NATURAL SWIMMING POOLS (NSPs) – PRINCIPLES AND TRIALS WITH SITE- CONFORM VEGETATION

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1 ABSTRACT
Natural swimming pools (NSPs) offer a new way to swim in fresh water that has not been treated with chemicals or preservation agents. Only biological processes purify the water. (Kircher & Thon, 2016, derived from FLL, 2006 & 2011). NSPs are purified by three different filtering methods, which effect either a phosphorus (P-) or a carbon (C-) limitation to guarantee clear water and low string-algae stock. Awareness of growth control by limitation of one nutrient is derived from basic plant nutrition research from Sprengel and v. Liebig (Liebig, 1876), transferred on anthropological NSPs including normative regulations such as FLL 2006 & 2011 and Önorm 2013. As a side product of the Phosphorus limitation, the nitrogen content in NSP waters tends to oligotrophic conditions. Most plants, which are generally used on filter bodies in NSPs, grow weakly and show severe deficiency symptoms (Kircher, 2007). The authors tested plants from oligotrophic bogs and fens on filter bodies of the “Technical Wetland” principal with three different variants of water percolation. These trials were run at Anhalt University to find resilient plant combinations for filter zones of NSPs. Good results were achieved mainly from fen plants, which are recommended for P-limited pools, since these comprise the necessary water hardness and a high pH value. For C-limited systems with low hardness, plants from acidic bogs are suitable. Sphagnum mosses however must be selected carefully since capabilities of Sphagnum species depend strongly on the water percolation.

1.1 Keywords
natural swimming pool, planting design, nutrients, water purification, bog, fen, Sphagnum
2 INTRODUCTION

Natural swimming pools (NSPs) are sealed against the subsoil and comprise a swimming area and a regeneration area. They are designed especially for swimming. Water must not be treated with any chemicals or UV radiation (FLL, 2006; ÖNORM, 2013; Grafinger 2004). NSPs integrate well into the environment, are gentle on eyes and skin. Only biological processes purify the water so there are no harmful side effects of chlorine, chlorine dioxide, mineral salts, organic biocides or ozone, which usually are added to the water of conventional swimming pools. Chemical treatment as well as UV radiators are not acceptable in natural pools because it reduces or disables the desired biological activity (Kircher & Thon, 2016, derived from FLL, 2006 & 2011).

NSPs can play an important role as a part of stormwater management by reducing the discharge speed of rainwater and unburden local sewage systems (Thon, 2009, Dunnett & Clayden, 2007).

In private gardens NSPs promote the biodiversity by increasing the flora and fauna species compared to a conventional garden design which emphasises lawn or monoculture plantings (see Thon, 2009, Abromas, Grecevicius, Marcius, 2007).

2.1 Filtration types of NSPs

Depending on scientific results of the trial at Anhalt University, on water movement, filtration techniques, partitioning and construction type of the swimming area the authors distinguish between four models of NSPs (table 1):

1. Standstill water body: densely planted filter zone (=“Hydrobotanical System”)
2. NSP with surface flow + Hydrobotanical System (HBS)
3. NSP with percolated planted filter bed (=Technical Wetland; TWL) + Hydrobotanical System
4. NSP with quickly percolated filter bed (= Biofilm accumulating Substrate Filter; BSF).

Microorganisms developing on the surfaces of the filter granulate form a biofilm that provides a very effective filtration. In Type 4 plants function as a decoration only (FLL, 2006; ÖNORM, 2013).

<table>
<thead>
<tr>
<th>Limological classification and planting</th>
<th>Hydrobotanical System (1)</th>
<th>Hydrobotanical System (2)</th>
<th>Technical Wetland (3)</th>
<th>Biofilm accumulating Substrate Filter (4)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Limological classification and planting</td>
<td>Standing water body with densely planted filter zone without surface flow or water movement</td>
<td>Slowly perfused with densely planted filter zone with surface flow</td>
<td>NSP with slow and possibly intermittently percolated, planted filter bed; should be combined with a Hydrobotanical System</td>
<td>Intensively, mainly vertically percolated filter beds with high water permeability, planted only for decoration. Permanent fast water movement</td>
</tr>
<tr>
<td>Main purification</td>
<td>Plants and plankton</td>
<td>Plants and plankton</td>
<td>Substrate, helophytes and microorganisms adjacent to roots and stems</td>
<td>Microorganisms developing on the surfaces of the filter granulate form a biofilm which provides a very effective filtration</td>
</tr>
<tr>
<td>Maintenance requirements</td>
<td>Trimming and harvesting plants</td>
<td>Trimming and harvesting plants</td>
<td>Trimming and harvesting plants</td>
<td>Regularly backwashing the Substrate Filter</td>
</tr>
</tbody>
</table>

Physical treatment, such as UV radiation, subsonic devices, copper salts and any items, which effect a non-selective impact on the water biology do not meet the requirements of guidelines for NSPs (FLL, 2011, ÖNORM, 2013). To guarantee clear water and a low string-algae stock, either phosphorus (P-) or carbon (C-) limitation should be envisaged (see Jaksch, Wesner & Fuchs, 2013).

Inundated zones of meso- to eutrophic standing waters accommodate a diverse range of plant species. In NSPs with percolated filter systems, such as Technical Wetlands, the nitrogen level constantly declines to a
very low level due to nitrification and denitrification processes (Baumhauer & Schmidt, 2008). The low nitrogen content will even effect oligotrophic conditions. Thus, most plants, which are generally used on filter bodies, grow weakly, mainly in NSPs of type 3 and 4 (Kircher & Thon, 2016).

2.2 Partitioning types of NSPs

Natural swimming pools can be designed as a single unit or as a series of two or more water bodies. The regeneration area comprises the filter as Hydrobotanical System, Technical Wetland or rather Biofilm accumulating Substrate Filter.

Partitioning type **A**

In situ: Regeneration area completely within the swimming area
(single-chamber system)

Partitioning type **B**

In situ + ex situ:
Regeneration area partly outsourced
(here: multiple-chamber system)

Partitioning type **C**

Ex situ: Regeneration area completely outsourced
(here: double-chamber system; the regeneration area could also comprise several bodies)

Figure 1. Schematic Partitioning Types for NSPs (Kircher & Thon, 2016)
2.3 Construction types of NSPs

The following principle-sketches show simplified sections of four possibilities how to frame the swimming zone (Kircher & Thon, 2016):

**No wall:** The edges of the swimming area are only modelled into the underground with a more or less steep slope and covered by the sealing. A covering of stones may be set on the slope to embellish its appearance.

**Wall on sealing:** A vertical wall framing the swimming area is constructed on the sealing. Natural stone walls or timber constructions are commonly used. Outside a special substrate is filled between sealing and wall, implementing the filter systems or planting zones.

**Wall under sealing:** The vertical wall defining the swimming area is built with concrete, masonry or special plastic elements. Outside sand is filled up to the intended depth of the regeneration area and compressed. Finally the sealing is placed on top.

**Separate pool** (analogous to partitioning type C): A pool without any regeneration area is built separately (regeneration area completely outsourced). A rectangular pool without any marginal plantings offers the possibility of covering the surface with a protection roller when not in use. This is the easiest variant for converting existing traditional pools into naturally purified ones: from the integrated skimmer the water will no longer be conventionally treated, but bypass through a filtration pool or chamber.

A detailed description of these characters as well as of the following models is given in Kircher & Thon, 2016.

2.4 Principle models of NSPs

The 4 basic models of natural swimming pools are defined according to their filtration equipment. Table 2 shows possible or rather recommended pool constellations.
Table 2: Four hydraulic and filtration types combined with three partitioning types result in nine models of NSPs (derived from Kircher & Thon, 2016)

<table>
<thead>
<tr>
<th>Partitioning type</th>
<th>A: In situ: Regeneration area entirely within the swimming area (single-chamber system)</th>
<th>B: In situ + ex situ: Regeneration area partly outsourced (double- or multiple-chamber system)</th>
<th>C: Ex situ: Regeneration area completely outsourced (double- or multiple-chamber system)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hydraulic &amp; filtration type</td>
<td>1A</td>
<td>---</td>
<td>---</td>
</tr>
<tr>
<td>Standing bodies of water without technical installations only natural circulation</td>
<td><strong>HBS ≥ 65 % densely planted area</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Bodies of water with surface flow water slowly flows through planting zone</td>
<td><strong>HBS ≥ 50 % densely planted area</strong></td>
<td></td>
<td>Not recommended</td>
</tr>
<tr>
<td>Bodies of running water with Technical Wetland filtration Percolation at moderate speed (&lt;300 l/m²/hr) through planted filter bed</td>
<td><strong>TWL + HBS ≥ 30-40 % densely planted area on percolated substrate</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Bodies of running water with Biofilm-accumulating Substrate Filter Controlled fast percolation (&gt;500 l/m²/hr) through substrate filter</td>
<td><strong>BSF ≥ 25 % filter area (≥ 5 - 20 % for professional systems); can be combined with TWL and HBS</strong></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

HBS = Hydrobotanical System; TWL = Technical Wetland; BSF = Biofilm accumulating Substrate Filter

2.5 The limiting factor as main approach to combat algae

According to the rule of the limiting factor from Sprengel and v. Liebig (Liebig, 1876) the main strategy of natural pools is to bring either carbon (C) or phosphorus (P) into minimum to combat algal emergence. These strategies demand contradictory measures to work successfully: C-limitation works best in soft water and at low pH, whilst phosphorus is eliminated through sedimentation as insoluble compounds, such as apatite, in hard water with a pH around 8.3 (Jaksch, Wesner & Fuchs, 2013). Pools of model 1 to 3 will work successfully with both, C- or P-limitation. Model 4-pools should operate with P-limitation only. The biofilm in the BSF grows best with high pH and hard water. To promote this, the filter substrate should contain carbonates, so often dolomite gravel is added. In an NSP it is not only P or C which decreases to very low levels, but also nitrogen. Mainly in facilities of model 3 and 4 (table 2) severe nutrient deficiency symptoms and a very weak and unsatisfactory growth occur at the conventionally used plants (Kircher, 2007). Percolated filter bodies are
mostly completely submerged. The range of plant-species, which accept both, oligotrophic conditions as well as a water level of more than 20 cm, is very restricted (Thon, 2014).

3 PROBLEM STATEMENT AND AIMS AND OBJECTIVES

NSPs are defined by purification of water free from chemicals. Due to nitrification and denitrification processes the N-level is often low. Therefore NSP designers and building companies recommend N fertilization to support the vitality of plants, microorganisms and biofilms. This is not consistent to the authors’ and most NSP-customers’ expectations in terms of a purely natural treatment.

NSPs with Technical Wetland or Biofilm accumulating Substrate Filters comprise limnologically a running water system with a low trophic level. The range of suitable plants for oligotrophic running waters is low (Kircher & Thon, 2016).

A research project at Anhalt University, Bernburg, aimed in testing alternative plantings of helophytes on filters and banks of NSPs, which provide an inundated substrate body with a shallow water level (Thon, 2014). The tested plant ranges derive from experiences made with pilot projects of model 2- and 3-pools (Kircher, 2007). Peat mosses (Sphagnum species) dominate certain types of acidic bogs. They even decrease the pH by their ability to exchange absorbed nutrient-cations with H+. Besides testing plant species for their suitability in terms of sustainable vitality the trial should proof, if Sphagnum mosses were able to thrive in NSPs and their impact on string-algae growth. In P-limited NSPs it is crucial to minimize the influx of phosphorus with the refilling water, so the plants’ transpiration should be as low as possible, which also was assessed in the trial.

Trial objectives of the research project at Anhalt University, Bernburg at a glance:

- Finding recommendable plant ranges to use on filter zones of NSPs with hard water (P-limitation, models 1-4, mainly model 4, or soft water (C-limitation; models 1-3)
- Testing the possibility to reduce string algae development by Sphagnum mosses
- Reducing water losses by using plants with a low transpiration rate

Besides the scientific approach to gain more information about the interaction of water quality and plantings in NSPs the authors intend to inform professionals about site conform plantings, which ensure its lush and vital development.

4 METHODS

The authors run the following experimental setup to comply with the objectives stated above. Plants from oligotrophic bogs and fens were tested on filter bodies of the “Technical Wetland” principal. In difference to Biofilm accumulating Substrate Filters this purification method allows hard water as well as soft water (aiming P- or rather C-limitation).

Wooden containers, sealed with a PVC liner (l x w x h = 1,15m x 0,9m x 0,80m) represented smaller sized NSPs of model 3A (see table 2). As filter area (TWL) plastic boxes (l x w x h = 0,80 m x 0,60 m x 0,60 m) were inserted and filled with a substrate: mixture of 50% rhyolite-gravel and 50% lime-gravel (grain sizes in stratification according to the section drawing below). As substrate for the “acidic bog” planting variant (see below) only pure rhyolite (siliceous magmatite) was used.

By investigating plant ranges in oligotrophic natural wetland habitats a significantly higher amount of species occur on emerged sites (bogs and fens), not on inundated sites. For that reason the surface of the filterbodies in the trial were adequately located about 5 cm above water level.
Factor vegetation:

1. Without planting
   - Cover layer according to planting
   - 4 cm → 2/5 mm
   - 10 cm → 2/16 mm
   - 20 cm → 16/32 mm

2. Conventional planting
   - Cover layer = Sand + standard substrate
   - (“Patzer-Einheitserde”) 1:1
   - Plants per replicate:
     1. Acorus calamus
     2. Carex elata
     3. Myosotis palustris
     4. Mentha cervina
     5. Typha shuttleworthii
     6. Lythrum salicaria
     7. Iris pseudacorus
     8. Caltha palustris

3. Lime fen
   - Cover layer = Sand + bog peat 1:1
   - Plants per replicate:
     1. Allium suaveolens
     2. Eriophorum latifolium
     3. Carex viridula
     4. Carex davalliana
     5. Parnassia palustris
     6. Epipactis palustris
     7. Dactylorhiza Hybr.

4. Acidic bog
   - Cover layer = bog peat
   - Plants per replicate:
     1. Eriophorum vaginatum
     2. Sarracenia purpurea
     3. Erica tetralix
     4. Pogonia ophioglossoides
     5. Narthecium ossifragum
     6. Vaccinium oxycoccos
     - Covered with Sphagnum palustre

Factor percolation:

1. Not actively percolated:
   - wall of the plastic box perforated:
     122 holes with 13 mm Ø

2. Percolated top - down:
   - 1500 l/m²/day;
   - On/off in 30 minute intervals

3. Percolated bottom - up:
   - 1500 l/m²/day;
   - On/off in 30 minute intervals

Three variants of plantings (factor vegetation) and three variants of percolation through the filter (factor percolation) were tested by the authors with four replicates (two per container). “Conventional planting” means...
helophyte species, which are mostly used on filter zones of NSPs. Most of these species do naturally occur in meso- to eutrophic wetlands. "Lime fen" represents a mixture of species from oligo- to mesotrophic fens with a distinct lime content, effecting an accordingly high pH. "Acidic bog" consists in species from meso- to oligotrophic bogs with very low carbonate content. The pH of the latter is usually below 6. The trials were installed in 2007, assessments followed in 2008, 2009, 2010; further observations - until 2014. Total phosphorus (Ptot), nitrate (NO3) and carbonate hardness (KH) were analyzed. Besides the water quality, water loss due to transpiration, algae growth (dry weight of string algae) and plant vitality were assessed in the trials at Anhalt University managed by Prof. Dr. Kircher.

Increasing the replicates was not possible for monetary reasons. A further research project on a larger scale of NSPs with standardized methods of influencing factors is in progress.

5 RESULTS:

Table 3 shows the enormous fluctuations of dissolved phosphorus (Ptot). The ammonium content was low enough to keep it unmentioned. The very low nitrate values refer to oligotrophic conditions.

Table 3: Measured values in the pool water 31st calender week 2009 (ranges of individual measurements) (Table by the authors).

<table>
<thead>
<tr>
<th>Variant</th>
<th>P\textsubscript{tot} / µg/L</th>
<th>NO\textsubscript{3} / mg/L</th>
<th>KH / mmol/L</th>
</tr>
</thead>
<tbody>
<tr>
<td>Without planting</td>
<td>4,7 – 215,2</td>
<td>&lt; 1</td>
<td>0,4 – 0,8</td>
</tr>
<tr>
<td>Conventional planting</td>
<td>4,7 – 359,5</td>
<td>&lt; 1</td>
<td>1,3 – 1,4</td>
</tr>
<tr>
<td>Lime fen planting</td>
<td>2,4 – 42,6</td>
<td>&lt; 1</td>
<td>1,0 – 1,6 (3,6)</td>
</tr>
<tr>
<td>Acidic bog</td>
<td>23,6 – 288,5</td>
<td>&lt;1 - 4</td>
<td>0,3 – 1,0</td>
</tr>
</tbody>
</table>

It were mainly the fen plants, which brought good results concerning visual effect of the planting and low evapotranspiration losses. Fen vegetation is recommended for P-limited pools, which comprise the necessary water hardness and a high pH value. For C-limited systems with low hardness, plants from acidic bogs have been proven suitable.

NSPs without fertilization can reproduce good water quality with low algae growth though the poor nutrient content will also reduce the activity of microorganisms and biofilm. The comparison of the string algae’s dry weight showed significantly differences between the four planting variants. Figure 4 shows the results from the measurements in 2009. The significantly lowest string algae production occurred in the acidic bog variants, but also the top-down percolated lime fen plots were rated similarly low. Sphagnum mosses formed attractive cushions and could reduce the emergence of string algae in the pool water, though they effect a great fluctuation of the pH. Sphagnum palustre thrived in standstill water, whilst on percolated filters only Sphagnum squarrosum worked well. From these results as well as from practical experiences with case studies of NSPs (Kircher, 2007) the authors derived recommendations for plant combinations in P- and C-limited pools in Kircher & Thon (2016).
Figure 4: Dry weight of string algae in the pool water 2009. Different letters above the variants show significantly different results (T-Test; \( \alpha = 0.5 \)) (figure by the authors).

Even in 2009, in which the conventional vegetation still showed good growth, the acidic bog plots lost more water by evapotranspiration than all other variants. Though Sphagnum-mosses form dense cushions, their transpiration rate must not be underestimated! The water loss effected by lime fen plots was not significantly higher than the loss of non-planted filters. The influence of the percolation direction was low, but bottom-up percolation effected significantly more transpiration than non-percolated plots.

Figure 5: Refilled water in 2009. Different letters above show significantly different results (T-Test; \( \alpha = 0.5 \)) (figure by the authors).
6 DISCUSSION AND CONCLUSIONS:

Mainly on Biofilm accumulating Substrate Filters (BSF), as used in NSPs of model 4, a planting with vegetation from oligotrophic lime fens is site conform, since this technology aims in lime containing hard water with a pH up to 8.4 to support P-limitation (ÖNORM, 2013). Typical lime fen species thrive on saturated substrate rising slightly above water level.

Kircher & Thon (2016) show planting lists for NSPs with lime fen plants in wetland and swamp area plus appropriate species in the neighbored areas. The distribution pattern follows the strategy of randomly mixed plantings according to Kircher et al. (2011). The fen vegetation reduces water loss through transpiration, so there is less need for refilling.

NSPs, which aim C-limitation, provide soft water and can look very attractive if surrounded with Sphagnum moss carpets in the wetland and swamp zone. Within the Sphagnum layer, attractive specialists of acidic bogs can thrive. In addition, the emergence of string algae can be low in a pool with Sphagnum vegetation, which supports C-limitation. It is an option only for NSPs of model 1, 2 and 3 and works best in a moist climate with cool summers and low evapotranspiration rates. Under such conditions, the high transpiration rate of Sphagnum mosses will be acceptable. Sphagnum palustre is suitable for areas with limited NSPs. The listed species proofed to be successful in the described trials or rather in several case studies (Kircher, 2007).

Table 4 lists recommendable species for plantings on filter zones, which provide a wetland habitat slightly above water level for P- as well as for C- limited NSPs. The listed species proofed to be successful in the described trials or rather in several case studies (Kircher, 2007).

Table 4: recommended plant species for C- and P-limited NSPs, hardy in Central Europe, to be used on TWL filters if the substrate protrudes 0 – 5 cm above water level (table by the authors).

<table>
<thead>
<tr>
<th>Plants for P-limitation (species from oligo- to mesotrophic fens and close related sites)</th>
<th>Plants for C-limitation (species from oligo- to mesotrophic bogs and close related sites)</th>
</tr>
</thead>
</table>

7 SUMMARY:

Depending on water movement, filtration techniques, partitioning and construction type of the swimming area the authors distinguish between four models of natural swimming pools (NSPs). To guarantee clear water and a low string-algae stock, either a phosphorus (P-) or a carbon (C-) limitation should be achieved. Parallel to this the nitrogen content in the water will tend to oligotrophic conditions. Most plants, which are generally used on filter bodies in NSPs, grow weakly. In trials at Anhalt University plants from oligotrophic bogs and fens were tested on filter bodies of the “Technical Wetland” principal with three different variants of water percolation. Good results were achieved mainly with lime-fen plants, which are recommended for P-limited pools, since these comprise the necessary water hardness and a high pH value. For C-limited systems with low hardness plants from acidic bogs are suitable.

Sphagnum mosses formed attractive cushions and could reduce the emergence of string algae in the pool water, though they effected a great fluctuation of the pH. Sphagnum palustre thrived in standstill water, whilst on percolated filters only Sphagnum squarrosum worked well. Recommendations for plant combinations in P- or C-limited pools are given.
REFERENCES:
CELA MEDIA STATEMENT

NATURAL SWIMMING POOLS (NSPS) – PRINCIPLES AND TRIALS WITH SITE- CONFORM VEGETATION

Prof. Dr. Andreas Thon, Hochschule Geisenheim University, Geisenheim, Germany. Andreas Thon teaches and researches in landscape construction. He is interested in NSPs, irrigation and water filtration techniques.

Prof. Dr. Wolfram Kircher, Anhalt University, Bernburg, Germany. Wolfram Kircher teaches and researches in planting design and vegetation techniques. His main interest is in NSPs, perennial plantings, maintenance techniques, greening of buildings.

MEDIA STATEMENT:

Natural swimming pools (NSPs) offer a new way to swim in fresh water that has not been treated with chemicals. Only biological processes purify the water by different filtering methods. As a side effect of the filtering, the nitrogen concentration declines, which causes weak growth of most traditionally used plants. In trials at Anhalt University, Bernburg, plants from nutrient-poor bogs and fens were successfully tested on “Technical Wetland” filters. The authors give application recommendations in their presentation and in their book “How to Build a Natural Swimming Pool” (2016, Filbert Press, UK).