Establishment of alvar conditions in the artificial lake of Albrunna limestone quarry, Degerhamn – current conditions, immediate problems and possible solutions

David Alvunger, Håkan Johansson, Emelie Nilsson, Johanna Sunde, Jesper Svensson
Institution of Natural Sciences, Linnaeus University, Kalmar, 2012

Albrunna limestone quarry is located amidst Stora alvaret on Öland, Sweden. The environment of Stora alvaret is unique and protected by Natura 2000 network. Further, the landscape is assigned as a world heritage site by UNESCO. Considering the previous degradation of this kind of environment, due to overgrowth, it is of importance to investigate possible rehabilitation efforts. According to European Union conservation politics, lakes of the kind found on the alvar is of special priority. Therefore the primary focus of this study is the artificial lake located in the Albrunna limestone quarry. This lake was compared to a nearby alvar lake, Resmoväten, to investigate if any significant differences could be found. Alvar lakes are typically low producing and are characterized by a clear water state, therefore focus was placed on comparisons between these functions. The results showed two main differences: the artificial lake has a different sediment composition compared to the alvar lake and the conductivity level in the artificial lake was approximately four times higher than expected. Based on these findings some possible rehabilitation efforts to enhance the similarities with an alvar lake are proposed.

A successful rehabilitation will result in a more alvar lake like state and will add important functions of an alvar lake ecosystem that is now missing in the artificial lake. One such function is to support a large variety of insects, which in turn serve as a food source for higher trophic levels, e.g. birds. One specific bird species of interest in this case is the nearly threatened Sand Martin (*Riparia riparia*) which has been observed nesting in the quarry. In an effort to help the Sand Martin, artificial nesting burrows were created close-by the old burrows to be able to compare them. The subject of comparison was the location of the burrows; the old burrows are located over water and the new over ground. The Sand Martins chose to nest in the old burrows. They are known to scout for nesting sites a year in advance and therefore further studies, in the next years, should be done for a more accurate evaluation.

KEYWORDS: ALVAR LAKE, SEDIMENT, PHOSPHORUS, CALCIUM, ALUM SHALE, OLIGOTROPHY, SAND MARTIN

Introduction

Albrunna limestone quarry covers roughly 500 hectares and is located amidst Stora alvaret – the largest continuous patch of alvar in the world – on Öland, Sweden. Considering the limited occurrence of alvar ecosystems on earth, combined with its large number of rare and endemic species, it's clear that Stora alvaret is of high biological and cultural interest. It is included in the Natura 2000-network as a protected area, and on UNESCO's world heritage list. Previously alvar lakes has degraded and lost functions due to overgrowth (Ekstam & Forshed, 2002), and it is therefore of interest to utilize opportunities to establish this kind of ecosystem. In accordance with the EEC habitats directive 31:40, priority should be given to "hard oligo-mesotrophic waters with benthic vegetation of *Chara spp.*" (Council directive 1992/43/EEC). A possibility for the development of such an ecosystem is presented in the Albrunna limestone quarry, where a ten hectare artificial lake is located. Rehabilitation efforts in Albrunna should be focused on developing alvar habitats, preferably with methods that won't interfere with ongoing quarrying so that this development can begin as soon as possible.

The artificial lake is one of few large open water bodies on Stora alvaret and is located in the southwestern part of the quarry. Due to its low altitude, runoff and groundwater from the surrounding area flows into the lake. Because of this, leachate can be expected to have a high impact on water quality and composition. Of special concern are the two landfills located in the northern part of the quarry. The landfills are used to dispose of cement kiln dust (CKD). CKD is a waste product from cement production in Cementa's factory in Degerhamn 3 km north of the quarry and consists mostly of calcium oxide, silicon dioxide and metals. Leachate from the landfills is routinely monitored in order to discover any leakage.

Characteristics of alvar ecosystems

The limestone of Stora alvaret consists of a large uniform layer resting on top of shale (alum and clay) and sandstone (Ekstam & Forshed, 2002). Thin layers of soil with low fertility and a weak ability to preserve water (Sand-Jensen *et al.*, 2010; Ekstam & Forshed, 2002) makes the environment stressful for plants and explains the adaptations found in these (Ekstam & Forshed, 2002). These conditions also lead to low productivity which is characteristic for alvar environment.

Like the soils, alvar lakes are also characterized by low productivity. The main nutrients limiting plant growth is usually nitrogen or phosphorus (Koerselman & Meuleman, 1996) and in alvar lakes a state of calcium-oligotrophy often occur (Naturvårdsverket, 2008). This is due to phosphorus binding to calcium, forming apatite crystals (Noe, Childers & Jones, 2001; Søndergaard *et al.*, 2003). Bonds in apatite are strong which makes phosphorus hard to access for plants. This unavailability of phosphorus makes it the limiting nutrient for plant growth, and addition of nitrogen will therefore have little or no effect on plant growth in alvar ecosystems (Søndergaard *et al.*, 2003). The scarcity of phosphorus in the water favors rooted vegetation that can access phosphorus from the limestone lakebed over phytoplankton (Hargeby, Blindow & Andersson, 2007; Søndergaard *et al.*, 2003). Disfavoring of phytoplankton is often enough to maintain a clear water state (Hansson *et al.*, 1998; Søndergaard *et al.*, 2003) and the rooted aquatic vegetation offers important habitats for many insects (Hargeby, 1990). The survival of many vertebrates is in turn dependent on insects as a source of food, making the binding of phosphorus a key component for the whole alvar lake ecosystems. An increase in the availability of phosphorus can be expected to lead to ecological succession favoring more competitive and productive species (Ekstam & Forshed, 2002; Naturvårdsverket, 2011), possibly to such an extent that many of the rare and endangered species only found in the alvar environment would be outcompeted.

Sand Martin (Riparia riparia)

An alvar lake ecosystem facilitates persistence of higher trophic levels. However, for some species additional requirements are also needed. When developing an alvar lake ecosystem, opportunities to meet such additional requirements should be taken into consideration. In Albrunna, the steep faces created by the quarrying provides an ample opportunity to meet the special condition of nesting habitats required by the locally declining Sand Martin (*Riparia riparia*), as evident by the already present nesting Martins. Over the last 30 years, the Sand Martin population has suffered a decline of at least 50 percent, prompting the Swedish University of Agricultural Sciences to list the Swedish Sand Martin population as near threatened (Swedish University of Agricultural Sciences, 2006). The decline is believed to be largely due to loss of nesting habitats, other reasons are thought to be lack of their primary food resource: insects (Swedish University of Agricultural Sciences, 2006). The martins usually nest in steep faces of sandy hills and are regularly found in sand pits. However, after quarrying in these sand pits has ceased, the unstable nature of sandy hills as well as ecological succession limits the life-span of these favorable nesting sites (Swedish University of Agricultural Sciences, 2006). The unique environments of the quarry steep faces in combination with the development of an alvar lake ecosystem would provide a good location for artificially created long-lasting nesting burrows to support the already present Sand Martin population.

Objectives

Based on the information in the introduction, our objectives for this project are:

- To analyze the water and sediment composition of the artificial lake in Albrunna limestone quarry, in order to be able to compare the artificial lake's current condition with that of a typical alvar lake.
- To use the gathered information to make recommendations on which actions would be appropriate for the development of an alvar lake ecosystem in the artificial lake in Albrunna limestone quarry.
- To create artificial nesting burrows for the Sand Martin (*Riparia riparia*) in the quarry steep faces and monitor nesting activity from May to August.
- To create recommendations for improvement of the design of nesting burrow by evaluating which factors are crucial for the nesting of Sand Martins.

Methods

Water samples were collected and tested with respect to turbidity, chlorophyll a concentrations and *p*H. Sediment samples were analyzed to determine element composition. Conductivity levels were measured in a series of open water bodies from the landfills to the artificial lake.

Turbidity

Water samples were collected on the 15th of March, as the lake was experiencing a non-clear water state atypical of alvar lakes. Turbidity measurements were carried out using a Turb 550 IR (WTW).

Chlorophyll a

In order to determine if the turbidity was being caused by phytoplankton a chlorophyll a-test were carried out. Five 50 ml water samples were collected on the 15th of March from the artificial lake and filtered through a 100 µm plankton net, in order to remove zooplankton. The water was then filtered through a glass fiber filter (type: A/E; pore size: 1µm; Pall Corporation) to extract all the phytoplankton from the water on the filter. The filters were put in separate test tubes and stored in a dark freezer (-20°C) until chlorophyll a-concentration analyses were executed. The analyses were carried out by pouring 4 ml of ethanol (96 %) in each test tube, letting the tubes rest covered in aluminum in a dark cupboard for at least twelve hours (12–18h) and analyzing the chlorophyll a-concentration of the ethanol using a Trilogy® Laboratory Fluorometer (Turner Designs). The chlorophyll a-concentration of the water sample were then calculated using the formula: $C_{water} = V_{Extraction} \times C_{Extraction} / V_{water}$, were C_{water} is the chlorophyll a-concentration of the water sample, $V_{Extraction}$ is the volume of the ethanol added to the test tube (4 ml), $C_{Extraction}$ is the chlorophyll a-concentration in the ethanol and V_{water} is the volume of the water sample (50 ml). As the results warranted further investigation of chlorophyll a-concentration, repeated measurements were carried out four more times, spaced out from April to September occasions (15th of March, 9th of April, 29th of June, 5th of August, 22nd of September), using the same method.

Limiting nutrient experiment

High turbidity and chlorophyll a concentration brought the presumed binding of phosphorus in the sediment into question. In order to determine if phosphorus acted as the limiting nutrient, an experiment was carried out twice (one on the 16th of March and one on the 10th of April).

Two liters of water, collected from the artificial lake on the 15th of March, were filtered through a 100 µm plankton net, in order to remove zooplankton. The following day the water was divided into 40 conical flasks (50ml) with 50 ml water in each flask. The flasks were divided into four groups with ten flasks in each group and each group was given treatments with four different solutions of nitrogen, phosphorus and MQ-water (table 1).

Table 1. Treatment given to four different groups, with 50 ml water from the artificial lake in each flask, in order to conduct a limiting nutrient experiment.

Group	Treatment
Control	4 ml MQ-water
Nitrogen	2 ml of nitrogen solution (30 mg N L^{-1}) and 2 ml MQ-water
Phosphorus	2 ml phosphorus solution (3 mg P L^{-1}) and 2 ml MQ-water
Nitrogen and Phosphorus	2 ml nitrogen solution (30 mg N L^{-1}) and 2 ml phosphorus solution (3 mg P L^{-1})

All flasks were covered with parafilm and a small hole (approximately 1 mm in diameter) was made in each cover. The flasks were then randomly distributed on two orbital shakers and kept in a constant room at a temperature of 20°C with constant light. After 12 days, chlorophyll a-analyses were carried out on 50 ml water from each flask, using the same method as that mentioned under "Turbidity and chlorophyll a".

The experiment was repeated a second time, on the 9th of April, with some minor changes in materials. The second time larger conical flasks (200 ml) and a larger amount (100 ml) of water from the artificial lake were used. The volumes of the added nutrients were also doubled. The groups were limited to five flasks each and were kept for 10 days, rather than 12, before chlorophyll a-concentration analyses were carried out. The results were analyzed using R statistics and one-way ANOVA and Tukey *post hoc* test.

pH

*p*H in open waters of Stora alvaret is typically high (*p*H > 7,5). To test if this was the case, five water samples were collected on the 15th of March and measurements of *p*H were taken on the 16th of March, using a *p*H electrode (MultiLine P4 with a SenTix 41 electrode, WTW). From the measurements a mean value was calculated.

Sediment analyses

Previous tests revealed differences between the artificial lake and the alvar lake, giving rise to questions regarding sediment composition. Comparisons of sediments from the artificial lake and the alvar lake, Resmoväten, with respect to element composition were carried out. The samples were collected on the 3rd of July and analyses were carried out during the 6th of July to the 13th of August.

Four 75 ml sediment samples were collected from the artificial lake in Albrunna and dried in aluminum cups at 75°C for 24 hours. 1 ml from each sample was grinded and glued on to separate specimen stubs and excess particles were removed using a compressed air system. From each sample two overview areas of 634 x 422 μm^2 were studied at 200 x magnification using a tabletop scanning electron microscope (Hitachi's SEM TM 3000), provided by Spectral Solutions. The element composition was measured using an energy dispersive x-ray spectroscopy system (Bruker Nano's Quantax 70). Two 75 ml samples collected from the alvar lake Resmoväten were treated using the same method. Statistical comparisons between the two sediments were carried out using Primer 6 and principal component analysis, ANOSIM and SIMPER.

Conductivity

To determine if ions from the landfills is transported with the water into the artificial lake conductivity measurements were made on the 15th of March using a standard conductivity cell (MultiLine P4 with a TetraCon® 325 cell, WTW) in four open water bodies located between the landfills and the artificial lake.

Daphnia magna

The high level of chlorophyll a indicates large numbers of phytoplankton in the artificial lake. A possible reason for this might be absence of grazing zooplankton. The high conductivity raised concern for the survival of zooplankton. To determine the survival rate of zooplankton, *Daphnia magna* were collected on the 18th of June from a pond in Kalmar City Park (+56° 39' 41.68", +16° 21' 21.30"). The water from the pond were filtered through a 100 µm plankton net, poured into three beakers and diluted with 0%, 50% and 100% water from the artificial lake respectively. To each of the three beakers eight *Daphnia magna* were added. The numbers of living Daphnia magna in each beaker were continuously observed during a week.

Nesting burrows for Sand Martins

Previous observations had discovered nesting Sand Martins in approximately 400 old burrows in a steep face, above water. Measurements of depth, entrance diameter and incline were taken of the old inhabited burrows, in order to evaluate differences between them and the newly constructed ones.

In order to compare if distance to water has an impact on the choice of nesting burrows, 210 new burrows were drilled 23rd of April into the southwestern quarry steep face. Twenty-one groups were constructed with the closest one approximately 20 meters from the edge of the artificial lake. Each group consisted of ten burrows, with five in each row. The vertical spacing between the burrows measured 800 mm and the horizontal spacing between the burrows in each row measured 400 mm. The groups were placed two meters apart and a minimum of five meters above the ground. Each individual burrow was made with an entrance diameter of 51 mm, a depth of 1 meter and an incline of 1/60. The burrows were continuously observed from May to August for any signs of Sand Martin activity.

Results

Turbidity

Average turbidity in the artificial lake on the 16th of March were 2,93 NTU (N = 5, *sd* = 0,892).

Chlorophyll a

Chlorophyll a concentration showed high values (mean for the entire period was 7,2 µg L^{-1}, N = 5, *sd* = 3,1) and variation during the project timespan (Figure 1).

Limiting nutrient experiment

Significant differences in phytoplankton growth response to different nutrient additions were found in both the first ($F_{4, 20}$ = 16,7; p < 0,05; ANOVA; Figure 2) and the second ($F_{4, 20}$ = 24,4; p < 0,05; ANOVA; Figure 3) experiment. Addition of nitrogen and phosphorus showed significantly higher chlorophyll a concentration, than the control, in both experiments (p < 0,05, Tukey *post hoc*). In both experiments neither addition of nitrogen or phosphorus alone showed any significant difference compared to the control (p > 0.05, Tukey *post hoc*). In the first experiment addition of nitrogen also showed no significant difference compared to addition of nitrogen and phosphorus (p < 0,05, Tukey *post hoc*).

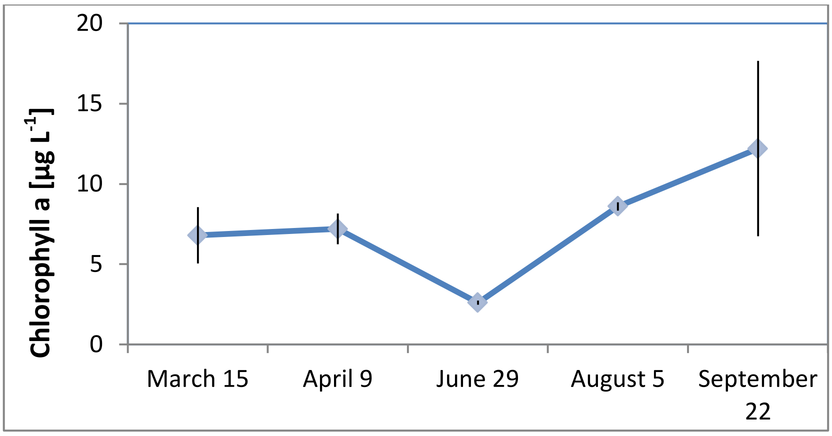


Figure 1. Variation in chlorophyll a concentration, measured in the artificial lake in Albrunna, from March to September 2012. Values varied between 2,6 µg L^{-1} and 12,2 µg L^{-1}, with a mean of 7,2 µg L^{-1}, N = 16 and sd = 3,1. Each data point is the mean value of chlorophyll a concentration taken at 5 separate occasions (15^{th} of March, N = 5, sd = 1,7; 9^{th} of April, N = 5, sd = 0,9; 29^{th} of June, N = 2, sd = 0,07; 5^{th} of August, N = 2, sd = 0,2; 22^{nd} of September, N = 2, sd = 5,4).

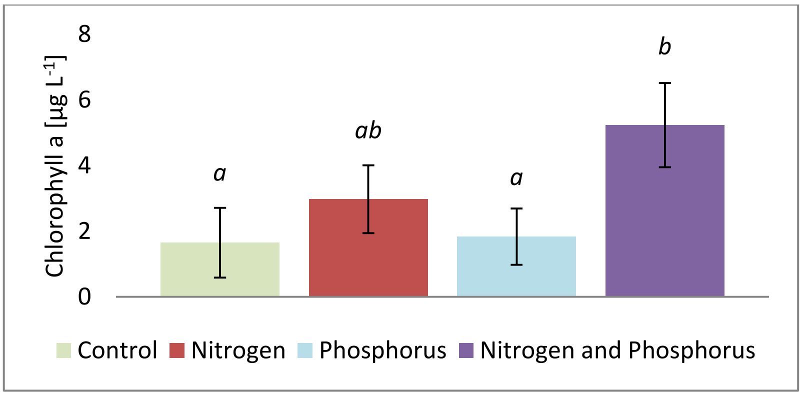


Figure 2. Significant differences in chlorophyll a-concentrations between control and treatment with both nitrogen and phosphorus (p < 0,05). There is no significant difference between treatment with nitrogen and treatment with both nitrogen and phosphorus (p > 0,05). Analyses were executed twelve days after addition of nutrients to water from the artificial lake in Albrunna. Same letter show no significant difference (p > 0,05, Tukey *post hoc*). Error bars show standard deviation.

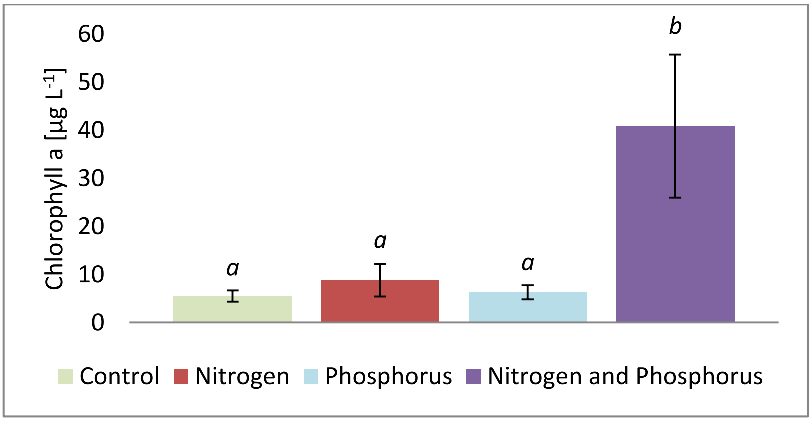


Figure 3. Significant differences in chlorophyll a-concentrations between treatment with both nitrogen and phosphorus and all other treatments (p < 0,05). Analyses were executed ten days after addition of nutrients to water from the artificial lake in Albrunna. Same letter show no significant difference (p > 0,05, Tukey *post hoc*). Error bars show standard deviation.

Sediment analyses

A principal component analysis (PCA) of the element composition in sediments from the artificial lake (pictures in appendix 1.1 & 1.2) and Resmoväten showed a significant difference between the two (R = 0,036; p < 0,05; ANOSIM; Figure 4). A SIMPER-test showed that the greatest contributors to the difference are silicon (14,88 %), aluminum (13,46 %), potassium (13,00 %) and sulfur (12,73 %). Figure 5 shows atomic percent of the elements in the sediments.

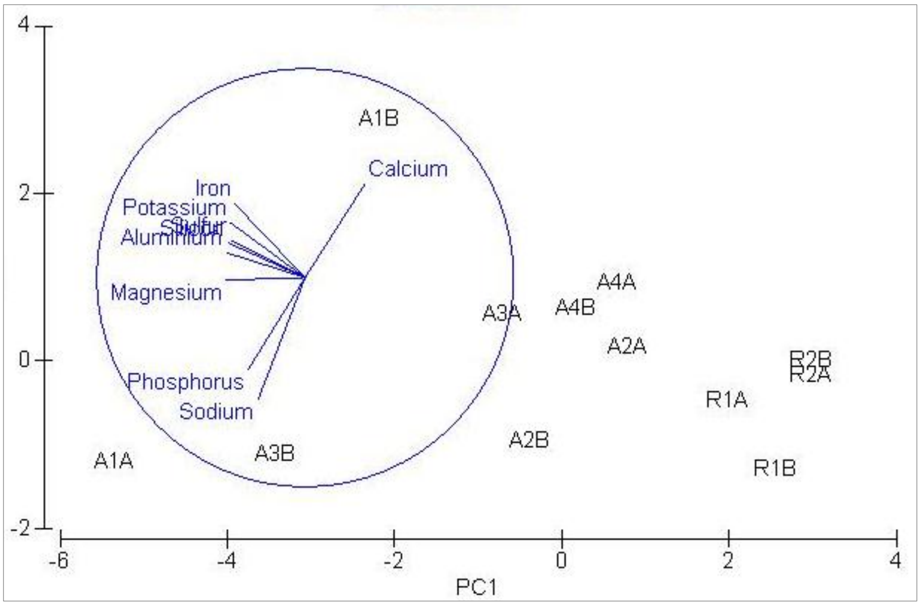


Figure 4. Principal component analysis (PCA) of element composition in sediments from the artificial lake in Albrunna (samples beginning with A) and Resmoväten (samples beginning with R), an alvar lake 25 km north of Albrunna. Results are shown in a multivariate distribution graph.

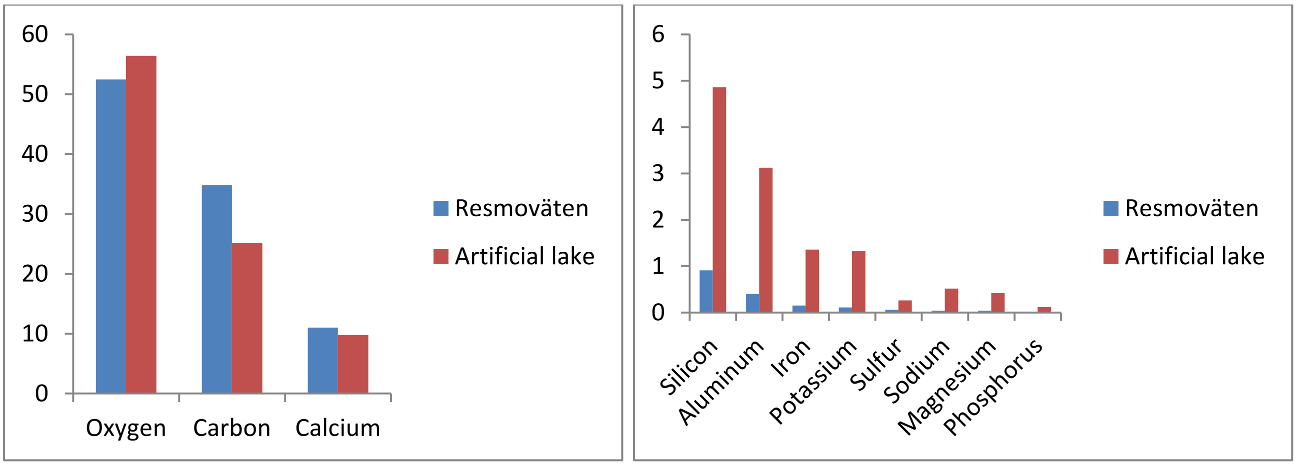


Figure 5. Mean values in atomic percent of elements in sediment samples from the artificial lake and the alvar lake. Please note the different scales on the y-axises.

Conductivity

Measurements of conductivity showed high values in a gradient with increased conductivity with decreased distance to the landfills. Measured values for each location: 1) 1020 mS m^{-1} 2) 825 mS m^{-1} 3) 777 mS m^{-1} 4) 283 mS m^{-1}.

Daphnia magna

All of the *Daphnia Magna* in treatment with 100% water from the artificial lake were dead after six hours, a mortality rate of 100%. The mortality rate for *D. magna* in the 50%-dilution of water reached 100% after 24 hours, at that time the mortality rate for *D. magna* in pure pond water where 25%. After one week all *D. magna* had died, regardless of treatment. Results are presented in Figure 6.

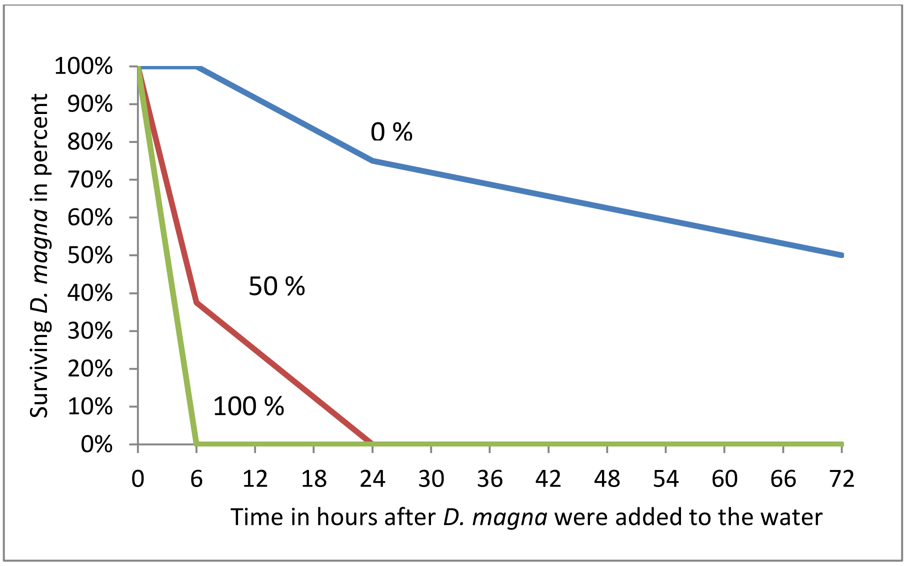


Figure 6. Surviving *Daphnia magna* in three different dilutions of water from the artificial lake in Albrunna (0%, 50% and 100%) and pond water collected from the same location as the *D. magna*. The solutions are given as percentages water from the artificial lake.

pH

Measurements of pH in the artificial lake on the 16th of March had a mean value of 6,9 (s = + 0,2; - 0,1).

Nesting burrows for Sand Martins

None of the observations of the artificial burrows showed any sign of nesting Sand Martins. The measurements of the old inhabited burrows showed an average depth of more than 2 m, an entrance diameter of 5,6 cm (s = 1,0) and no distinguishable incline.

Discussion

When comparing the characteristics of the artificial lake with those of an alvar lake the results indicated two main differences. The first is the difference in compositions of the sediments, which greatly influences the artificial lake's ecosystem. The second is the higher conductivity in the artificial lake. Plausible causes and consequences of these are discussed below.

The results revealed higher values of turbidity in the artificial lake (mean 2,93 NTU) than in a typical calcareous lake(0,25 – 1,78 NTU; Nishri *et al*., 2000). One explanation to this could be the high chlorophyll a concentration. Water in calcareous lakes is usually low in phosphorus (Schaefer & Larson, 1997) due to the strong bindings with calcium in the sediments Turbid states are therefore unusual in alvar lakes (Hobbs, Irvine & Donohue, 2005). This raised the question why the artificial lake does not show the characteristics of a typical alvar lake. The results of chlorophyll a concentration analyses showed levels between 2,6 µg $L^{-1}$and 12,2 µg L^{-1} with a mean that is approximately three times as high as that of a typical calcareous lake (4,5 µg L^{-1}; Carvalho *et al*., 2008). As calcareous lakes do not normally support large populations of phytoplankton

(Hobbs, Irvine & Donohue, 2005), high levels of chlorophyll a are indicative of either external addition of phosphorus, to such an extent that the sediment is saturated, or interference in the binding of phosphorus in the sediment (Hobbs, Irvine & Donohue, 2005). The nutrient limitation experiment suggested a balance between nitrogen and phosphorus, supporting the notion that phosphorus is not acting as a limiting nutrient as would be expected in a calcareous lake (Søndergaard *et al.*, 2003). It is evident from analyses of sediment from the artificial lake that the calcium content differs greatly from what would be expected in a calcareous lake (Hobbs, Irvine & Donohue, 2005). Furthermore, the analyses show high levels of iron, sulfur and silicon all of which are indicative of alum shale (Falk, Lavergren & Bergbäck, 2005). Alum shale withering is known to decrease *p*H (Falk, Lavergren, Bergbäck, 2005) and provides a plausible explanation of the relatively low *p*H-levels measured. Unlike calcium, iron readily oxidizes at low oxygen levels, which causes release of phosphorus back into the water (Eckert, Nishri & Parparova, 1997; Søndergaard *et al.*, 2003). Considering the low pH in the lake and the high iron content of alum shale it is a highly plausible cause for the loss of oligotrophy in the lake. That alum shale would constitute a large portion of the lakebed is in accordance with records of quarrying methods (Cementa Degerhamn) and visual inspection (appendix 1.3 & 1.4). Taken together the results show that the lake is neither calcareous, nor oligotrophic. In order to develop an alvar lake ecosystem in the lake, steps must be taken to aid binding of phosphorus in the sediment and mitigate the negative impact of alum shale on plant-life, mainly anaerobic lakebed conditions and release of sulfuric acid during decomposition (Falk, Lavergren & Bergbäck, 2005).

Further differences between the artificial lake and typical alvar lakes were discovered when measurements of electrolytic conductivity yielded results approximately four times higher than what is expected in calcareous lakes (approximately 70 mS m^{-1}; River Basin Management, 2005), suggesting addition of electrolytes from an external source. Measurements taken from four of the open water bodies connecting the landfill and the artificial lake reveal a gradient as conductivity sinks closer towards the lake, suggesting leachate from the landfills as the external source of electrolytes. The continuous measurements of leachate from the landfill reveal high levels of potassium, confirming the landfill as a plausible cause of the high conductivity. High levels of potassium are associated with many detrimental effects on plant-life (Fageria, 2001). Furthermore, experiments on *Daphnia magna*-survival in water from the artificial lake confirms that the high conductivity is likely detrimental to the health of zooplankton, otherwise a mitigating factor in determining the size of the phytoplankton population. In order to develop an alvar lake ecosystem in the artificial lake, the excessive addition of electrolytes must be lowered.

Sand Martins

Sand Martins were observed in the area, but showed no signs of nesting in the artificial burrows. As Sand Martins prefer to nest above water to avoid predators (Environment Agency, 2001), the positioning of the artificial burrows, with the group closest to the water approximately 20 meters from the edge of the lake, remains a possible explanation for the absence of nesting. However, Sand Martins are known to scout areas for appropriate places to build burrows a year in advance (Environment Agency, 2001), making any evaluation within a year after drilling unreliable.

Conclusion

The artificial lake in Albrunna provides a great opportunity to develop a rare alvar lake ecosystem, due to its size and location. The classification of Stora alvaret as a Natura 2000-protected area, and its place on

UNESCO's world heritage list, indicates how important it is to utilize an opportunity like this. Evident from the results of our measurements, two primary concerns for the development of the artificial lake into an alvar ecosystem needs to be addressed in order to assure success: the sediment composition and the high conductivity. Evaluation of the creation of artificial burrows for the Sand Martin is also discussed below.

Considering the fundamental role the sediment plays in determining the structure of the lake ecosystem, affecting not only lakebed conditions but in extension the niche structure, efforts to address the sediment composition should be highly prioritized. Considering that the detrimental effects of the alum shale on the lakebed and water conditions is likely to continue until the shale is removed from the system, our current recommendations is to look into possibilities to cover the shale with soil. Utilizing overburden (i.e. alvar soil removed in the quarrying process) would have the added benefit of providing a seed bank with appropriate species. Along with covering the shale with soil, liming could be used to bind phosphorus and drive the lake towards the oligotrophic condition of typical alvar lakes. Our assessment is that the combined effort of covering the shale and liming is very likely to prove successful, although further studies are needed to provide details for the execution.

Addressing the issue of high conductivity should primarily focus on limiting the addition of potassium, as repeated measurements show very high levels. Furthermore, the measurements indicate the landfills as a plausible source of the excess electrolytes. As the current open-air heap is scheduled to be removed, new measurements should be taken after the removal is completed to determine whether further steps to limit electrolyte addition are necessary. Storage of cement kiln dust (CKD) in open-air heaps should, if possible, be avoided, until their effect on the lake and surrounding areas can be determined.

Sand Martins

As no nesting in the drilled burrows occurred during the projects time frame, comparisons with the old inhabited burrows were made in order to determine the likelihood of future nesting. The only discernible difference expected to affect the occurrence of future nesting was the location. Although, due to the alleged scouting behavior of Sand Martins, conclusions about the rate of nesting in the drilled burrows drawn so soon after construction are bound to be unreliable. We recommend a follow-up study be undertaken during 2013, and that conclusions about possible improvements to the method and nest design are drawn from the results of that study.

Acknowledgments

The authors would like to thank Börje Ekstam Ph. D. for all the help with ideas, reviews and guidance through the entire project; Claes Kollberg, environmental manager at Cementa AB Degerhamn, for the help with getting practical moments executed; Spectral solutions for letting us utilize the tabletop scanning electron microscope (Hitachi's SEM TM 3000) and energy dispersive x-ray spectroscopy system (Bruker Nano's EDS Quantax 70); Torbjörn Sunde Ph. D. for the introduction course of the SEM and EDS; Sara Gunnarsson for the access to the laboratory and equipment. The authors also want to thank Roland Engkvist Ph. D for the help with the statistical calculations and the interpreting of the results; Anders Månsson, Henrik Hallberg and Emmelie Nilsson for all the help with equipment; Jan Herrmann Ph. D. and Anders Hargeby Ph. D. for the help with experimental design. Further the authors also want to give thanks to the Linnaeus University in Kalmar and HeidelbergCement.

References

Carvalho, L., Solimini, A., Phillips, G., van den Berg, M., Pietiläinen, O-P., Lyche Solheim, A., Poikane, S. & Mischke, U., 2008. Chlorophyll reference conditions for European lake types used for intercalibration of ecological status. *Aquatic Ecology,* 42 (2), pp. 203-211.

Cementa Degerhamn. Aqualog AB, 2006. *Utredning av befintlig deponi, hydrogeologisk del.* [Investigation of the existing landfill, hydrogeological part].

Council Directive 1992/43/EEC of 21 May 1992 on the conservation of natural habitats and of wild fauna and flora.

Eckert, W., Nishri, A. & Parparova, R., 1997. Factors regulating the flux of phosphate at the sediment – water interface of a subtropical calcareous lake: a simulation study with intact sediment cores. *Water, Air & Soil Pollution,* 99 (1-4), pp.401-409.

Ekstam, U. & Forshed, N. 2002. *Svenska alvarmarker – historia och ekologi*. Värnamo: Naturvårdsverkets förlag.

Environment Agency, 2001. *Artificial Bank Creation for Sand Martins and Kingfishers*. Rotterham: Environment Agency.

Fageria, V. D., 2001. Nutrient interactions in crop plants. *Journal of Plant Nutrition,* 24(8), pp. 1269-1290

Falk, H., Lavergren, U. & Bergbäck, B., 2005. Metal mobility in alum shale from Öland, Sweden. *Journal of Geochemical Exploration,* 90 (3), pp. 157-165.

Hansson L-A., Annadotter H., Bergman E., Hamrin S.F., Jeppesen E., Kairesalo T., Loukkanen E., Nilsson P-E., Søndergaard M. & Strand J., 1998. Biomanipulation as an application of food-chain theory: constraints, synthesis, and recommendations for temperate lakes. *Ecosystems*, 1, pp. 558-574.

Hargeby, A., 1990. Macrophyte associated invertebrates and the effect of habitat permanence. *Oikos,* 57 (3), pp. 338-346.

Hargeby A., Blindow I. & Andersson G., 2007. Long-term patterns of shifts between clear and turbid states in lake Krankensjön and lake Tåkern. *Ecosystems*, 10, pp. 28-35.

Hobbs, W., Irvine, K., Donohue, I., 2005. Using sediments to assess the resistance of a calcareous lake to diffuse nutrient loading. *Archiv für Hydrobiologie*, 164 (1), pp. 109-125.

Koerselman, W. & Meuleman, A.F.M. 1996. The vegetation N:P ratio: a new tool to detect the nature of nutrient limitation. *Journal of Applied Ecology,* 33, pp.1441-1450.

Naturvårdsverket, 2008. *Åtgärdsprogram för hotade kransalger: arter i kalkrika sjöar 2008-2011*. [Action programs for threatened chara: species in calcareous lakes 2008-2011]. Bromma: Naturvårdsverket.

Naturvårdsverket, 2011. *Alvar – Nordiskt alvar och prekambriska kalkhällmarker, EU-kod 6280.* [Nordic alvar and precambrian calcareous flatrocks, EU-code: 6280]. Stockholm: Naturvårdsverket.

Nishri, A., Imberger, J., Eckert, W., Ostrovsky, I. & Geifman, Y. 2000. The physical regime and the respective biogeochemical processes in the lower water mass of Lake Kinneret. *Limnology and Oceanography.* 45 (4), pp. 972-981.

Noe, G. B., Childers D. L. & Jones R.D., 2001. Phosphorus biogeochemistry and the impact of phosphorus enrichment: Why is the everglades so unique?, *Ecosystems* 4: 603-624.

River Basin Management, 2005. *A Calcareous/ Non-Calcareous Classification of Bedrock in Northern Ireland*. Ireland: River Basin Management.

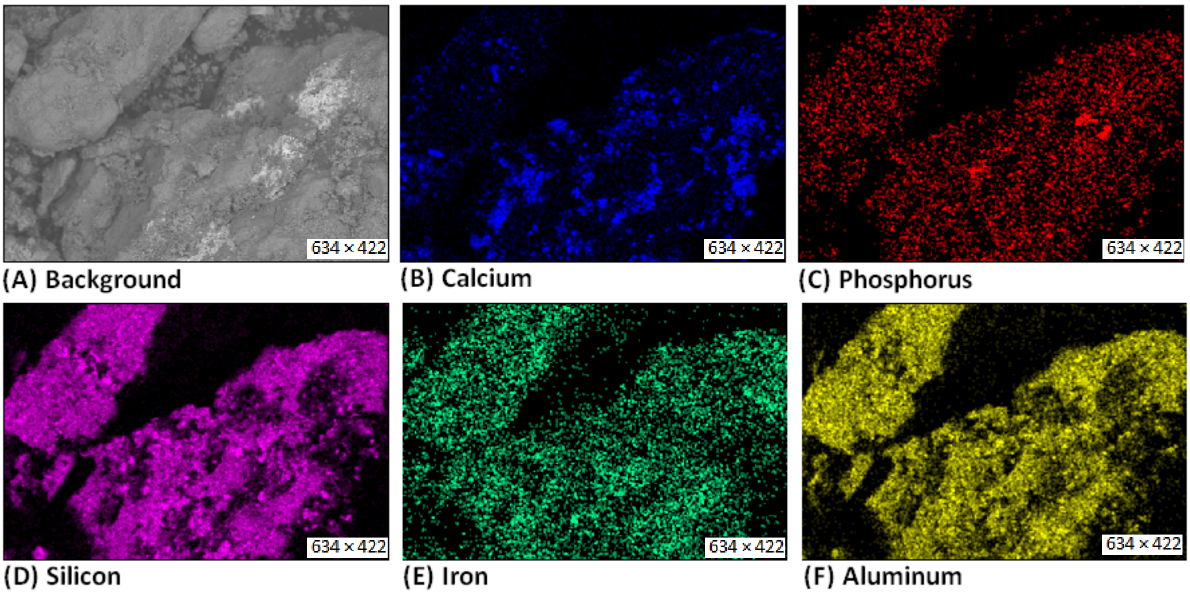
Sand-Jensen, K., Baastrup-Sphor, L., Winkel, A., Lindskov Møller, C., Borum, J., Brodersen, K. P., Lindell, T. & Stæhr, P. A., 2010. Ett kalkbrott på Ölands alvar – en stenöken med knivskarpa miljögränser. [A limestone quarry on Öland alvar - a stone desert with razor sharp environmental limits] *Svensk Botanisk Tidskrift,* 104 (1) pp. 23-31.

Schaefer, C. A. & Larson, D. W., 1997. Vegetation, environmental characteristics and ideas on the maintenance of alvars on the Bruce Peninsula, Canada. *Journal of Vegetation Science* 8, pp. 797-810.

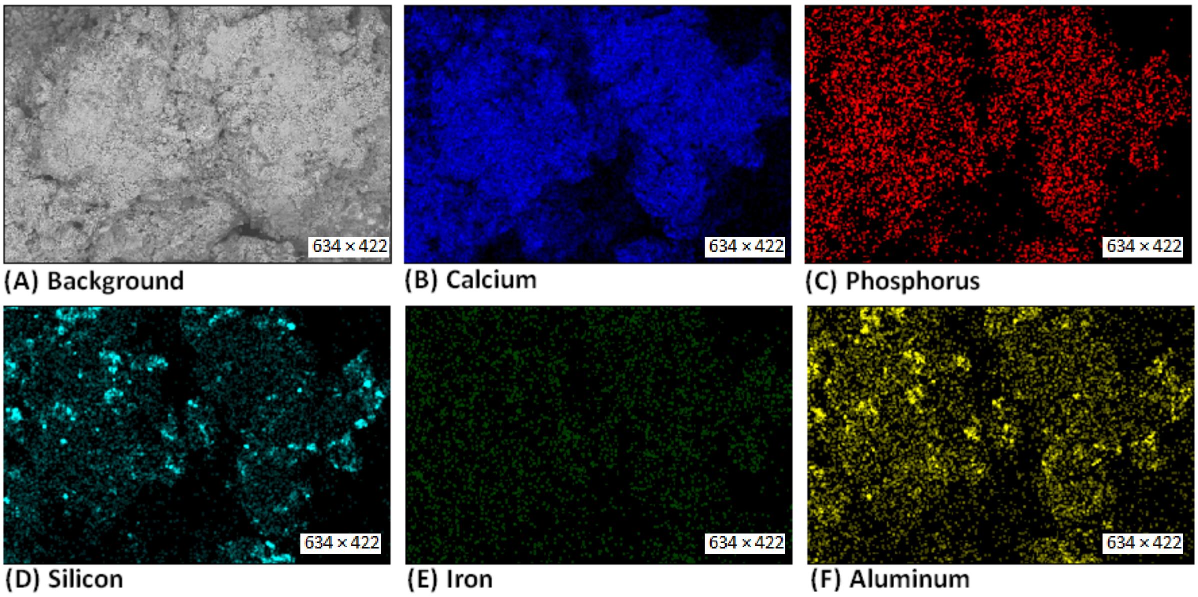
Swedish University of Agricultural Sciences, 2006 [rev. 2010]. *Riparia riparia – backsvala* [Riparia riparia – Sand Martin]. Uppsala: ArtDatabanken.

Søndergaard, M., Jensen, J. P. & Jeppesen, E., 2003. Role of sediment and internal loading of phosphorus in shallow lakes. *Hydrobiologia*. 506–509 (1-3), pp. 135–145.

Appendix 1.



1.1 Overview pictures (634 x 422 µm) of sediment from the artificial lake in Albrunna limestone quarry. Pictures are taken with 200 x magnification using Hitachi's tabletop scanning electron microscope TM3000 provided by Spectral solutions. (A) Picture of the sediment in a 200 x magnification, (B) - (F) Content of specific elements in the sediment sample.



1.2 Overview pictures (634 x 422 µm) of sediment from the alvar lake, Resmoväten. Pictures are taken with 200 x magnification using Hitachi's tabletop scanning electron microscope TM3000 provided by Spectral solutions. (A) Picture of the sediment in a 200 x magnification, (B) - (F) Content of specific elements in the sediment sample.

1.3 Overview of the lakebed, consisting mostly of alum shale, in the drained artificial lake in Albrunna limestone quarry.

1.4 Close-up of exposed alum shale layer in the lakebed in the drained artificial lake in Albrunna limestone quarry.