Lärjeåns garden

Development of waterpurification marsh for sewage treatment

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Abstract
In 2006 the water purification marsh (WPM) in Lärjeåns gardens was built as a part of the EU project Strategic Partnership in River Corridors (SPARC) to treat the sewage water from the garden and increase the knowledge of the function in the WPM. To compare the type of organisms in a newly constructed WPM with an older, the WPM at Bergums Farm, built 1995, in the Community of Göteborg Sweden was used (Pehrsson 2001).
Already after a week phytoplankton was established in the new ponds but the number of species and individuals were fewer than in the older WPM. The principle is that the water is cleaned through transference of biomass, i.e. the nutrients are transported from primary producers via zooplankton to top consumers such as insects, snakes, birds and amphibians, which can transport the nutrients from the ponds.
The primary production measured as oxygen production and consumption indicated a community in balance, because oxygen produced through photosynthesis was quickly consumed by oxygen demanding organisms.

Introduction
The first WPM was developed at a farm in order to find an ecological way to reduce nutrients both from manure in the barn as well as the domestic waste water (Pehrsson 1994).
The design of the WPM is founded on some ecological principles. Shallow wetland with effluents belongs to the most productive ecosystems on earth, because light, heat, water and nutrients occur in optimal proportions. Since the first three factors are constant, increased supply of nutrients of right composition may increase production of plant biomass and consequently reduce the concentration of nutrients.
The concept of optimum sustained yield implies that the production is highest when a population of an organism is reduced by exploitation to about half of its carrying capacity. High yield of primary production is thus enhanced through grazing animals of both invertebrates and vertebrates which together with their predators are allowed to form food chains and food webs which, however, tend to be relatively simple but effective in early stages, especially in temporary water (Pehrsson 1994).
Since production is highest in early successions management efforts in a WPM should favor the maintenance of organisms in the early succession like bacteria, phyto- and zooplankton that appear during the first growing season, thereby preventing mature or climax stages to develop, which reduce light and heat in the shallow water.
The above-ground ecosystem allowed in WPM imports energy circuits of both a grazing circuit and organic detritus circuit, since both decomposition of dead materials of organic origin and consumption of living plants or plants produced from released inorganic nutrients are utilized in the food chains. In the traditional sewage treatment plants and subsurface sand filters, the food chains usually stop after bacteria, fungi and protozoa, and released nutrients are not transformed to algae until they reach the sea.
In a WPM, there is also a water circuit. Increasing sun light and heat favors evaporation; this in turn, increases nutrient concentration in the remaining water and consequently, increase plant growth. Some of this water returns to the ground and as dew, a circulation that is favorable to the local climate, especially during long and dry periods. In the winter, ice formation also concentrates the nutrients, which favors algal growth and nutrient reduction. Nutrient concentration from both evaporation and ice formation is favored by a large water surface in relation to water volume, which gives another reason to create a very shallow marsh. Moreover, in slowly flouting shallow water, dissolved oxygen is easily available from both the atmosphere and from photosynthetic sources. In subsurface sand filters, both domestic waste water and ground water, both contributing to

groundwater lowering, are rapidly brought to the sea in dark and cold underground culverts.
The purpose of this project was to establish a sustainable sewage treatment in Lärjeåns garden and increase the knowledge of the function.

Material and methods
An important part was to study the succession development of different species in the marsh, due to time of the year and the ageing of the marsh.
The plant was constructed in June 2006 (Fig.1 and 3). The first measurements of chlorophyll content and the composition of microorganisms were carried out one week after the sewage water was turned on to the plant. To compare a new developed marsh with a marsh used in ten years measurements at Bergum were done at the same time (Fig. 2).
In the summer of 2007 the measurements of plankton was repeated in Lärjeåns garden as well as primary production and measurements of nutrient content was carried out.

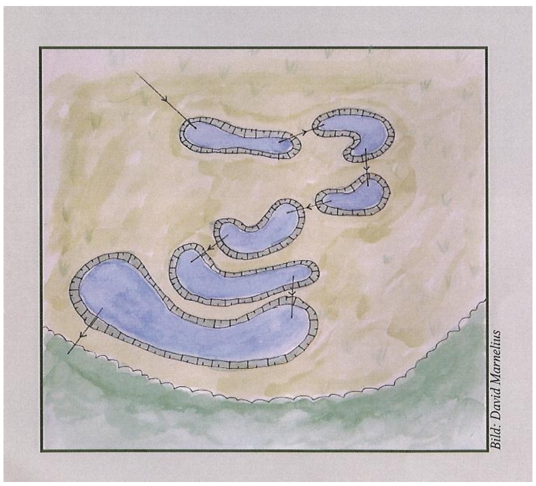


Figure1. Drawing of the water purification marsh in Lärjeåns gardens. Illustration David Marnelius 2006

Figure 2. Bergums waterpurification marsh constructed 1995. Photo Olof Pehrsson 2007

Figure 3. Newly constructed water purification march 2006 and after one year 2007. Photo Gunilla Magnusson

Chlorophyll
In each pond at five randomly choused places 100 ml water were sampled. The water was mixed from each pond in a bucket and was filled on 200 ml bottles, two from each pond all together twelve. The bottles were stored in darkness and analyzed the next day. Through analyze of the content of chlorophyll-a (ISO-standard method) the plant plankton abundance was measured. The chlorophyll was measured in a

spectrophotometer Hitachi model 100 and after counting the chlorophyll *a* as µg/ml. The chlorophyll concentration was calculated using the formula

Chlorophyll *a* (µg/ml) = (A664 A720) x 11,85 (A647 A720) x 1,54 (A630 A720) x 0,08

Plankton

At the same time samples were taken to analyze the species (in certain cases only the order were determined) and number content of micro organisms. The number of micro organisms was calculated in a Bürker-chamber, a glass plate with a certain number of squares with a certain volume is inscribed. For each pond three replicates were calculated.

The amount was calculated using the formula:

The amount of plankton per ml = x * 1000 * 250 were x are the amount of plankton found.

Nutrient content

In 2007 nitrogen (N) and phosphorus (P) were determined four times in May, July, September and December, both inorganic N as nitrate (NO_3) and ammonium (NH_4) and total-N and phosphate (PO_4) and total-P in incoming water and outgoing from pond number five. The bacteria E-coli, coliform bacteria 35ºC and enterococks and the biological demand (BOD_7) were also measured. At the accredited Laboratory AnalyCen the analyzes were done.

Photosynthetic measurements

Oxygen fluxes were carried out using 24 cm long Plexiglass cores i.d 8cm (Sundbäck et al. 2003) with magnetic stirrer (Multiple, AS 631) placed in the air next to the ponds giving incident light once a month from May to October 2007 (Fig. 4). Water from pond one, four, five and six was incubated for one hour, two replicates in light and one cylinder were darkened to count for the community respiration. Incident light was measured during the incubation with a Skye quantum light sensor, later recalculated to mean daily values at Kristineberg Marine biological station about 150 km away from the garden. Light in the cores were evaluated to the same value just below the surface as in the ponds. Oxygen fluxes in the light were used as a measure of net primary production (NP). Gross primary production was calculated as the sum NP and oxygen consumption in the dark (community respiration, CR). At the same time as the photosynthetic measurements was done temperature, oxygen content, pH and conductivity were measured in the ponds.

Figure 4. Expirimental upset for Measurement of photosyntheses

Results

The conditions in the ponds

During 2006 samples for plankton analyses were taken at five different occasions in Lärjeåns garden, seven times in Bergum and five times in Lärjeåns garden in 2007. The summer 2006 was warm and dry while the summer 2007 was cold and rainy. In and around the WPM in Bergum usually a lot of frogs occur and during spring and early summer numerous tadpoles are in the ponds. Year 2006 was extreme with an enormous

amount, especially in pond 2 from May until June. When developing into frogs they were in all over the marsh.
In Lärjeåns garden the sewage water only reached the first pond and some rainwater in pond 2, 5 and 6. The other ponds were dry. In pond 5 and 6 the water probably was ground water breaking through. The cladoceran *Daphnia magna* occurred in large numbers.
In 2007 the same characters were observed in the ponds. In spite of the rainy weather no water occurred in pond 2 and 3. In the end of June the first pond was divided in two parts. From July duckweed (*Lemna minor*) had developed in pond 6 and its surface was totally covered in the end of the summer as well as in spots in pond 5. A duck family visited the march regularly and was feeding on the duckweed. The characteristics of the active species in the different ponds are presented in table 1 to 3.

17-May	Rather much duckweed in the first pond and darkgreeen water, more brown and turbid in the last. Many tadpoles in levee 2-4. ”Boiling” of them in levee 2. Several leeches in pond 2.
05-June	Rather much duckweed in the first pond, more in spots in the last. Brown water. Turbid in pond 2, probably due to the tadpoles. Many tadpoles in pond 2-4, a few in pond 5 and 6. Many insects in pond 5 and 6
21-June	Pond 1-4 covered with duckweed. Spots of duckweed in pond 5 and 6. Red-brownish water and tadpoles in all ponds. In pond 2-4 have some developed legs. Leeches in all ponds, most in pond 2-4
04-July	All ponds are covered with duckweed. Brown water in all ponds. Very low water level in parts of pond 2 and 3. Frogs and leeches in pond 1-5. Shadowing plants around the ponds. Warm and sunny period.
17-July	All ponds are covered with duckweed. Brown water in all ponds. Very low water level in parts of pond 2 and 3. Frogs and leeches in pond 1-5. Shadowing plants around the ponds. Warm and sunny period.
27-July	Pond 1-4 covered with duckweed. Much, but not all covered with duckweed in pond 5 and 6. Very low waterlevel in some parts of pond 2 and 3. Brown water in all ponds. Frogs and leeches in pond 1-5. Clusters of red algae in levee 6. Warm and sunny weather for a longer period.
08-Aug	Pond 1-4 covered with duckweed. Much, but not all covered with duckweed in pond 5 and 6. Brown water in all ponds. Frogs and leeches in pond 1-5. Clusters of red algae in pond 6. Shadowing plants around the ponds.

Table 1. The visible characteristics conditions in Bergum 2006 at the sampling occasions.

21-jun	Sewage water in the first pond, the sewage has been connected during a week. Rainwater in pond 2, 5 and 6.
04-jul	Only sewage water in the first pond, dark green in colour, larvae and *Merismopedia sp*. in spots. Rainwater and larvae in pond 2, 5 and 6.
17-jul	Only sewage water in the first pond, dark green in colour, larvae and *Merismopedia sp*. in spots. Rainwater and larvae in pond 2. Ground water breaking through in pond 5 and 6 and were filled with water in rest of the summer. Daphnia magna in levee 2 and 5.
27-jul	Only sewage water in the first pond. Larvae in all ponds with water. *Daphnia magna* in levee 2, 5 and 6. *Ephemeroptera* larvae (dayfly) in pond 6.
08-aug	Only sewage water in the first pond. Spots of *Merismopedia sp*. Larvae in all ponds with water. Larvae in pond 1 and 2. Many Daphnia magna in pond 2, 5 och 6. *Ephemeroptera* larvae

Table 2. The visible characteristics conditions in Lärjeåns gardens 2006 at the sampling occasions.

5-June	Sewage water in the first pond, no water in pond 2 and 3. Many larvae in pond 1. Many *Daphnia magna* in 4, 5 and 6.
26-June	Sewage water in the first and second pond. Larvae in levee 1 red/green algal mat (probably in *Microcystis sp)*. *Daphnia magna* in 4, 5 and 6. No water in levee 3.
14-July	Levee 1 now devided in 2. Much darkgreen lumps in pond 1:1 and 1:2 (probably in *Microcystis sp*. Foum on the surface in pond 4. Much Daphnia magna in pond 4 and 6. Duckweed in pond 6.
26-July	Much darkgreen lumps and algal mat in pond 1:1, 1:2 and 4 (probably in *Microcystis sp*.) *Daphnia magna* in pond 4, 5 and 6. Pond 6 covered in duckweed.

21-Aug	Red/green scattered spots of algae on the surface pond 1:1 and 1:2. Some duckweed in pond 5 and pond 6 all covered. A duck family visit the marsh regularly

Table 3. The visible characteristics conditions in Lärjeåns gardens 2007at the sample occasion.

Chlorophyll

The chlorophyll-concentrations varied during the period (Fig. 5 and 6). Highest value was measured in May with 3,5 ug/ml. The low values in pond 2-4 in Bergum were a result of the shadowing effect of the duckweed and the tadpoles effectively grazing the algae.

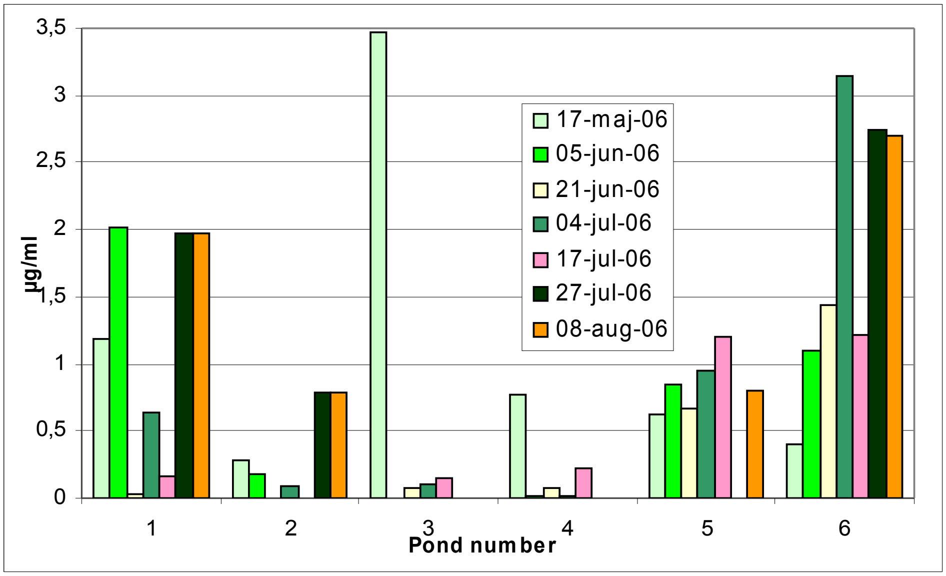


Figure 5. Chlorophyll content (µg/ml) in each levee in Bergums waterpurification marsh. Five randomly samples taken in each levee mixed in a bottle, two replicates from each bottle.

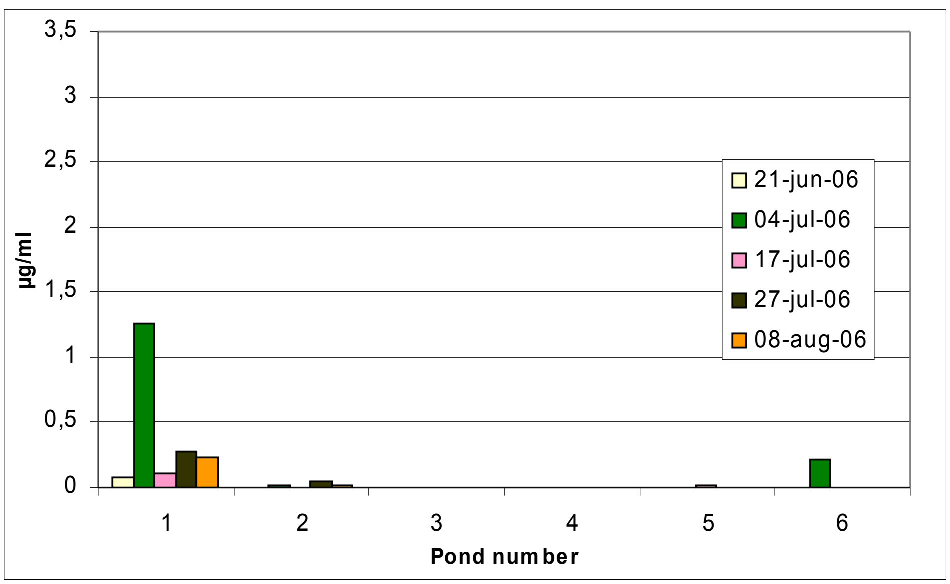


Figure 6. Chlorophyll content (µg/ml) in each levee in Lärjeåns gardens waterpurification marsh. Five randomly samples taken in each levee mixed in a bottle, two replicates from each bottle.

In Lärjeåns gardens the first sample was taken one week after the sewage water was connected. First measurement showed a low content in the first pond but already after two weeks the chlorophyll content increased, followed by low content. In the last pond influenced of ground water rather than sewage water the cladoceran *Daphnia magna* soon invaded.

Plankton

In both Bergum and Lärjeån gardens different plankton species replaced each other in time and space. In Bergum the number of species varied between 1 and 18, most species in all ponds in May. During the whole season most species were found in pond 5 and 6 but a high number of individuals occurred in the first ponds (Fig. 7-9). During 2006 in Lärjeåns garden the variation was between 5 and 1, with most species in the first pond. The amount increased in 2007 to 9 in the second pond.
The amount of species increased and also the amount per volume in Lärjaåns gardens during 2007 (Fig.9-11).

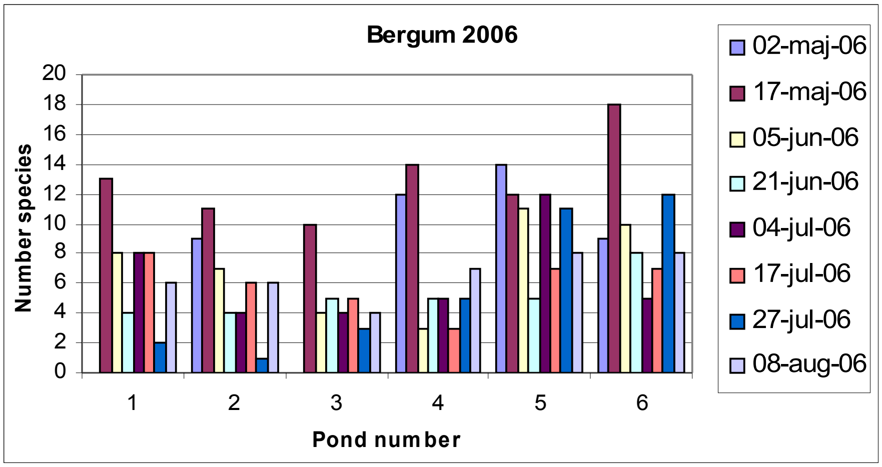


Figure 7. Number of species of plankton (both phyto and zooplankton) in Bergum water purification marsh during 2006.

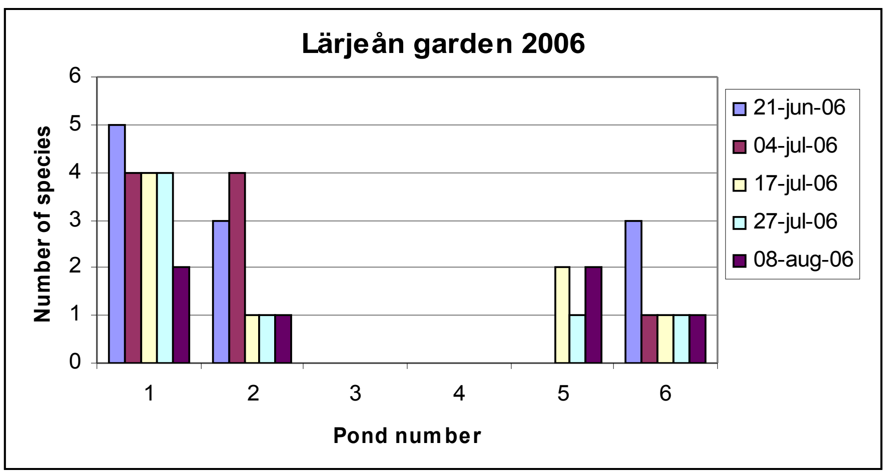


Figure 8. Number of species of plankton (both phyto and zooplankton) in Lärjeåns gardens water purification marsh during 2006.

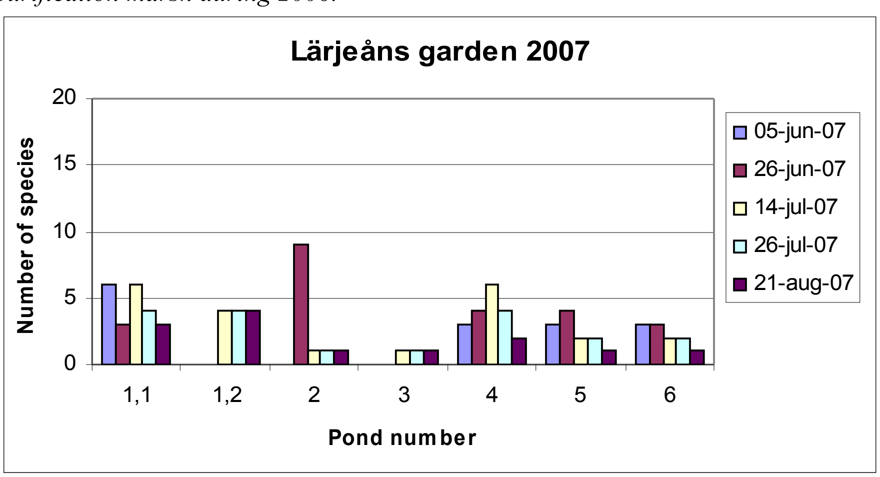


Figure 9. Number of species of plankton (both phyto and zooplankton) in Lärjeåns gardens water purification marsh during 2007.

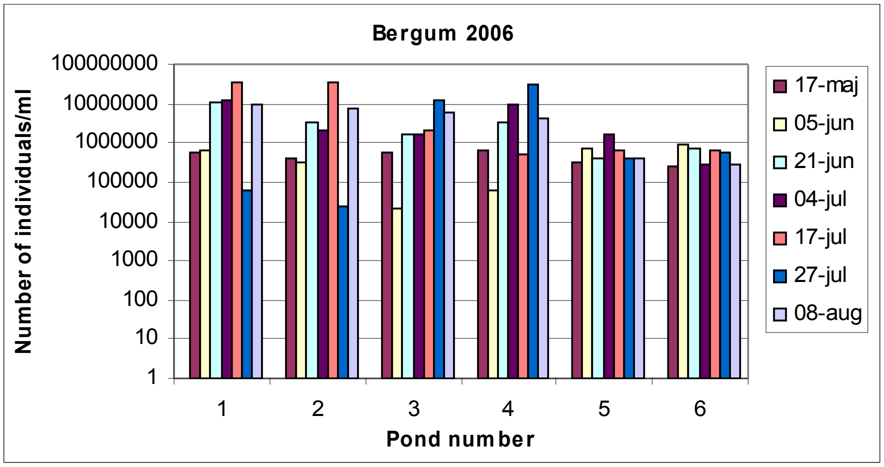


Figure 10. The amount of plankton/ml in Bergum in 2006. The value is the mean value of three replicates in each pond.

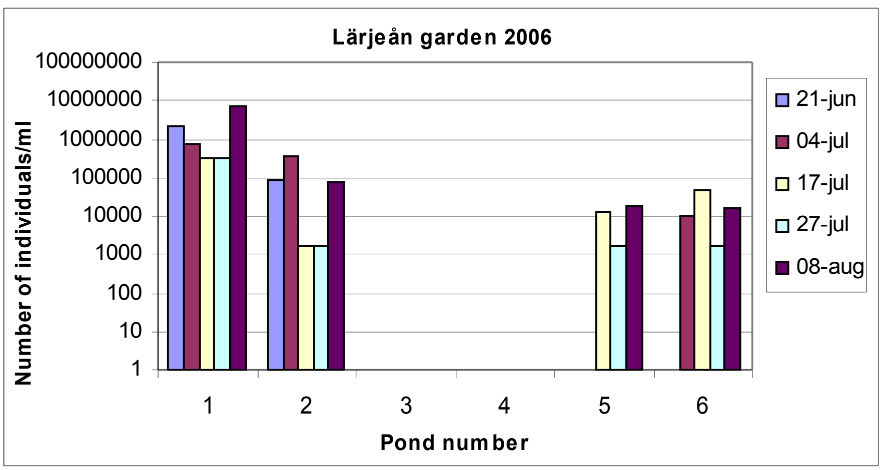


Figure 11.The amount of plankton/ml in Lärjeåns garden in 2006. The value is the mean value of three replicates in each pond.

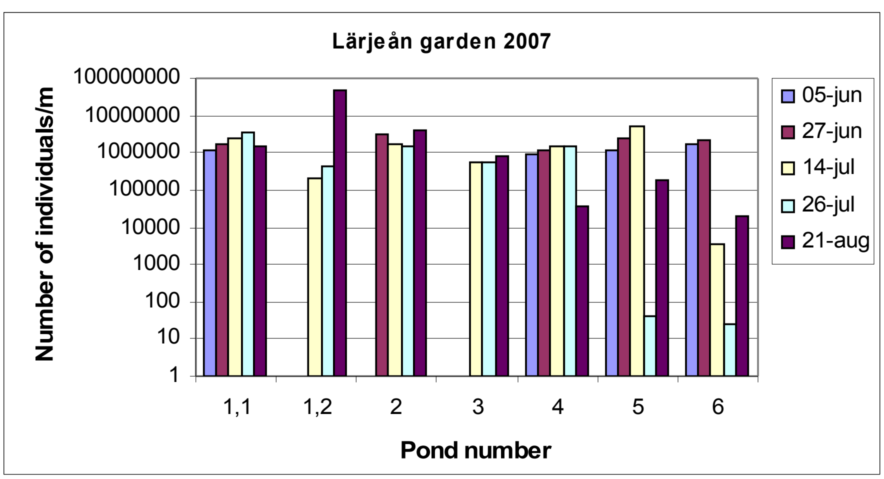


Figure 12. The amount of plankton/ml in Lärjeåns garden in 2007. The value is the mean value of three replicates in each pond.

Bergum, phytoplankton.

At the first sampling on the 17th of May the Merismopedia sp. (Chyanophyta) dominated in pond 1 and 2, Euglena sp. in pond 3 and Monoraphidium sp.(Chlorophyta) in pond 4 (Table 4). Also Trachelomonas sp. (Euglenophyta) appeared in big concentrations, especially in pond 4-6.
At the next sampling, 5th of June, the amount of Merismopedia sp. had increased in pond 1 but decreased in pond 2 and increased a bit in pond 4 and 5. Monoraphidium sp. was no longer dominating in pond 4, the number was relatively low and increased a bit in pond 5 and 6 which was dominated by the order of Chlorococcales sp., for example *Westella botryoides* and Dictospaerium sp.(Chlorophyta). Also Oscillatoriales (Chyanophyta) increased in pond 5 and 6.
At the third sampling on the 21th of June Merismopedia sp. had the highest level during the season (10 650 000 individuls /ml) in pond 1-4 with the highest peak in pond 1. In pond 5 and 6 Chlorococcales and Trachelomonas sp. increased a bit.
On the 4th of July dominated Merismopedia sp. pond 1-5 with the highest rates in 1 and 4. In pond 5 and 6 Trachelomonas sp. increased a bit.
On the 17th again Merismopedia sp. dominated in pond 1-3.
On the 27th Merismopedia sp. dominated again in pond 3 and 4. Different Trachelomonas-species (*T. hispida, T. varians, T. oblonga* and *T. klebsii*) increased in the last ponds.
At the last sampling, 8th of August also *Merismopedia sp*. dominated in pond 1-4 Different Trachelomonas-species (*hispida, varians och klebsii*) and Chlamydomonas sp. (Chlorophyta) increased in numbers in the last ponds.

Zooplankton

At the first sampling occasion on the 17th of May Prorodon sp. was found in pond 1 and the *Strobilidium spiralis* (Ciliophora) in pond 4, 5 and 6. Also some Gastropus sp. (Rotophera) was found in pond 1 (Table 5).
The 5th of June Heliozoa (Protozoa) and Rotophera was found in all ponds, but Heliozoa dominated in pond 6. In pond 4-6 also *Strobilidium spiralis* was found.
On the 21st of June there was no zooplankton at all.
On the 4th of July the ciliate Paramecium sp. (Ciliophora) appeared in a high amount in pond 1 and Prorodon sp. was in pond 5 as well as Amoebae (Protozoa). Heliozoa was found in pond 5 and 6.
On the 17th of July Prorodon sp. was found in all ponds, most in pond 3 followed by pond 1. Also the Mesocyclops sp. (Atrophoda; copepoda) was found in all ponds with highest rates in pond 1 and 4.
On the 27th of July dominated Prorodon sp. in pond 5, was also found in pond 4. In pond 3 the Euchlanis sp. (Rotophera) and in pond 6 Keratella sp. (Rotiphera) was found.
At the last sampling on the 8th of August zooplankton was only found in pond 2 which was Paramecium sp.

	Appearance in pond number					
Specie/Group	**1**	**2**	**3**	**4**	**5**	**6**
Spirolina sp (Chyanophyta)	x					
Nostocales (Chyanophyta)	x			x		
Euglena sp (Euglenophyta)	x	x	x	x	x	
Microcystis sp (Chyanophyta)	x	x	x	x		x
Pennales (Nizchia, Navicula) (Diatomophyceae, Chrysophyta)	x	x	x	x	x	x
Trachelomonas sp (Euglenophyta)	x	x	x	x	x	x
Zygnematales (Conjugatophyceae, Chlorophyta)	x	x	x	x	x	x
Oscillatoriales (Chyanophyta)	x	x	x	x	x	x

Clamydomonas sp (Chorophyta)	x	x	x	x	x	x
Merismopedia sp (Chyanophyta)	x	x	x	x	x	x
Trachelomonas hispida (Euglenophyta)	x		x	x	x	x
Scenedesmus quadricauda (Chorophyta)	x			x	x	x
Stephanodiscus/Cyclotella/Cyclostephanos (Diatomophyceae, Chrysophyta)	x	x			x	x
Trachelomonas varians (Euglenophyta)	x	x				
Dinophyceae (Dinophyta)		x		x		
Chrysocuccus sp (Chrysophycea, Chrysophyta)			x	x	x	x
Chlorococcales (Westella sp Dictospaerium sp) (Chlorophyta)			x	x	x	x
Chorogonium minimum (Chlorophyta)				x	x	x
Cosmarium sp (Chlorophyta)				x	x	x
Chlosterium (Conjugatophyceae, Chlorophyta)					x	x
Scenedesmus sp (Chlorophyta)					x	x
Phacus (Euglenophyta)					x	x
Trachelomonas oblonga (Euglenophyta)					x	x
Trachelomonas klebsii (Euglenophyta)					x	x
Cryptomonas sp (Chryptophyta)					x	
Staurastrum sp (Chlorophyta)						x

Table 4. Different species and groups of phytoplankton in different ponds in Bergum from May to August 2006.

Specie/Group	**Appearance in pond number**					
	1	**2**	**3**	**4**	**5**	**6**
Paramecium sp (Ciliophora)	x					
Gastropus sp (Rotophera)	x					
Rotophera	x	x	x	x	x	x
Mesocyclops sp (Copepoda, Artropoda)	x	x	x	x	x	x
Heliozoa (Protozoa)	x	x	x	x	x	x
Prorodon sp (Ciliophora)	x		x	x	x	x
Euchlanis sp (Rotophera)			x			
Strobilidium spiralis (Ciliophora)				x	x	x
Amoeba sp (Protozoa)					x	
Keratella sp (Protozoa)						x

Table 5. Different species and groups of zooplankton in different ponds in Bergum from May to August 2006.

Lärjeåns gardens, phytoplankton.

Already after a week, on 21st of June with sewage water the first pond was colonized by micro algae like Oscillatoria sp. and Microcystis sp., (Cyanophyta), Thracholomonas sp., (Euglenophyta), Chlamydymonas (Chlorophyta) and Chryssococcus (Chrysophyta), table

6. The sewage water had not reached pond 2 but the Oscillatoria sp. (Cyanophyta) and Chryssococcus (Chrysophyta) occur in great number (1 900 000 individuals/ml).
At the sampling day of 4th of July the amount of Chlamydomonas sp. in pond 1 had increased and dominated and was also found in pond 6. Chlorococcales was found in pond 1 and 2 and in pond 1 Chlorogonium sp. (Chlorophyta) and Chrysococcus sp., but the amount had decreased a lot since the last sampling. In pond 2 were also Zygnematales and Nostocales and Microcystis sp. was found.
On the 17th of July the amount of Chlamydomonas sp. had decreased to half of the level. In the pond also Chrysococcus sp., Nostocales (Cyanophyta) and *Trachelomonas hispida* was found. Scenedesmus sp. (Chlorophyta) was found in pond 5 and Cryptomonas sp. (Chryptophyta) in pond 6.
On the 27th of July the amount of Chlamydomonas sp. decreased further but dominated still in pond 1 together with Chlorococcales and the order Pennales (Chrysophyta). In the other ponds no phytoplankton was found.
At the last sampling at the 8th of August only Chlamydomonas sp. appeared in pond 1 and 2 in a relatively high density. In pond 5 the order Zygnematales (Chlorophyta) and in pond 6 the order Oscillatoriales was found.
Merismopedia sp, Oscillatoriales, Microcystis sp and Nostocales appeared at all sampling occasions, but not as big amounts as in Bergum where specially Merismopedia sp dominated the phytoplankton flora.

Zooplankton
At the two first sampling occasions no individuals were found at all but at the third sampling occasion 17th of July the *Daphnia magna* (Atrophoda; cladocera) was found in pond 2 and 5. They were also found 27th of July except from pond 2 and 5 also in pond 6. On the 8th of August the amount had increased but was only found pond 2 and 5 (Table 7).

Specie/Group	**Appearance in pond number**					
	1	**2**	**3**	**4**	**5**	**6**
Trachelomonas hispida (Euglenophyta)	x					
Trachelomonas sp (Euglenophyta)	x					
Pennales (Nizchia, Navicula) (Diatomophyceae, Chrysophyta)	x					
Chorogonium sp(Chlorophyta)	x					
Merismopedia sp (Chyanophyta)	x					
Chlorococcales (Westella sp Dictospaerium sp) (Chlorophyta)	x	x				
Chrysocuccus sp (Chrysophycea, Chrysophyta)	x	x				
Nostocales (Chyanophyta)	x	x				
Microcystis sp (Chyanophyta)	x	x				
Clamydomonas sp (Chorophyta)	x	x				
Oscillatoriales (Chyanophyta)	x	x				
Zygnematales (Conjugatophyceae, Chlorophyta)		x			x	
Scenedesmus sp (Chlorophyta)					x	
Cryptomonas sp (Chryptophyta)						x

Table 6. Different species and groups of phytoplankton in different ponds in Lärjeåns garden from June to August

	Appearance in pond number					
Specie/Group	**1**	**2**	**3**	**4**	**5**	**6**
Daphnia magna (Cladocera, Artropoda)		x			x	x

Table 7. Different species and groups of zooplankton in different ponds in Lärjeåns garden from June to August

Lärjeåns garden 2007

In 2007 the sampling was repeated in Lärjeåns garden. The summer 2007 was much colder and more rainy but still only little water remained in pond 2 and 3. From pond 3 -6 the water was not influenced by waste-water, rather by ground-water. A slight increase in number of species in the second year was found. In the newly constructed pond 1:2 the number of individuals increased from 200 000/ml in July to 50 000 000/ml in August but only 4 different species (table 8).

Lärjeåns garden, phytoplankton

In the beginning of June in the first pond the family Chrococcales (Cyanophyta), Cryptomonas sp.(Chryptophyta), Stephanodiscus sp/ Cyclotella sp/Cyclostephanos sp. (Chrysophyta) and Thracheolomonas varians (Euglenophyta) and Chlamydymonas sp. (Chlorophyta) were found. In pond 4, 5 and 6 the phytoplankton all belonged to Chlorophyta.

In the end of June the waste water had reached the second pond. 4 different species belonging to the family Chroccocales appeared in all ponds with water (4, 5 and 6). Two species belonging to Chlorophyta was also found and in pond 4 Cryptomonas sp. (Chryptophyta) and Chlamydomonas sp. (Chlorophyta) and Clostridium sp. In pond 5 Centrales (Chrysophyta) was found. In pond 6 only one Clostridium sp. (Chlorophyta) was found.

The 14th of July the first sampling was done after the division of the first pond into two parts. The amount of to the family Chroccocales particulary Microcystis sp. (Chyanophyta) appeared in a red/green mat in the first two ponds 1:1 and 1:2. In 1:1 and 1:2 belonging to Oscillatoriales and Nostocales like Anabena (Chyanophyta) and like Stephanodiscus sp. (Chrysophyta) appeared. In pond 4 Cryptomonas sp. (Chryptophyta) and in pond 6 the Euglena sp. (Euglenophyta) occurred.

On the 26th of July still Microcystis sp. appeared in the form of a red/green mat in the first two ponds 1:1 and 1:2 and the same species were found in pond 4-6. The Euglena sp. and Thracholomonas sp. (Euglenophyta) was also found in 1:1 and 1:2. In 1:1 also Clostridium sp. (Chlorophyta) was found. In pond 1:2 and 4 Centrales (Chrysophyta) was found.

In 21st of August still Microcystis sp. appeared in red/green spots in the first two ponds 1:1 and 1:2. Also in 1:2 Cyclotella sp., Stephanodiscus sp. and Cyclostephanos sp. (Chrysophyta), appeared. Euglena sp. (Euglenophyta) was found in 1:1 and 1:2 and in pond 4. Cryptomonas sp. (Chryptophyta) appeared again in pond 4 and also in pond 6.

Zooplankton

In the beginning of June the Prorodon sp. (Ciliophora) was found in pond 6. In the first pond numerous Chironomidae was found and numerous *Daphnia magna* (Atrophoda; cladocera) in pond 4-6.

On the 21st June Rotiphera were found in pond 1 and the Paramecium sp. (Ciliphora). in pond 2. The *Daphnia magna* was still found in pond 4, 5 and 6. In the first pond numerous Chironomidae occurred.

On the 14th of July Paramecium sp. and Prorodon sp. were found in pond 4. The *Daphnia magna* now also invaded pond 2 was but still found in pond 4 and 6.
On the 26th of July the Paramecium sp. was observed in pond 1:1 and pond 4. *Daphnia magna* was also found in the last 3 ponds.
On the last sampling occasion the 8th of August the only zooplankton found was Rotiphera.

	Appearance in pond number						
Specie/Group	**1:1**	**1:2**	**2**	**3**	**4**	**5**	**6**
Fragilaria sp (Chrysophyta)	x						
Nostocales (Chyanophyta)	x	x					
Anabena (Chyanophyta)	x	x					
Trachelomonas sp (Euglenophyta)	x	x					
Spirolina sp (Chyanophyta)	x	x					
Stephanodiscus/Cyclotella/Cyclostephanos (Diatomophyceae, Chrysophyta)	x	x					
Trachelomonas varians (Euglenophyta)	x	x					
Clamydomonas sp (Chorophyta)	x		x		x		
Chroccocales (Chyanophyta)	x	x	x		x	x	x
Microcystis sp (Chyanophyta)	x	x	x		x	x	x
Euglena sp (Euglenophyta)	x	x	x		x	x	
Oscillatoriales (Chyanophyta)	x	x	x				
Cryptomonas sp (Chryptophyta)	x	x			x		x
Centrales (Chrysophyta)		x			x	x	
Cyclotella sp (Chrysophyta)		x					
Chlorococcales (Chlorophyta)			x				
Ulotrichales (Chlorophyta)			x				
Pennales (Nizchia, Navicula) (Diatomophyceae, Chrysophyta)					x		
Chlosterium (Conjugatophyceae, Chlorophyta)					x	x	x

Table 8. Different species and groups of phytoplankton in different ponds in Lärjeåns gareden from June to August 2007.

	Appearance in pond number						
Specie/Group	**1:1**	**1:2**	**2**	**3**	**4**	**5**	**6**
Paramecium sp (Ciliophora)	x		x		x		
Rotophera	x	x					
Chironomidae (Diptera)	x	x					
Daphnia magna (Cladocera, Artropoda)		x			x	x	x
Prorodon sp (Ciliophora)					x		x

Table 9. Different species and groups of zooplankton in different ponds in Lärjeåns garden from June to August 2007.

Nutrient content

During 2007 samples were taken due to the operating instructions in May, July, September and December, table 10.
Although the year 2007 was wet and cold the second and third pond was nearly always empty or only little water was left in the bottom. The ponds were sealed both in the bottom and between the ponds excluding any possibilities for leakage. The explanation to the water shortness could be that the plant is too big for present loading and the evaporation is too big. Lots of stones in the ponds store the heat and strengthen the evaporation.

The fact that there are only waste water in the first and second pond there are no possibilities to count the difference between pond 1 and 5 as uptake of nutrients.
The garden was open from April until September and had approximately 100 visitors per day and 10 employees.
The results show the highest values of nutrients and bacteria in July, table10. Pond 5 was not influenced by waste water, showed by low bacteria content, nutrient and conductivity and high oxygen content. The analyses in December show that the influence of waste water had stopped.

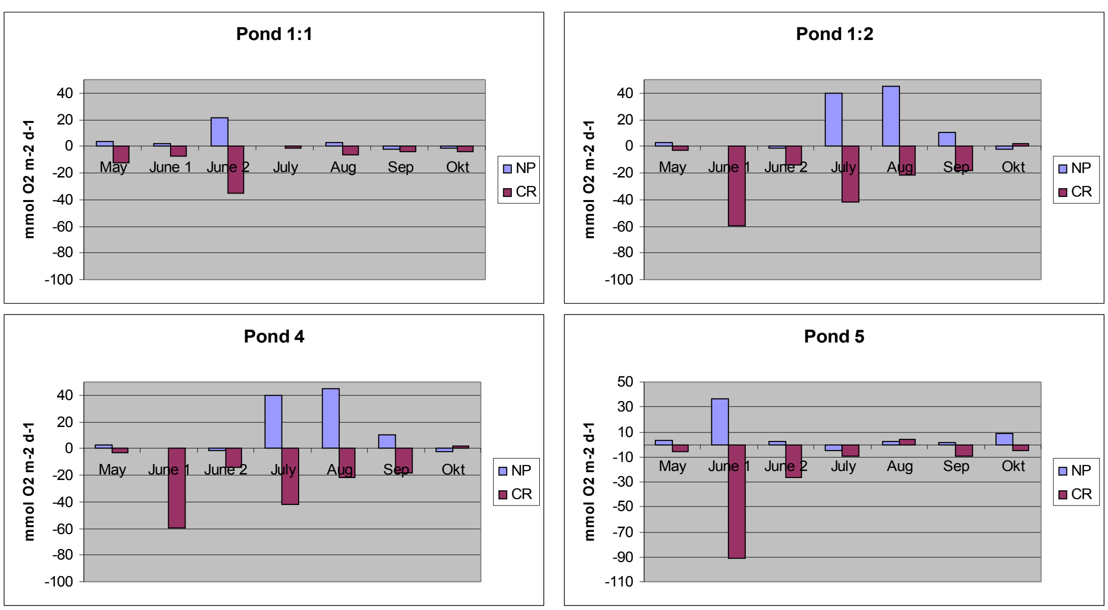
Nutrients in Lärjeåns garden 2007		070515	070525	070519	071207	Mean
Tot-P (mg/l)	in	5	9,8	6,4	0,83	5,51
	ut	0,96	1,9	4,1	0,78	1,94
Fosfat-P (mg/l)	in	5,4	6,5	6,4	0,41	4,68
	ut	1	1,9	3,5	0,5	1,73
Tot-N (mg/l)	in	20	46	42	4,5	28,13
	ut	2,9	11	12	3,2	7,28
Ammomium-N (mg/l)	in	15	28	34	2,5	19,88
	ut	0,56	5,2	6,7	1,4	3,47
Nitrat-N (mg/l)	in	<0,1	<0,1	<0,1	0,15	0,15
	ut	1,2	1,1	3	0,19	1,37
N/P-kvot (tot.)	in	4	4,7	6,6	5,4	5,18
	ut	1,5	5,8	2,9	4,1	3,58
N/P-kvot (oorg.)	in	2,8	4,3	5,3	5,3	4,43
	ut	1,76	3,3	2,77	3,18	2,75
Enterokocker / 100 ml	in	1200	32000	720	23	84856
	ut	500	10	1	34	136
Koliforma bakt. 35 gr. C / 100 ml	in		160000	>10000	22000	91000

	ut		46000	6	7000	17669
E. coli / 100 ml	in	170	160000	>10000	5	53392
	ut	5	10	2	5	5,5
BOD7 mg / ml	in		170	110	12	97
	ut		9	3	<3	6
Temperature (gr. C)	in	14,5	24	12,5	6,2	14,3
	ut	12,4	23	9	6,1	12,63

Table 10. Nutrient and bacteria content in Lärjeåns garden 2007.

Photosynthesis

There were two different kinds of water in the WPM, sewage water only reaching the two first ponds but evaporated when reaching pond number two. In the fifth pond groundwater penetrated giving water support to the last ponds. In June 2007 the first pond was divided in two for continuous water supply. The first measurement in the new pond in July showed little net oxygen production (NP) and community respiration (CR). In August there was no oxygen at all. The highest NP was measured in pond 4 in August. The pond with sewage water generally had low content of oxygen, between (0 – 7 mg l^{-1}) compared with pond influenced by natural water with a variation of 0.3-20 mg l^{-1}. Daily oxygen fluxes varied between a net primary consumption (negative NP) 15 mmol $O_2\,m^{-2}\,d^{-1}$ in pond 6 to a NP in 45 mmol $O_2\,m^{-2}\,d^{-1}$ in pond 4. Figure 13 show that the system is both heterotrophic (net consumption) and autotrophic (net production). The community respiration (CR) fluxes between 7-91 mmol $O_2\,m^{-2}\,d^{-1}$ indicating a variation of zooplankton activity. Most of the occasions the ponds were dominated with autotrophic organisms but sometimes the heterotrophic organisms dominated without any difference between the ponds. In dominance of heterotrophic organisms both uptake of dissolved inorganic nitrogen (DIN) and dissolved inorganic phosphor (DIP) were less than in a community dominated of autotrophs (Sundbäck et al. 2003). In the water purification marsh autotrophs dominated during summer, only at a few occasions had the heterotrophs dominance. The relatively small values in the NP and CR can be an indication of a community in balance, because oxygen produced by photosynthesis is quickly consumed by oxygen demanding organisms.



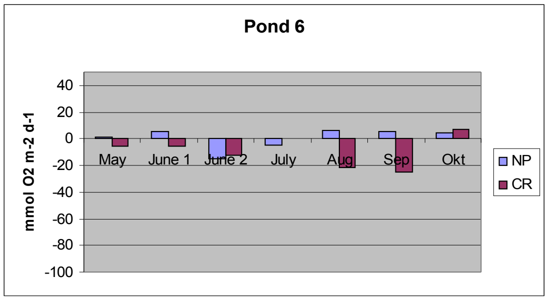


Figure 13. Daily net primary productivity (NP) and community (CR) in the different ponds at Lärjeåns garden expredded as daily oxygen fluxes.

Oxygen content

Measurements of oxygen content during 2006 show lower values at most occasions in Bergum compared with earlier years (In Manuscript). Especially on the 27th of July the rate was low. In Lärjeåns gardens oxygen measured at 5 occasions in 2006 in pond 1, 2, 5 and 6, there were higher values during the whole summer than in Bergum, table 11. The oxygen content was also measured in pond 4 in Lärjeåns garden in 2007, table12.

Oxygen ml/l	060602	060615	060712	060727	060808	070511	070608	070625	070704	070731	070814
in 1	2,8	>20	3,4	0,5	1,2	>20	1	1	0,9	0,8	0,95
ut 1	2,6	>20	2,5		1	>20	3,5				
in 2	2,5		2,8	0,5	1	10	3,2	2,5	2,6	2,1	1,5
ut 2	2,4		3,2	0,5	1	13	1,2	1,2	2,6	3	1,8
in 3	1,8		3,2	0,8	1	10	7,5	3	0,8	0,6	1,4
ut 3	2,4	>20	2,4	0,5	0,8	>20	5,4	14	1,8		1,6
4 in	2,2		3	0,8	0,8	>20	5,4	2,3	1,8	1,6	3,5
4 ut	2,2		3,4	0,5	1,5	>20	1	1,5	2,4	4	10,2
5 in	2,1		4,2	5,5		>20	1,5	1,3	1,1	3,7	1,4
5 ut	2,1		4,1	4	3,8	>20	2	15	0,7	2,5	11,5
6 ut	2,2		4,2	2,7	2	>20	0,8	8	3,2	0,8	1,2

Table 11. Oxygen content ml/l in Bergum in the summer of 2006 and 2007.

Oxygen ml/l	060712	060727	060808	060824	060908	060829	070515	070608	070625	070725	070820	070919	071015
in 1	2,4	3,3	14,5	2,3	2,5	0,9	2,9	0,7	7,3	0,3	0,6	1	2,1
ut 1	2,0	6,5			2								
2	2,9	13	13	19,5									
4							10,9	13,4	8,8	20,3	9,1	8,5	1
5	2,4	7,5	15,5	11	3,3	10	9,5	21,6	3,9	2,7	2,7	7,8	2
6	1,8	7,5	11,5	13	4,5	9	0,3	4,6	11	6,4	7	14,5	9,7

Table 12. Oxygen content ml/l in Lärjeåns garden in the summer of 2006 and 2007.

Conductivity

The conductivity in Bergum has during the summer of 2006 been low in spite of low oxygen content and decreasing amount of plankton, table 13. Already in the end of the first pond show decreased values probably because most of the nutrient reduction was in the first part of the pond. In the outlet from pond 2 and further down in the system the values are constant, corresponding well with earlier studies showing that most of nutrient reduction was in the first pond (Magnusson 2004).

In Lärjeåns gardens the conductivity was measured at 4 occasions in 2006 and during 2007 at 7 occasions, table 14. In 2006 higher values in incoming water show that the water was more evaporated as the weather was warm during that year, table 14.

Conductivity mS/m	060602	060615	060712	060808	070511	070608	070704	070731	070814
in 1	86	125	98	45	127	151	81	37	127
ut 1	27	58	45		59	82			
in 2	25		46	87	60	70	31	22	32
ut 2	29		27	55	52	71	23	19	59
in 3	29	28	24	49	44	47	21	17	43
ut 3	20	35	25	41	34	41	23		47
4 in	26	30	14	42	33	41	19	19	35
4 ut	26	27	22	34	30	37	22	13	32
5 in	20	19	25	15	28	41	22	15	25
5 ut	11	13	24	26	26	40	19	14	17
6 ut	18	12	16		25	39	19	13	16

Table13. Conductivity mS m^{-1} in Bergum during 2006 and 2007

Conductivity mS/m	060712	060808	060824	060908	070515	070608	070625	070725	070820	070919	071015
in 1	95	93	102	117	50	86	35	72	89	81	37
ut 1	89	43	88	117	52			62	86	76	44
2	24		67				50				
4					38	82	57	28	52	41	46
5	25	26	52	66	26	55		30	44	35	50
6	16	16	41	43	23	29		19	25	29	30

Table 14. The conductivity mS m^{-1} in Lärjeåns garden in the summer of 2006 and 2007.

Discussion

Chlorophyll

The chlorophyll content, the density of algae, varied much in Bergum during the summer partly depending of warm weather and little rain during the whole of July. Due to Sveriges Meterologiska och Hydrologiska Institut (SMHI) the rain was only 50% of normal rainfall in the area and the mean temperature for the month was 4-5 degrees higher than normal.

High light intensity and high nutrient content stimulate algal growth but also growth of duckweed, *Lemna minor*. Especially the mats of duckweed that covered the water surface competed with the algae of incoming radiation and as a result decreased growth of microalgae. On the 17th of July the water was very turbid in pond 2 and 5 probably due to big amount of frogs lowering the light in the water column. The measurements show that the chlorophyll content in pond 2-4 was considerable lower during the whole summer (Fig. 5). From May until middle of June the ponds were crowded with tadpoles and later

followed by duckweed covering. Also in these ponds the dominant species was the cyanophyta Merismopedia sp., being able to photosynthesize at low light intensities (Aktan and Aykulu 2003). Other plankton had been out competed of duckweed giving the low rate of chlorophyll in pond 2-4.
In Lärjeåns gardens the chlorophyll content the whole summer was much lower than in Bergum at the same time. The result is based on the fact that the marsh at Lärjeån gardens was newly developed with fewer species and individuals of algae.

Succession of plankton and bacteria
The water purification marsh is a very complex system with the connection between bacteria, primary and secondary production and all the different organisms living in the marsh during different part of their lifecycle. The succession could be divided in different parts depending on the annual cycle, the aging of the marsh and the weather changes, giving quick changes in light, temperature and nutrient concentrations but always with the same N/P-ratio.
Ecological stoichiometry, the relation between carbon (C), nitrogen (N), and phosphor (P) is the study of the balance of energy and multiple chemical elements in ecological interactions. This relation can strongly affect the food-web structure that occurs in eutrophic lakes and the stoichiometric mechanisms play a potentially important role in generating different effects (Elser et al. 2000). Species composition of the zooplankton community can have strong influence on the N:P ratio of recycled nutrients and thereby affect resource completion between phytoplankton species (Andersen and Hessen 1991). Zooplankton at low tropic level in the pelagial can quickly regulate the balance between access to nutrients and hence being dependent of the primary production (Elser et al 1988). This shows the importance of biological diversity, many species can compensate each other to different nutrient conditions by the fact that different species have different demand of different N/P ratios due to variations of element ratios of N and P. The WPM with the division in different ponds give space to different species in the trophic levels since both phyto- and zooplankton seems in short time being able to replace each other. Different organisms have their optimal N/P ratio in their cells regulating the uptake of nutrients (Chrzanowski et al. 1996, Sterner et al. 1992, Rhee and Gotham 1980). Downing and McCauley (1992) published data on how the N/P-ratio varies with lake trophic status. N/P ratio reflects the source of nutrients, the ratio is high in oligotrophic lakes because they receive their N and P from natural, undisturbed watersheds which export much less P than N, mesotrophic and eutrophic lakes receive various mixtures of nutrient sources that have lower average N/P, and very eutrophic lakes have N/P that correspond very nearly to the N/P of sewage and water from the WPM.
Compared with Redfeild mass N/P ratio of 7,2, the value for biological production and three different N/P ratio for sewage were showed, 10, 5,3 and 2,8, (Downing and McCauley 1992) in this study the difference is 5,2 in Lärjeån (table 10 and 15) and 6,2 in Bergum (table 15) probably due the differences in phosphor content. Average N/P mass ratios were also given for some aquatic organisms like macrophytes in oligotrophic lake (13.6) compared to macrophytes in eutrophic lake (6,8) can reflect two facts, plants are more efficient in their P uptake than N uptake or they adapt to the nutrient in their environment. Whole community of algae's N/P ratio was 7,0 in analogy with Redfield ratio 7,2 (Downing and McCauley 1992). The zooplankton, (Cladocera as a group) had an N/P-ratio of 8.8 and the Cladocera (Daphnia spp.) 6.6 (Andersen and Hessen 1991), thus *Daphnia magna* found in masses in Lärjeån during both years could be related to the low N/P ratio in the ponds.
Frogs are always in the vicinity and in the water purification marsh in Bergum, especially 2006 must have been a good year for them because the amount of tadpoles was enormous. Regarding the number and with a N/P ratio of 17.8 in frogs (Downing and

McCauley 1992) their uptake of nutrients especially N might be taken into consideration especially through grazing on phytoplankton showed as clear water and small amounts of chlorophyll (Fig. 5).
The first pond with highest content of bacteria, photosynthetic measurements show that most organisms were autotrophic from May until August and heterotrophic in September and October (Fig.13). Earlier studies show (Chrzanowski et al. 1996) that there is compelling evidence indicating that bacteria have the potential to compete with phytoplankton for P. Thus during periods when bacteria are actively increasing and characterized by low N/P ratios, they should directly compete with phytoplankton for P. In the end of June with highest primary productivity the first grazing zooplankton (Rotiphera) was found in the pond 1. In July the primary productivity was none but with some respiration which might be a result of bacterivores grazing on the bacteria.

During the first year in Lärjeåns garden there were no grazers in the marsh but in the second year some ciliates where present coinciding with low N/P ratio in the water. On the other hand they were present in the water purification marsh in Bergum more or less during the summer probably indicating that they are present more or less in an older well developed marsh. Also the water in the first pond sometimes is clear indicating no or little occurrence of phytoplankton.
A study of Rhee and Gotham (1980) show that the internal N/P ratio in the algae reflects the limiting nutrient. One of the noted species with low N/P mass ratio (3.8) in the cells in that study was found in Lärjeåns gardens, Microsystis sp. in pond 1 on the first sampling day in the end of June and in pond 2 on the 4th of July 2006. Also 2007 the dominating specie was Microcystis sp. or other species belonging to the same genera that might be adapted to low N/P ratios. The N/P ratio in the inlet was 5,2 with high P-concentration meaning that the water is N-limited. Cyanophyta are as a group related to low N/P ratios (Degerholm 2002), but in the cells of Cyanobacteria in blooms N/P-ratio of 16,3 was measured (Downing and McCauley 1992).
In Bergum the pond 1-4 was dominated by Merismopedia sp. belonging to the same family as Microcystis. In Bergum the N/P ratio in incoming water is higher (6,2, table 15) and not limited by any nutrient, the competition could be caused by the warm weather, which benefits the bloom of cyanobacteria and that Merismopedia sp. may be very effective to photosynthezie in low solar radiation compared with other plankton.
In Lärjeåns garden the Scenedesmus sp. (Chlorophyta) with a N:P ratio of around 14 (meaning that they are P limitated) (Rhee 1978) was found on the 17th of July 2006 in pond 5 and in pond 9 at Aröd (Pehrsson 1994) which was not influenced by sewage water. In the second year measurements show that the water in pond 5 had a relatively low N/P ratio (4) and Scenedesmus was not found. Other species of both chlorophyta and cyanophyta were found (Table 8) but during July and August the ponds were invaded of the cladoceran *Daphnia magna* with especially low N:P compared to all other zooplankton (Sterner et al 1992, Andersen and Hessen 1991) Being a relatively unselective filter feeder, Daphnia can exert strong top-down impact on phytoplankton as well as on the protozoan and bacterial assemblages (Zöllner et al. 2003).
In the WPM *Daphnia magna* proceed in the early successions in Aröd and Lärjeåns gardens, but in Bergum the copepod Mesocyclops sp. was found at the same time as ciliates were in abundant occurrence in pond 1 and 2 (table 5 and rapport Bergum 2002) probably feeding on bacterial assemblages. The importance of the bacterial abundance in an ecosystem may have been underestimated, a suspicious condition found due to the great conversion on lower trophic levels in the two first ponds in Bergum. If Daphnia spp. greatly affects the zooplankton species compared with the copepods, giving space to higher diversity, maybe the daphnies would not be wanted, but the development of the copepods can also be seen as a later state in the succession giving possibilities for

development of richer diversity. The division of the different ponds in the water purification marsh gives the space to this development and the amount of species and groups also increased in the following ponds (Fig 7-12).
In Bergum both measurements of chlorophyll, oxygen and plankton show that the quantity of plankton decreased during the summer. This decrease of growth is probably caused by the competition of *Lemna minor* that covered the ponds during most of the summer and thereby increased the light to the plankton. However this does not necessarily lead to decreased nutrient uptake. Other studies (Körner and Vermaat 1998) showed an uptake even when the water was covered, in that case with *Lemna gibba*. In their study as well as in Bergum the N/P was around 7, the optimal for nutrient uptake.

Nutrient content and N/P-ratio
To confirm that water originates from sewage an adequate parameter to calculate is the ratio between nitrogen and phosphor, the N/P ratio. Since nutritional biological material from human emanate from food that consist of living organisms have a rather constant N/P ratio (about 7) rest products from households coincide with the same N/P ratio. Different parts of sewage water have different N/P-ratios (table 15).
The N/P-ratio both in the inlet and outlet in the water in Lärjeåns gardens are some less than in Bergums water purification marsh as well as in the inlet to Ryaverket (the sewage treatment plant in Göteborg). Most of the sewage water originates from dishwater thus giving lower N/P ratio and the outlet originates from dwelling groundwater with rather high phosphor concentrations see table10. The groundwater in the area has a content of PO_4 and NO_3 10-20 mg l^{-1} (www.sgu.se in van der Berg and Smit 2007). Corresponding values in this study are lower, equal values of NO_3 and PO_4 are between 0,5-3,5 mg l^{-1}. The corresponding values of the N/P ratio in the inlet and outlet of Bergum show the similarity between our food and biological production while the ratio increase in Ryaverken depending on better phosphorous than nitrogen reduction in sewage treatment plants.
The N/P ratio and the concentrations of nutrients in the inlet to the marsh in Lärjeåns garden show a composition a bit different to sewage, while the inlet to Ryaverken have the N/P ratio regarding to sewage, but strongly diluted. This strengthen the fact that the inlet to Bergum, being a clean sewage water show more than twice as high concentrations of nutrient (Pehrsson 2001).

Content in sewage (Naturvårdsverket)	g / person / day		
	N	P	N/P
Urine	11	1,0	11
Faeces	1,5	0,5	3,0
BDT	1,0	0,6	1,7
Urine + faeces	12,5	1,5	8,3
Urine +BDT	12,0	1,6	10,4
Total	13,5	2,1	6,4
Concentrations of nutrients in inlet and outlet water	mg/l	mg/l	
Lärjeåns trädgårdar in	28,1	5,5	5,2
Lärjeåns trädgårdar out	7,3	1,9	4,0
Bergum in	76,4	12,4	6,2
Bergum out	8,6	1,3	6,6
Ryaverket in (www.gryaab.se/ 2006)	23,3	3,8	6,1
Ryaverket out	10,0	0,5	20

Table 15. Outlet per person and day (Naturvårdsverket) and comparisons with mean value of inlet and outlet from water purification marshes and sewage treatment plant.

Primary productivity and nutrient uptake

Primary productivity between 0 to 45 mmol O_2 m^{-2} d^{-1} corresponded with the productivity in a community in a shallow brackish water bay in the west coast of Sweden 6-46 mmol O_2 m^{-2} d^{-1} (Sundbäck et al 2003).

By using the basic equation (H_2O +CO_2+photons=1/6[$C_6H_{12}O_6$]+O_2) indicating equimolecular exchanges between CO_2 consumed and O_2 released (the photosynthetic quotient P/Q, mol O_2 evolved /mol CO_2 assimilated, is 1, Reynolds 2006) daily productivity of carbon can be calculated. In pond 4 the highest mean value of 170 mg C m^{-2} d^{-1} compared with 5,5 mg C m^{-2} d^{-1} in the last pond.

From May to October pond 6 had low mean productivity, was heterotrophic in June and July (Fig.13) maybe as a result of *Daphnia magna* and the surface covered with *Lemna minor* from late June and through the summer. Low dissolved oxygen to anoxic conditions in the water column due to shading from a dense cover of *Lemna minor* (Cronk and Mitsch1994) corresponds with the result in this study in pond 6. The production of phytoplankton may thus be more effective than the macrophytes and the longer vegetative period of phytoplankton give a good reason to keep macrophytes away from the WPM.

In a study in Denmark (www.aaa.dk/nm or www.nja.dk) primary productivity was calculated from two different areas, Alborg Bugt open water system in the Western part of Kattegatt and Mariager fjord the longest Danish fjord (42 km) with outlet in Kattegatt. In Ålborg Bugt the productivity varied between 56 to 900 mg C $m^{-2}d^{-1}$ during the year and at the summer between 500 to 700 mg C $m^{-2}d^{-1}$. Corresponding values in Mariager fjord was 5-9050 mg $m^{-2}d^{-1}$ with a summer value of 4000 mg $m^{-2}d^{-1}$. The big difference in productivity in the WPM and in the Danish report can be related to the different methods. In this study with productivity calculated on the whole community while the Danish report is based on chlorophyll. The productivity in relation to eutrophic lakes varies between 0-5000 mg C $m^{-2}d^{-1}$ (Wetzel 2001) corresponds with the Danish report but differ from the WPM with a variation between 0-540 mg C $m^{-2}d^{-1}$.

Oxygen and conductivity

The measurements of the oxygen content (a measure of the photosynthesis activity) showed lower rate than earlier year, especially on the 27th of July, as a result of less plankton. Low numbers of individuals in the first ponds and the chlorophyll content in the middle ponds decreased very much, certainly as a result of the duckweed covering the water surface.

The reduction of plankton production may be expected to result in less efficiency of the marsh cleaning effect, meaning lower uptake of nutrients in the primary production being the first step in the nutrient chain. High density of phytoplankton results in much food for the organisms in the food chain and efficient reduction of nutrients from the system. But, the lower oxygen content can also be a result of the balance between production and consumption of oxygen and not a result of low nutrient uptake. This theory is supported by the fact that the conductivity in the marsh was low in spite of relatively low oxygen content (table 13 and 14).

Different wetlands

Most wetland are planted with higher plants were N mainly are supposed to be reduced by denitrification and P limitation by fixation to particles settled into the bottom substrate. N and P are treated separated without taking any notice of N/P ratio, the very important parameter when discussing the possibility of nutrient uptake of plants. With a

N/P ratio much higher than 7 showing surplus of N show that the efficiency is negligent and even negative for Tot-N when the N/P ratio is high because the lack of P for primary production. When the N/P ratio is high a certain amount of reduction of P can be possible but not comparable with the high efficiency when both N and P are in the optimal rate and at high concentrations. In comparison with other kind of wetland due to efficiency of nutrient reduction in the WPM reach between 80-100 % of both N and P on annual basic (Pehrsson 2001), were the reduction is referred to uptake by phytoplankton while wetlands with macrophytes (reed beds) only have between 3-20% of N and 20-40 % of P (Braskerud 2002). The difference can also be regarded from wetlands from diffuse outlets like farmlands where approximately 45% of the particulate-P was retained, compared with only 5% for dissolved-P that sedimentation was a far more important retention process than uptake by algae and macrophytes (Braskerud 2002).
Table 16 show the difference between the efficiency and average concentration of the reduction from different constructed wetlands for treating concentrated livestock wastewaters (Knight, et al. 2000), and the first WPM in Aröd (Pehrsson 1994).
The average reduction of ammonium-nitrogen (NH_4-N) was 60%, total-nitrogen (TN) 51%, and total-phosphor (TP) 42%. Corresponding values in Aröd were NH_4-N 95%, TN 93%, and TP 84%.

	Dairy, in (mg/l)	Dairy, out (mg/l)	Reduction (%)	% NH_4-N in of TN in	% NH_4-N out of TN out
NH_4-N (USA)	105	42	60	100	82
NH_4-N (Aröd)	84,95	4,69	94,5	75	59
TN (USA)	103	51	51		
TN (Aröd)	112,7	7,93	93,0		

Table 16. Incomming (in) and outgoing (out) concentrations of total-N in USA (Knight, et al 2000) and from Aröd (Pehrsson 1994).

The most commonly used plant species for livestock wastewaters, in order of their occurrence in treatment wetland cells, were cattails (Typha spp.), bulrush (Scirpus spp.) and common reed (*Phragmites australis).* Inlet NO_3-N concentrations were generally low at most sites, which would be expected because of the anaerobic conditions found in most pre-treatment systems. The N/P ratio in incoming water was optimal and the denitrification was probably not higher than in Aröd. The reason for the low efficiency in USA compared WPM Aröd must be the shadowing macrophytes.
Another example of wetlands designed for the secondary treatment of domestic or municipal wastewater is from the Czech Republic. The size of wetlands ranges between 18 and 4500 m^2 from a population between 4 and 1100 (Vymazal 2002). In some of these wetlands the optimal N/P ratio is destroyed in the treatment plant because a better P reduction than N reduction (ex. Kode sewage treatment plant) in Pehrsson 2002.
The treatment efficiency is high in terms of BOD_5 (88.0% for vegetated beds) and suspended solids (84,3% for vegetated beds). The removal of nutrients is lower for vegetated beds, averages 51 and 41,6% for TP and TN respectively (Vymazal 2002). The dominating vegetative uptake through primary production are short in macrophytes compared to the phytoplankton community were primary production are possible all through the year. Both processes have their uptake at the same optimal N/P ratio. In the WPM the BOD_5 reduction reaches 96%. But since the organic material entering the marsh is used up in the biological processes the organic material leaving is developed in the WPM this parameter from is of no interest.
Already a half century ago it was clear that sun light and photosynthesis in algae could reduce nutrient from sewage (Oswald and Gotaas 1957) in Hoffmann (1998). This must

have been before the sewage treatment plants separated N and P. This early ecological method is more developed in warmer areas than in temperate zones were the technicians have developed the sewage treatment plant. These original artificial ponds were designed for effective harvesting of the algal biomass in order to remove the nutrients. However, in recent years there has been an increased research emphasis on the use of no suspended algae, either as unialgal cultures immobilized in a polymeric matrix as attached algal communities (biofilm/periphyton) growing in shallow, artificial streams or on the surface of rotating biological contactors (RBC/bio discs). Another constraint is climate; these systems function best in warmer regions not subjected to freezing winters (Hoffmann, 1998). This is in contrary with the WPM where the produced biomass is transported into biological food chain involving also the top predators in the ecological food chain. The primary purpose with the WPM is to prevent that high rates of inorganic nutrients are transported quickly to lakes and seas. Instead they should be locally incorporated in new biomass and by consumers and breaking down organisms with minimal loss and remain in the biological food chain. Through the nutrients chains activity in the different ponds giving the opportunity for different ecosystems to develop and always space for new production. In temperate zones light is the limiting factor. The winter problem can be solved with putting light sources in the water (Bergum 2004) providing light for primary productivity. On the other hand algal-fish systems are not possible due to the risk of bottom freezing. Also fish do not transport away any nutrients to the surroundings. The diversity of fast growing both plankton and attached algae give the possibility of primary productivity all over the year due to light, temperature and grazers.

Other methods of sewage treatment

In Sweden the most common cleaning method for sewage water from household without connection to sewage treatment plants is different kinds of infiltration and filters. Another treatment in progress at least in Sweden is small sewage treatment plants. In comparison with other methods both in nutrient and bacteria reduction the WPM show good reduction results (Pettersson et al 2006). The efficiency of nutrient reduction; BOD_7 and bacteria are showed in table17.

Reduction method	Reduction %			
	Tot-P	Tot-N	BOD_7	Bacteria
Only three compartment tanks	5-10	10-15	10-20	25
Filterbed	10-40	25-50	90-99	95-99
Infiltration	25-80	20-40	90-95	99
Mini sewage treatment plant	70-90	20-50	80-95	60
Bergums WPM	91	90	96	84

Tabell 17.Effeincy of nutrient and bacteria reduction in different methods

In conclusion the four different cleaning methods are good in reducing BOD_7-reduction. Due to nutrients reduction the different filter methods have low efficiency both regarding N and P. In this case the mini sewage treatment plants are better. Regarding bacteria reduction both WPM and the mini sewage treatment plant are lower but in test the WPM managed bathing quality (Magnusson 2003).

Bacteria and infection

In open water systems there are always risks of transmission of infection, increasing with increasing amount of people connected to the WPM (Mårtensson et al 2006). In 2003, the WPM method was approved in relation infectiousness protection, as the bacterial reduction was judged to be acceptable to let out to a recipient, when compared with other water cleaning methods. In order to minimize risks of transmission the location must be taken into consideration (Schönning and Stenström 2003). Direct contact with the water should be avoided and signs with information about the potential risks having direct contact with the water are recommended.

Curtis et al 1999 concluded that damage of microorganisms (fecal coliforms) was highly sensitive to elevated pH values and dissolved oxygen. This emphasizes the importance of keeping a good light environment with autotrophies dominating the ponds and not allowing higher plant to shadow the ponds. An earlier study shows that placing a light –source in the water increase the opportunities keeping the photosynthetic process also during winter (Magnusson 2004).

Winter activity

The main activity in the garden are from April to October thus during wintertime the need for sewage treatment is limited. The water in the WPM will follow the temperature and can both be frozen and covered with snow. This is not a disadvantage to the function of the WPM, in spring when snow melts and the light increase the natural microorganism's activity start giving high nutrient reduction. Earlier studies show (Magnusson 2003) a very good reduction after a cold winter in the melted ice. The nutrients are stored in the ice and are used in the phytoplankton as soon as the right conditions appear. If the activity in the garden is growing with activity even in winter time the WPM also will function then. As the WPM is supplied with warm waste water ice is growing from beneath. An aerated space will occur between the water surface and the ice, enough for phytoplankton and bacteria to achieve oxygen for its activity and keep the reduction of nutrients and bacteria in an acceptable level.

Conclusionen

- The primary purpose with the water purification marshes (WPM) is to prevent that high rates of inorganic nutrients are quickly transported to lakes and seas. Instead they should be locally incorporated in new biomass and by consumers and breaking down organisms with minimal loss remain in the biological food chain.
- Through nutrient chains activity in the different levees (ponds) gives opportunity for different ecosystems and always space for new production.
- Since production is highest in early successions management efforts in a WPM should favor the maintenance of organisms in the early succession like bacteria, phyto- and zooplankton that appear during the first growing season, thereby preventing mature or climax stages (higher plants) to develop, which reduce light and heat in the shallow water.
- Necessary condition for high productivity is continuously access of nutrient rich water with nitrogen and phosphorous in right relation.
- The diversity of fast growing plankton and attached algae give the possibility of primary productivity all over the year due to light, temperature and grazers.

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