group was disregarded in the further analysis.

A littoral site can be situated

- on a shoal or on or next to a (small) island (type A)
- on the littoral platform *without* connection to the present shoreline (type B)
- dto., *with* connection to the shoreline (type C)
- in a fringing wetland like a reed belt, riverine forest, extensively used grassland with connection to the shoreline (type D)
- on or below dry land (including recent land fills), intensively used by man in most cases, *with* connection to the shoreline, often armored with retaining walls or ripraps (type E)
- in a wetland *without* a connection to the shoreline (type F)
- on dry land *without* a connection to the shoreline (type G)

Furthermore, an archaeological site can stretch over several zones, e.g. from the littoral platform over fringing wetlands to dry land, a fact which is represented by an appropriate combination code (e.g. type CDG).

Relevant Information was taken from map excerpts depicting the sites, which were delivered with the *Palafittes Database* in PDF format, and aerial photographs.

In close cooperation with the *Swiss Coordination Group UNESCO Palafittes*, Basel (CH) a questionnaire was developed, and English, German, French and Italian versions were distributed to the regional competent authorities or contact persons in June 2015 (see English version in the Appendix). The questionees filled in their name, affiliation and email address so that they could be contacted in case of doubt.

The questionnaire consisted of a short instruction how to fill in the form, and six questions. The main purpose was to shed light on the hazard conditions due to lake-born factors, potential causes and backgrounds, and monitoring and preservation measures including scientific research programs. Besides assured facts the questionnaire inquired the expert opinion based on a sound knowledge of the excavation findings, the recent landscape history and present ecological problems at the findspot in question. It was intended that a person who is familiar with the local conditions should be able to fill in the questionnaire within 15 min.

Four out of six questions offered up to eleven pre-formulated answer options, where multiple selections were allowed. Additionally the option '*others'* was offered, which was to be specified by the questionee, if applicable. The informants were encouraged to rank the areal extent, importance or strength of a specified causal factor, preservation measure etc. by awarding the scores 0, 1, …, 4.

Most of the completed questionnaires were returned within three month so that the survey was finished by the end of January 2016. Then, completeness and plausibility checks were performed. In case of open questions the informants were contacted and asked for clarification or revision. This move was completed in July 2016.

3. Results

3.1 Database

The *Palafittes Database* contained 804 records which represent the same number of archaeological sites. Basically, each record represented a geographically distinct site with no spatial overlap with another site. A single site consisted of either (i) extensive cultural layers and/or pile fields with one or several superimposed archaeological strata, or (ii) a spatially limited findspot.

However, seven erroneous records were detected[1], since these entries did not represent a single site ('component site') but a generalised union of several sites which were already elements of the database (redundancy problem). These entries were eliminated so that the following evaluation is based on 797 sites.

264 component sites were selected by the competent authorities to form 115 candidate sites for the UNESCO World Heritage list. One World Heritage Site (WHS) candidate included one or more, up to 28, component sites. Finally 111 of the candidate sites with 259 component sites were tabled in the WHS list.

The competent authorities grouped the components sites in four groups, considering various aspects. Table 1 shows the number of the grouped sited in each country. Evidently, by far the most sites are located in Switzerland, followed by Germany and France. The 111 listed WHS are composed of 111 WH/S1, 75 AS/S2, 2 PD/S3, and 71 RS/S4 sites.

[1] Sursee Halbinsel (CH); Rapperswil-Jona/Hombrechtikon Feldbach (CH); Arbon Bleiche 2-3 (CH); Hüttwilen-Uerschhausen Nussbaumersee (CH); Doucier/Fontenu/Marigny Lac de Chalain, rive occidentale (FR); Gaienhofen Hornstaad-Hörnle (DE); Bodman-Ludwigshafen Bodman-Schachen/Löchle (DE)

Table 1:

Number of grouped circum-alpine pile dwelling sites (WH/S1, AS/S2, PD/S3, RS/S4) in the six relevant countries. The total number of sites is given in normal letters, the number of littoral sites (see Table 2) is put in brackets. Data were extracted from the *Palafittes* database.

Country	WH/S1 Word Heritage Sites	AS/S2 Associated Pile Dwelling Sites	PD/S3 Pile Dwelling Sites	RS/S4 Related Sites	total
AT	5 *(5)*	4 *(4)*	17 *(17)*	0 *(0)*	26 *(26)*
CH	52 *(34)*	62 *(32)*	334 *(235)*	14 *(10)*	462 *(311)*
DE	16 (9)	7 *(5)*	93 *(71)*	9 *(9)*	125 *(94)*
FR	10 *(10)*	18 *(14)*	18 *(18)*	41 *(35)*	87 *(77)*
IT	19 *(12)*	4 *(3)*	32 *(20)*	0 *(0)*	55 *(35)*
SI	2 *(0)*	8 *(0)*	23 *(0)*	9 *(0)*	42 *(0)*
total	104 *(70)*	103 *(58)*	517 *(361)*	73 *(54)*	797 *(543)*

3.2 Classification of sites

The major part of the sites were lakeshore sites in the broader sense (675 sites, 84.7 %), only 122 sites are situated in moorland or fluvial valleys. The total area of the sites was estimated at 17.43 km^2.

Most of the lakeshore sites (543) were, at least with a part of their surface, bound to the littoral floor or to the shoreline, no matter whether natural or modified by human structures or activities (Table 2). The minor part lied in remote wetlands (52 sites) without connections to the lake, or under dry land which in most cases is intensively used by man, e.g. filled-up areas, transport routes and built-up areas (77 sites).

The 543 classified littoral sites in the stricter sense can potentially be affected by waves and sediment transport, or might be subjected to waterborne activities (e.g. passenger ship traffic, boating and anchoring, swimming) and structures (e.g. marinas, landing stages, retaining walls, ripraps, different kinds of wave breakers).

The focus of this contribution is on lakeshore sites *s. str.*, i.e. on the 543 classified sites.

Table 2:

Classification of archaeological sites (n=797) as lakeshore sites (types A to X, incl. combinations) and moorland or floodplain sites. The classification scheme is based on the present situation (topographic maps, aerial photographs), not on the situation when the places were settled. Site areas were extracted from the *Palafittes Database*.

Type	Description	Number	Site Area (km^2)	exposed to wave action and/or waterside activities
A	islands, shallow banks	16	0,301	yes
B	littoral platform, without connection to the shoreline	159	1,876	yes
BE	extented over B and E	1	0,000	yes
C	littoral platform, with connection to the shoreline	146	2,392	yes
CD	extended over C and D	58	1,209	yes
CDE	extended over C and D and E	5	0,155	yes
CDG	extended over C and D and G	6	3,101	yes
CE	extended over C and E	49	1,235	yes
D	reed belt and/or fringing wetlands with connection to the shoreline	58	0,483	yes
DE	extended over D and E	8	4,892	yes
DG	extended over D and G	3	0,042	yes
E	dry land with connection to the shoreline	34	0,310	yes
F	reed belt and/or fringing wetland with connection to the shoreline	52	0,528	no
FG	extended over F and G	2	0,035	no
G	dry land without connection to the shoreline	77	0,867	no
X	former peatland, presently shallow lake	1	0,030	no
others	moorland and floodplain sites	122	2,024	no
total		797	19,47821	

3.3 Lakes

The lake littoral sites (n=543) are located in the littoral or in the next perimeter of 52 lakes which span five orders of magnitude in size (from 0.01 to 580 km^2).

The great number of sites (82.5 %) is restricted to large and very large lakes with surface areas of 10 km^2 and above (Table 3). The shoreline of these lakes make up 91.1 % of the total shoreline length. However, the density of sites is at maximum in very small lakes (1.61 per km), and drops continuously down to 0.25 km^{-1} in very large lakes. The total area of sites amounts to 15.995 km^2 out of which 94.4 % are concentrated around the two largest lake size classes.

Table 3:

Distribution of lakeshore pile dwelling sites in different lake size classes. Data of surface area and shoreline length were taken from internet sources, completed by own measurements using the Google™ Earth measuring tool.

Class	Description	Surface Area (Range)	No. of Lakes	Length of Shoreline (km)	No. of Sites	Area of Sites (km^2)
VSL	very small lakes	< 0.1 km^2	8	8.1	13	0.132
SL	small lakes	0.1 – 1 km^2	14	40.1	29	0.353
ML	medium sized lakes	1 – 10 km^2	9	92.0	53	0.406
LL	large lakes	10 – 100 km^2	16	710.4	268	11.886
VLL	very large lakes	> 100 km^2	5	725.2	180	3.219
	total		52	1575.7	543	15.995

3.4 Evaluation of the questionnaires

A total of 129 completed questionnaires returned. Most of them referred to a single component site, only 6 replies referred to two or more sites located close together. In these cases the answers were assigned to all sites. Hence, the completed questionnaires covered 165 component sites. Out of these, 148 sites were littoral sites *sensu stricto* (i.e. exposed to wave action and/or waterside activities, see Table 2).

The types of sites in the five relevant countries were represented to different degrees (Table 4). 83 % of a total of 70 WH/S1 sites were incorporated but only 10 % of the PD/S3 sites. In the end, the 148 sites from the completed questionnaires represented 27 % of all littoral sites.

Table 4:

Number of littoral pile dwelling sites (WH/S1, AS/S2, PD/S3, RS/S4) addressed in the completed questionnaires. The number of sites is given in normal letters, the percentage (100 % - all lakeshore sites, see Table 1) is in italics. ns(*) – not specified (no lakeshore sites in this group, see Table 1).

Country	WH/S1 Word Heritage Sites	AS/S2 Associated Pile Dwelling Sites	PD/S3 Pile Dwelling Sites	RS/S4 Related Sites	Total
AT	5 100 %	4 100 %	1 6 %	0 ns(*)	10 38 %
CH	27 79 %	14 44 %	28 12 %	5 50 %	74 24 %
DE	9 100 %	0 0 %	6 8 %	9 100 %	24 26 %
FR	10 100 %	0 0 %	0 0 %	23 66 %	33 43 %
IT	7 58 %	0 0 %	0 0 %	0 ns(*)	7 20
SI	0 ns(*)	0 ns(*)	0 ns(*)	0 ns(*)	 ns(*)
total	58 83 %	18 31 %	35 10 %	37 69 %	148 27 %

The sites in different lake size classes are represented to different degrees (Table 5). 53 % of sites in the medium sized lakes (ML) were covered by a response but only 12 to 17 % of sites in VLL and SL.

In conclusion, these figures show that the patterns of returned questionnaires do not represent the patterns of sites very well so that the representativity is limited. Hence, the results reported below should be regarded with a certain amount of reserve.

Table 5:

Distribution of lakeshore sites addressed in the completed questionnaires in different lake size classes. The percentage values refer to the total number of sites (100 %) in each size class (see Table 3).

Class	Description	Surface Area (Range)	No. of Sites in the Questionnaires	Percentage of addressed Sites
VSL	very small lakes	< 0.1 km^2	4	30,8
SL	small lakes	0.1 – 1 km^2	5	17,2
ML	medium sized lakes	1 – 10 km^2	28	52,8
LL	large lakes	10 – 100 km^2	90	33,6
VLL	very large lakes	> 100 km^2	21	11,7
	total		148	27,3

3.4.1 Question: *When was the first time (year) the station was examined (probes, excavations, pile field examinations) by versed personnel (archaeologist, trained laymen)?*

The first question aimed at the history of discovery and exploration of the sites. The speculation was that the extent of losses may have accumulated during the time span of 'visible' existence. However, due to inconsistencies in the answer to this question we dispense with an evaluation.

3.4.2 Question: *Have there been losses of substance of the site since the first examinations (see above)?*

The second question tried to find out whether there had been considerable losses of the substance of the monuments, and what had been the underlying background. Losses of variable extent were reported for 132 of 148 sites. Only in 5 sites losses were negligible or nonexistent. In 11 cases no information was provided.

Table 6 shows the relative importance of factors which were made responsible for the losses. Scores (W0, …, W4) could be allotted to indicate whether the factor in question was estimated

to have had no (W0), little (W1), moderate (W2), high (W3) or overriding (W4) importance. The most important factor, in terms of number of sites affected and degree of severity, was *flushing out of occupation layers caused by erosion (waves, currents)*, by which 91 sites were affected to at least a moderate degree (W2 and higher). Other very important factors were *authorised excavations/collections, construction timber retrieval by experts, etc.* which inevitably leads to a diminution of the archaeological substance, and the *corrosion of building timber* which occurred parallel to the flushing out of cultural layers[2]. *Illegal excavations/unauthorised collections* were also some importance in many sites, as well as *unsystematic excavations/collections, etc. (mostly during the first years after discovery)*. The relevance of biotic activities, i.e. *roots of reed/marsh plants or riparian woodland* was perceived as significant by many informants. However, the *role of burrowing activities etc. of animals (crustaceans, fish, water birds, mammals)* seemed to be of minor importance. Other factors included recreational fishing, bathing activities, presence of anchoring stones of moored buoys and the burrows of insect larvae in the building timbers.

Table 6:

Questionnaire results: answers to the question *Have there been losses of substance of the site since the first examinations?* – W0, …, W4 – scores reflecting the importance of the factor in question; n.a. – no answer, not applicable; figures – number of sites (total number 148).

	W0	W1	W2	W3	W4	n.a.
… through unsystematic excavations/collections, etc. (mostly during the first years)	43	5	12	22	16	50
… through illegal excavations/unauthorised collections	32	12	13	27	11	53
… through authorised excavations/collections/ construction timber retrieval by experts, etc.	29	20	44	17	19	19
… through lake bed slumping	95	0	0	1	2	50
… through flushing out of occupation layers caused by erosion (waves, currents)	12	19	16	41	34	26
… through corrosion of building timber	14	35	4	35	13	47
… through roots of reed/marsh plants or riparian woodland	54	15	15	4	23	37
… burrowing activities etc.of animals (crustaceans, fish, water birds, mammals)	38	13	11	7	1	78
… other (please specify:)	140	3	1	1	0	3

[2] statistical test: contingency table, n = 97, df = 16, log likelihood = -67.1, chi^2 = 134.2, $p < 0.0001$

Neither the grade of erosion in the cultural layers nor the degree of corrosion of wooden structures depended on lake size[3]. However, all sites in lakes with $A \leq 1.0$ km^2 did not show any sign of erosion.

3.4.3 Question: *What do you think is the reason for the losses through erosion (possibly also corrosion of construction timber, slumpings) in the stations or their immediate surroundings?*

If slumping, erosion and/or corrosion of timbers occurred (Table 6), the question (3) on the causes and background had to be answered (Table 7). *Natural factors/processes without the influence of human beings* were reported for 83 sites. They included mainly storm waves and littoral currents, but also the slumping of the littoral platform, earth quakes and an artificial storm water run-off channel from the 15th century. However, *artificial banks, land reclamation, bank stabilisation (e.g. retaining walls)* and *waves of passing ships (large ships, motorboats)* were of higher importance according to the amount of entries and the weights given. The most important factor which is connected with erosional losses of archaeological substance was the *artificial rising or drop down of the lake water level*. Most of the lake level manipulation dated back to the 19th century and the first years of the 20th century, others were realised during the WW II in the Swiss midlands in the course of agricultural drainage works. The first lake level drop down leading to significant losses was reported for the Zugersee in 1591/92 which caused the slumping of the site Zug-Otterswil/Insel Eielen.

Losses were also dedicated to the *loss of the reed belt and/or the underwater vegetation* which, under ecologically intact conditions, protect the outcropping cultural layers due to its capacity to dissipate wave energy and to enhance sedimentation.

Other background factors were *changes of the wave movement/currents through installations transverse to the banks (e.g. breakwaters)* and *underwater dredging (gravel and sand extraction, deepening of waterways, etc.)* which may had led to losses due to their sheer existence but also, in the long term, due to modification of the wave climate. Waterside leisure facilities and activities (*lido, leisure facilities, anchoring of boats or permanent mooring locations)* which may harm cultural layers and timbers directly formed another important factor complex.

Other factors which were named in the questionnaire had nothing to do with erosion.

[3] statistical test: logistic regression with the scores (ordinal scaled) on the $\log_{10}$ of lake surface area

According to the results from this questionnaire the effects of natural wave action did not depend on lake size. However, the effects of *waves of passing ships*[4] and *anchoring of boats or permanent mooring locations*[5] increased significantly parallel to the lake surface area.

Table 7:

Questionnaire results: answers to the question *What do you think is the reason for the losses through erosion (possibly also corrosion of construction timber, slumpings) in the stations or their immediate surroundings?* –Figures – number of sites (total number 118 valid responses); see Table 6 for further explanations.

	W0	W1	W2	W3	W4	n.a.
… natural factors/processes without the influence of human beings (if so, which?)	45	16	13	3	6	35
… artificial rising or drop down of the lake water level (if so, in which year?)	60	1	5	11	40	1
… artificial banks, land reclamation, bank stabilisation (e.g. retaining walls)	62	5	3	30	12	6
… harbour, swimming pier/landing stage, landing stages for (large) ships	59	9	8	5	11	26
… underwater dredging (gravel and sand extraction, deepening of waterways, etc.)	65	4	3	2	8	36
… lido, leisure facilities	65	16	6	5	3	23
… disturbance through berthing and departurering ships (e.g. passenger ships)	61	8	12	3	5	29
… waves of passing ships (large ships, motorboats)	23	21	19	8	19	28
… changes of the wave movement/currents through installations transverse to the banks (e.g. breakwaters)	72	2	4	4	7	29
… loss of the reed belt and/or the underwater vegetation	41	11	6	7	10	43
… anchoring of boats or permanent mooring locations with single buoys or in a buoy field	43	9	16	3	7	40
… reduced sediment yield through inflows	75	1	1	0	0	41
… other (please specify:)	85	0	3	23	0	7

[4] statistical test: logistic regression with the scores (ordinal scaled) on the $\log_{10}$ of lake surface area, logLikelihood (difference full-reduced model) = 2.07, df = 1, chi^2 = 4.14, p = 0.04

[5] statistical test: logistic regression with the scores (ordinal scaled) on the $\log_{10}$ of lake surface area, logLikelihood (difference full-reduced model) = 2.26, df = 1, chi^2 = 4.52, p = 0.03

3.4.4 Question: *Is multi-annual erosion monitoring carried out in the station?*

The fourth question should clarify the extent of site-specific monitoring programs in case of erosive load. The results refer to the total number of 148 sites represented in the completed questionnaires (Table 8). In 90 sites some kind of monitoring was or is currently performed. The monitoring lays mainly in *archaeological controls (state of the occupation layer, construction timber),* and secondly in the deployment of some kind of *erosion markers* (48 sites). As a rule, the markers consisted of wooden poles with one or more markings along which the present distance to the floor, sediment or archaeological strata, could be measured. In 30 sites *repeated measurement of the lake bed level* with modern surveying technology was performed. The works were occasionally supplemented by photographic documentation.

In 50 sites only one option was established, in an additional 33 sites two or three monitoring techniques were realised.

Table 8:

Questionnaire results: answers to the question *Is multi-annual erosion monitoring carried out in the station?* – Figures – number of sites (total number 148 sites); see Table 6 for further explanations.

	W0	W1	W2	W3	W4	n.a.
… by means of archaeological controls (state of the occupation layer, construction timber)	51	7	38	10	28	14
… repeated measurement of the lake bed level	79	2	21	4	3	39
… erosion marker (if so, which type?)	76	0	14	4	20	34
… other (please specify:)	103	0	7	0	1	33

3.4.5 Question: *Were erosion protection measures carried out in the period until 2014/2015?*

In 36 littoral pile dwelling sites (24 %) some kind of protection measures had been carried out (Table 9). The most frequent kind of measure was the *removal of buoy berths or buoy fields or anchoring prohibitions* which was started as early as in the 1980s and 1990s in two sites, and in 2014 and 2015 in most other cases. *Prohibition for boats to drive in these areas* came a close second. Such restrictions were mandated in the 1980s, in six cases not until 2011. In 13

sites *coverings with sand/gravel/detritus fillings (without geotextiles)* and *coverings with geotextiles plus sand/gravel/detritus fillings* (10 sites) were conducted. In most sites the works started in the 1980s and 1990s and stretched over a couple of years. In the most recent years (2014, 2015) measures in only two sites were initiated. In another 8 cases *palisades, sheet pilings, breakwaters, etc.* were constructed, mostly in the 1980s.

Other types of protection measures like *covering with geotextiles, possibly fixed with reinforcement steel mesh (without filling), resettlement of shore vegetation* and *removal/chamfer of bank walls, block stone fillings, etc.* were of minor importance.

Other measures comprised the protection of erosional scarps and excavation profile walls with gabion-like geotextile tubes, and clearing of stranded flotsam together with cutting of washed-out trees to save them from falling.

Table 9:

Questionnaire results: answers to the question *Were erosion protection measures carried out in the period until 2014/2015? If so, in which year was the finish of this measure?* Number of sites (total number 148 sites); no scores were assigned.

	No. of Sites	**Years (No. of Sites)**
… covering with geotextiles, possibly fixed with reinforcement steel mesh (without filling)	*2*	*1994, 2001*
… covering with sand/gravel/detritus fillings (without geotextiles)	*13*	*1980s – 1990s (n=8)*
… covering with geotextiles plus sand/gravel/detritus fillings	*10*	*1990s – 2012 (n=6)*
… complete filling up to the water surface with/without subsequent use	*0*	
… palisades, sheet pilings, breakwaters, etc.	*8*	*1980 (n=6)*
… resettlement of shore vegetation (especially reed plants, reedbeds, riparian woodland)	*2*	*1995*
… removal of buoy berths or buoy fields or anchoring prohibitions	*19*	*2014, 2015 (n = 8)*
… prohibition for boats to drive in these areas (especially motorboats, passenger ships)	*17*	*1980s (n=10) 2014-2015 (n=3)*
… reduction of the driving speed of motorboats (especially passenger ships)	*0*	
… relocation of shipping routes	*1*	*1984*
… removal/chamfer of bank walls, block stone fillings, etc.	*2*	*1995*
… other (please specify:)	*4*	

3.4.6 Question: *Are or have investigations involving environmental science been carried out regarding the causes and condomitants of the erosion?*

The last question aimed to identify investigation programs into the causes and attendant circumstances of the erosion (if it occurred in the sites considered). 37 out of 543 relevant sites were involved in such programs (Table 10). In most cases miscellaneous investigations on local bathymetry, micromorphology of sediments etc. were undertaken. Only on Lake Constance and Lake Biel concerted measurements and modeling of winds, waves, currents, sediment quality and solid matter transport were undertaken in the frame of interdisciplinary projects, financed by third-party funds. The results of the EROSEE project (Lake Biel) and the INTERREG IV project *Erosion und Denkmalschutz am Bodensee und Zürichsee* can be downloaded from the website or are otherwise published (Brem et al. 2013).

The cooperative *HyMoBioStrategy* project which is currently running on Lake Constance (2015 – 2018) is not yet included in this list (www. http://hymobiostrategie.de).

Table 11:

Questionnaire results: answers to the question: *Are or have investigations involving environmental science been carried out regarding the causes and condomitants of the erosion?* Investigation programs and number of sites involved (total number 148 sites); no scores were assigned.

Program	Lake (Sites)	No. of sites	Time Frame
cooperation with Federal State institutes (not specified)	*Keutschacher See (AT); Mondsee (AT)*	*2*	*2014; 2015*
micromorphology	*Zugersee (Lake Zug) (CH)*	*1*	*ongoing*
EROSEE (http://www.erosee.org)	*Lac de Bienne (Lake Biel) (CH)*	*1*	*2007*
bathymetric studies (not specified)	*Lac de Neuchâtel (Lake of Neuchâtel) (CH)*	*3*	*ns*
Interreg IV Program "Erosion und Denkmalschutz am Bodensee und Zürichsee" (http://www.erosion-und-denkmalschutz-bodensee-zuerichsee.eu/willkommen.html; Brem et al. 2013)	*Lake Constance (Obersee, Untersee) (CH, DE)*	*4*	*2008 - 2011*
studies (not specified)	*Lac de Chalain (FR)*	*ca. 23*	*2000 - 2008*
bathymetric studies and others (not specified)	*Lago di Varese (IT)*	*2*	*ns*
dendrochronological studies (not specified)	*Lago di Viverone (IT)*	*1*	*ns*

Summary and Conclusions

The published literature reports that cultural layers and pile fields of many prehistoric sites along Alpine lakeshores are subjected to an enduring destruction due to wave action and littoral erosion. Based on information from the *Palafittes Database*, a questionary was developed and distributed to local specialists in the competent monuments authorities in AT, CH, DE, FR and IT. The objectives were (i) to concisely collate the current knowledge of the present risk situation of lakeshore pile dwelling monuments of getting eroded, and (ii) to identify the main causes and concomitant circumstances.

Out of a total 797 pile dwelling sites in the *Palafittes Database*, 543 were classified as lake littoral sites in the stricter sense which can potentially be affected by waves and sediment transport, or might be subjected to waterborne activities. By far the most sites are located in Switzerland, followed by Germany and France. 82.5 % of littoral sites and 94.4 % of the total area of sites are situated around large and very large lakes with surface areas of 10 km^2 and above.

A total of 129 completed questionnaires returned, covering 148 littoral sites represented 27 % of all lakeshore sites. Losses of archaeological matter were reported for 132 sites. The most important factor was *flushing out of occupation layers caused by erosion (waves, currents)*, by which 91 stations were affected to at least a moderate degree. All sites around lakes with less than 1.0 km^2 surface area did not show any sign of erosion. Concerning the causes and backgrounds of erosional losses, *artificial banks, land reclamation, bank stabilisation (e.g. retaining walls), waves of passing ships (large ships, motorboats)* and the *artificial rising or drop down of the lake water level* were of highest significance.

In 90 sites a monitoring of the preservation status was, or is currently performed. The monitoring lays mainly in *archaeological controls (state of the occupation layer, construction timber),* and secondly in the deployment of some kind of *erosion markers* like wooden poles In 36 sites some kind of protection measure had been carried out. The most frequent type was the *removal of buoy berths or buoy fields or anchoring prohibitions.* In 13 sites *coverings with sand/gravel/detritus fillings (without geotextiles)* and *coverings with geotextiles plus sand/gravel/detritus fillings* (10 sites) were conducted. Only on Lake Constance and Lake Biel concerted measurements and modeling of winds, waves, currents, sediment quality and solid matter transport were undertaken in the frame of large interdisciplinary projects.

In conclusion, the amount of present knowledge of the erosional destruction of prehistoric pile dwelling remains in the lake littoral is fairly large but widely scattered. Structured questionnaires distributed to local experts are useful tools for screening the significance of certain factors in order to organise interdisciplinary research projects and preservation programs.

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Appendix

Questionnaire: State of preservation of lakeshore stations of UNESCO World Heritage Sites

Dear colleagues,
the nomination documents of the World Heritage "Prehistoric Pile dwellings around the Alps" showed that many stations are threatened by bank erosion. The International Coordination Group*, in cooperation with the Limnological Institute at the University of Konstanz, took this as an occasion to retrieve some information about the current condition. We would be obliged if you fill in the questionnaire based on currently available information and return it by 12 June 2015 electronically to* info@palafittes.org *or as a paper copy to:* Aixa Andreetta, c/o Archäologie Schweiz, Petersgraben 51, 4051 Basel, Switzerland *!*
With many thanks for your support and with collegial regards
Aixa Andreetta, International Coordination Group

Your name : ……
Institution : ……..……
Email : ……

Details for filling in the questionnaire:
(1) The questionnaire refers to "UNESCO World Heritage Sites" (WH/S1) ***and*** "Associated Pile Dwelling Sites" (AS/S2). Every page of this questionnaire offers space for 3 of these Heritage Sites. Please use additional pages for additional Heritage sites and name them respectively
(2) The questionnaire ***only*** to those station or parts of stations, the occupation layer and/or pile fields of which lie underneath the average present-day water level of the respective lake. Stations which are situation in moors or towards the landside of the shores are **not** taken into consideration.
(3) The Code describes the severity code, the significance or the areal expansion: **n.s.** – not specified/unknown/not examined; **0** – not available/not relevant/of no account; **1** – little significance, severity or area proportion; **2** – moderate importance, etc.; **3** – high significance, etc.; **4** – very high, paramount significance, etc. – Please only enter one (!) code, even if you think it is not specified (= n**.** s.) or if the alternative concerned is not relevant according to your assessment (= **0**).

	Station 1 (Code/Name)	Station 1 (Code/Name)	Station 1 (Code/Name)
(1) When was the first time (year) the station was examined (probes, excavations, pile field examinations) by versed personnel (archaeologist, trained laymen)?	Year:	Year:	Year:
(2) Have there been losses of substance of the site since the first examinations (see above)?	Please enter a code: n.s. / 0 / 1 / 2 / 3 / 4		
… through unsystematic excavations/collections, etc. (mostly during the first years)			
… through illegal excavations/unauthorised collections			
… through authorised excavations/collections/construction timber retrieval by experts, etc.			

… through lake bed slumping			
… through flushing out of occupation layers caused by erosion (waves, currents)			
… through corrosion of building timber			
… through roots of reed/marsh plants or riparian woodland			
… burrowing activities etc.of animals (crustaceans, fish, water birds, mammals)			
… other (please specify:)			
(3) What do you think is the reason for the losses through <u>erosion</u> (possibly also corrosion of construction timber, slumpings) in the stations or their immediate surroundings?	Please enter a code: n.s. / 0 / 1 / 2 / 3 / 4		
… natural factors/processes without the influence of human beings (if so, which?)			
… artificial rising or drop down of the lake water level (if so, in which year?)	Code: Year:	Code: Year:	Code: Year:
… artificial banks, land reclamation, bank stabilisation (e.g. retaining walls)			
… harbour, swimming pier/landing stage, landing stages for (large) ships			
… underwater dredging (gravel and sand extraction, deepening of waterways, etc.)			
… lido, leisure facilities			
… disturbance through berting and departurering ships (e.g. passenger ships)			
… waves of passing ships (large ships, motorboats)			
… changes of the wave movement/currents through installations transverse to the banks (e.g. breakwaters)			
… loss of the reed belt and/or the underwater vegetation			
… anchoring of boats or permanent mooring locations with single buoys or in a buoy field			
… reduced sediment yield through inflows			
… other (please specify:)			
(4) Is multi-annual erosion monitoring carried out in the station?	Please enter a code: n.s / 0 / 1 / 2 / 3 / 4		
… by means of archaeological controls (state of the occupation layer, construction timber)			
… repeated measurement of the sea bed level			
… erosion marker (if so, which type?)			
… other (please specify:)			
(5) Were erosion protection measures carried out in the period until 2014/2015? If so, in which year was the finish of this measure?	Please enter the year and a code: n.s. / 0 / 1 / 2 / 3 / 4		
… covering with geotextiles, possible fixed with reinforcement steel mesh (without filling)	Code: Year:	Code: Year:	Code: Year:
… covering with sand/gravel/detritus fillings (without geotextiles)	Code: Year:	Code: Year:	Code: Year:
… covering with geotextiles plus sand/gravel/detritus fillings	Code: Year:	Code: Year:	Code: Year:
… complete filling up to the water surface with/without subsequent use	Code: Year:	Code: Year:	Code: Year:
… palisades, sheet pilings, breakwaters, etc.	Code: Year:	Code: Year:	Code: Year:
… resettlement of shore vegetation (especially reed plants, reedbeds, riparian woodland)	Code: Year:	Code: Year:	Code: Year:
… removal of buoy berths or buoy fields or anchoring prohibitions	Code: Year:	Code: Year:	Code: Year:

… prohibition for boats to drive in these areas (especially motorboats, passenger ships)	Code: Year:	Code: Year:	Code: Year:
… reduction of the driving speed of motorboats (especially passenger ships)	Code: Year:	Code: Year:	Code: Year:
… relocation of shipping routes	Code: Year:	Code: Year:	Code: Year:
… removal/chamfer of bank walls, block stone fillings, etc.	Code: Year:	Code: Year:	Code: Year:
… other (please specify:)	Code: Year:	Code: Year:	Code: Year:
(**6) Are or have investigations involving environmental science been carried out regarding the causes and condomitants of the erosion?**	yes /no :	yes /no :	yes /no :
… if so, please specify and name year:			

Other comments: