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INFLUENCE OF COAGULANTS USED FOR LAKE RESTORATION ON *DAPHNIA MAGNA* STRAUS (CRUSTACEA, CLADOCERA)

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Abstract

This study examined the influence of ferric and aluminium coagulants (PIX 113 and PAX 18) and ferrous sulphate, used for lake restoration, on growth and mortality of cladocerans *Daphnia magna* Straus. We observed that addition of these coagulants in concentrations comparable to those used in various restored lakes reduced significantly the increase of *Daphnia* biomass comparing to the results obtained in the samples without coagulants. This phenomenon was directly proportional to the coagulant concentration. Ferrous sulphate turns out to have been the most toxic compound, while PAX 18 was the less harmful. Ferric coagulants also caused crustacean mortality ranging from 4 to 36%.

Key words: *Daphnia magna*, lake restoration, iron coagulant, aluminium coagulant, toxicity

INTRODUCTION

Due to enhanced eutrophication of lakes, technical restoration is often the only way to improve lake condition. One of popular methods used in recent years is phosphorus removal from water by precipitation with iron or aluminium coagulants, widely used in wastewater treatment plants. In Poland, this method was used, among others, for restoration of lake Malta in Poznań with PIX 112 formulation (Kozak et al. 2007), or lake Długie in Olsztyn, lake Głęboczek in Tuchola and lake Wolsztyn with PAX 18 formulation (Gawrońska et al. 2004, Lossow et al. 2004, Gawrońska et al. 2007). Its effectiveness seems to have been confirmed by the results of those restoration activities. Authors of the above mentioned publications indicate a clear improvement in physicochemical parameters, such as decreased phosphate concentrations, increased hypolimnetic oxygen content in summer, or increased Secchi depth. The method is presented as effective and safe for organisms. In fact, however, few studies have been undertaken on the influence of coagulants on aquatic biota. Planktonic cladocerans, being the most effective filtrators, are exposed to direct contact with coagulants introduced to the lake water. Therefore we decided to examine in a micro scale the reaction of invertebrates on the presence of the chemicals, using a test with *Daphnia magna* Straus. The test has proved repeatedly to be useful for examination of surface water (Szlauer et al. 1994, Szlauer 1999). *Daphnia* is known to be sensitive to various chemicals present in water even in very low concentrations, which manifests in symptoms such as growth inhibition and mortality (Szlauer et al. 1994, Piasecki et al. 2004). Therefore *D. magna* can be a sensitive bioindicator of advantageous or disadvantageous influence of the above mentioned coagulants. The study aimed to examine the reaction of *Daphnia magna* to coagulant concentrations comparable to those used for lake restoration.

MATERIALS AND METHODS

This study comprised tree coagulants the most often applied for restoration of open waters; two liquid formulations – PIX 113, that is iron(III) sulphate(VI) (chemical formula: $Fe_2(SO_4)_3 + H_2O$ + modifier + H_2SO_4) and PAX 18, that is polyaluminium chloride (chemical formula: $Al_{1,2}O_{1,2}{\cdot}yCl_{1,8} + H_2O$), and one solid substance used in wastewater treatment plants – ferrous sulphate (iron(II) sulphate(VI); $FeSO_4{\cdot}7H_2O$).

The experiment was based on the "Daphnia" test for water fertility developed by Szlauer (Szlauer et al. 1994). The test organism was water flea, *Daphnia magna* Straus, from a stable culture conducted by the Department of Hydrobiology at the West Pomeranian University of Technology in Szczecin, Poland. Water used in the experiment derived from a small, highly eutrophic downtown pond.

The water was collected from the pond prior each series of the experiment. After delivery to the laboratory, the water was passed through a 50-µm sieve to rid it of undesirable animals, and next 200-ml portions of the sieved water were poured into bakers. The bakers with water had been left under lighting for 7 days to enable incubation of planktonic algae. After 7 days, 5 newly hatched females of *Daphnia magna*, not older than 24 hours, were introduced to each baker. Prior to the introduction, 10 individuals of the initial herd were measured to determine the average initial biomass. After 24 hours, the number of individuals was checked and next the coagulants were added in appropriate concentrations. After 5 days from females introduction, all individuals were caught and measured, and the laid eggs were counted. The body mass of *D. magna* was read from the tables of Starmach (1955). Next, the production of the *Daphnia* herd was determined and converted into $mg_{ww}{\cdot}dm^{-3}$. The increase was calculated by subtracting the biomass of initially introduced individuals, which equalled 1 $mg_{ww}{\cdot}dm^{-3}$ in all cases. Water temperature was stable at 24°C. Water pH was measured 4 times during the experiment: prior the coagulant addition, immediately after the addition, after 24 hours and after further 4 days, that is just before the culture termination. In this experiment, three versions of coagulant concentrations were used: 0.03, 0.05 and 0.10 $g{\cdot}dm^3$. The concentrations were chosen on the basis of descriptions of restoration works in lake Głęboczek in Tuchola, where a single dose of 0.03 $g{\cdot}dm^3$ was applied (Lossow et al. 2004) and in lake Wolsztyńskie where the single dose applied amounted to about 0.05 $g{\cdot}dm^3$ (Gawrońska et al. 2007). Each series of experiment was run in 5 replicates.

RESULTS

The course of pH changes during the experiments with various concentrations of coagulants are presented by charts (Fig. 1). In all cases, pH decreased just after the

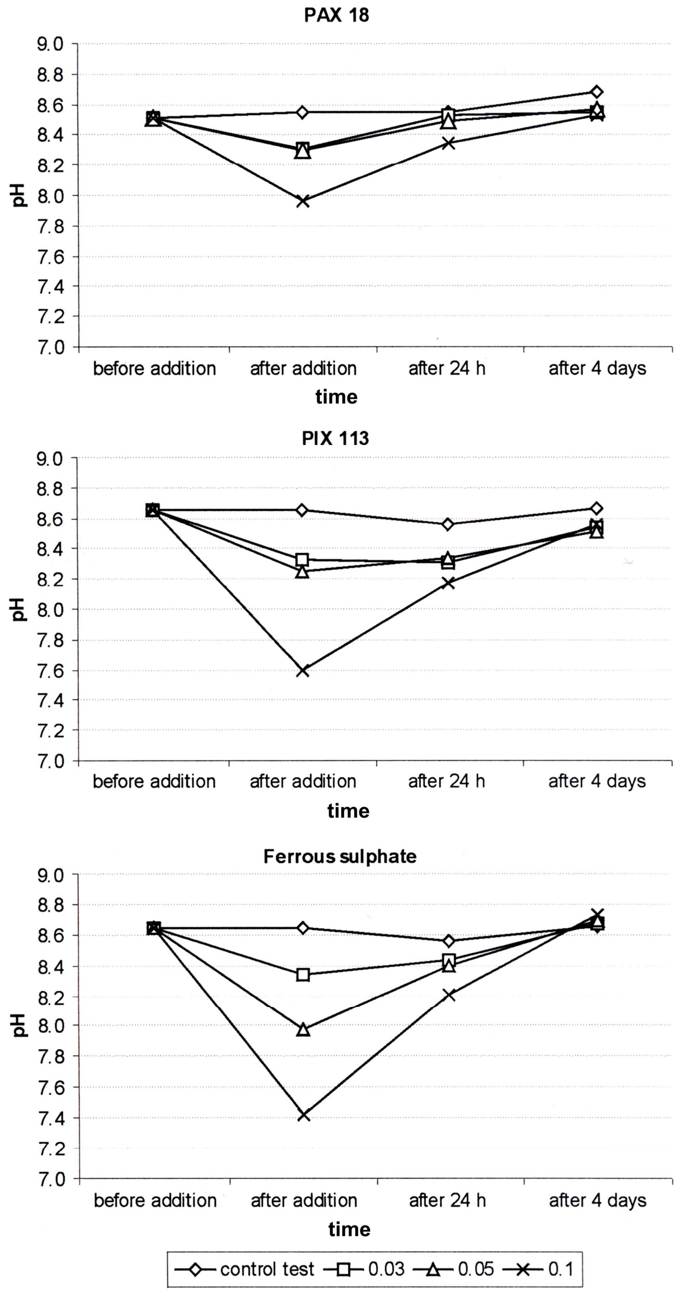

Fig. 1. Changes in water pH at various coagulant concentrations [$g \cdot dm^{-3}$]

coagulants addition by 0.2 to 1.3 of pH unit, and next gradually returned to the initial level. For higher coagulant concentrations stronger pH fluctuations were observed. Worth noticing is that the greatest pH decreases occurred for iron(II) sulphate, and the smallest for PAX 18 formulation.

Absolute values of *Daphnia magna* mass increments [g·dm^3] obtained during the experiment do not reveal the actual influence of coagulants on crustaceans, because in each series different results in the control groups were obtained. However, the results of different series may be compared as relative values, assuming that the mass increment in the control group amounted to 100%, and particular increments at various coagulant concentrations were adequate percentages of the control.

In each series, the greatest mass increments were obtained in the control group. In the samples exposed to coagulants, the final mass of individuals was inversely proportional to the coagulant concentration (Fig. 2). Ferrous sulphate was the substance that restricted *Daphnia* growth most significantly. Even the lowest concentration (0.03 g·dm^3) limited the growth to 36.1% of the control result. Mass increments obtained in subsequent PAX 18 concentrations (0.03, 0.05 and 0.10 g·dm^3) amounted to 53.4, 43.4 and 33.5% of the control increment result, respectively. In case of PAX 113, at two lower concentrations the results were similar – 51.4 and 51.2% of the control increment value, while the highest coagulant concentration (0.10 g·dm^3) reduced growth to 21.8%. The statistical treatment (*t* test; Microsoft Excel) showed the differences of Daphnia increments between the control and series with coagulants was significant ($p<0.01$) in all cases.

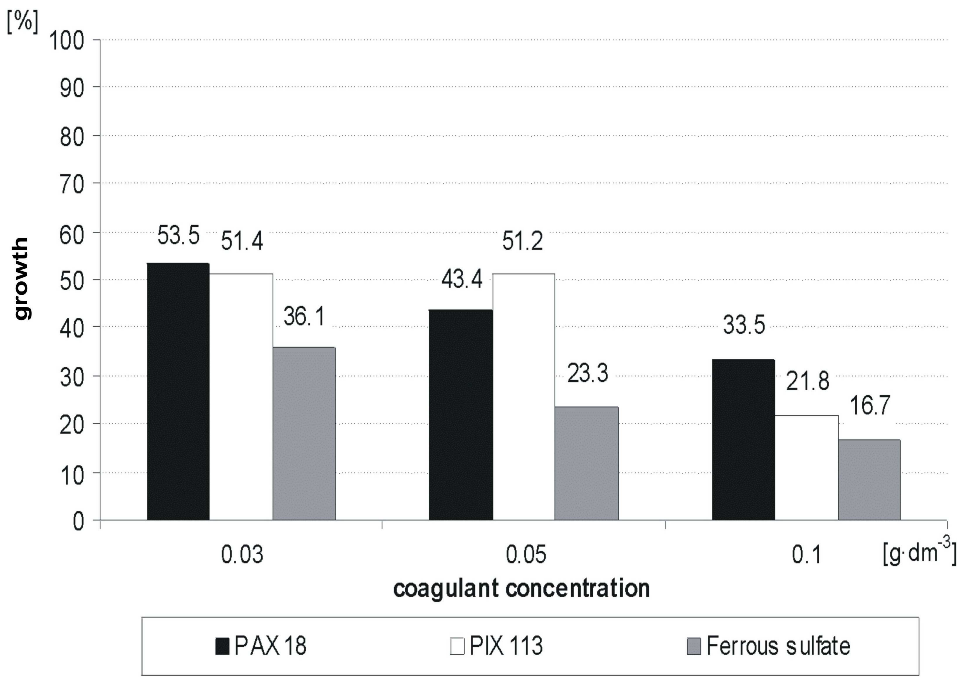

Fig. 2. *Daphnia magna* mass increments [%] after 5 days of incubation at various coagulant concentrations [g·dm^{-3}] as a percentage of the control increments

Table 1
Daphnia magna mortality [%] at various coagulant concentrations [g·dm^{-3}]

Coagulant concentration	0	0.03	0.05	0.1
Control test	0	-	-	-
PAX 18	-	0	0	0
PIX 113	-	4	4	24
Ferrous sulphate (II)	-	8	36	28

During this study, all *D. magna* individuals survived in the control groups. Deaths were observed in the presence of coagulants only. PAX 18 turns out to have been the less toxic, causing no cases of death. Mortality from PIX 113 at concentrations of 0.03 and 0.05 g·dm^3 averaged 4%, while at 0.10 g·dm^3 mortality increased to 24%. The highest numbers of dead individuals were observed in the samples with ferrous sulphate (Table 1).

DISCUSSION

Lake restoration by inactivation of orthophosphates with iron and aluminium coagulants counts among the most efficient methods improving physicochemical conditions of degraded waters, as indicated by the results of the above cited papers (Gawrońska et al. 2004; Lossow et al. 2004; Gawrońska et al. 2007; Jankowski 2007). However, their authors omitted the biological constituents of lakes and reservoirs, not indifferent to the chemicals introduced to water, as shown by this experiment. The main method for introducing coagulants into water is to distribute them evenly on the lake surface with a system of pipes dragged behind a boat. The phosphorus binding substance is placed just below the water surface, so high concentrations of the chemical occurred temporally in the subsurface layer. That is why a planktonic species *Daphnia magna* was chosen as an experimental object. What is more, the method required the youngest and the tiniest form of the species, which usually stays in the subsurface layer during the day (Mikulski 1982), and therefore is exposed to adverse effects of coagulants. Our study revealed that even the lowest concentrations of coagulants applied influenced *Daphnia* development. In all the samples with coagulants added, the crustaceans biomass increments were significantly lower comparing to the controls (Fig. 2). Even at the lowest concentrations of PAX 18 and PIX 113, biomass increments oscillated just slightly above 50% of the control result. For ferrous sulphate the increments were even lower. As presented in Table 1, the low concentrations of each coagulant applied were enough to cause deaths in the samples examined, and usually the mortality increased along with concentration. The only exception was the series with ferrous sulphate, were the highest mortality was observed at concentration 0.05 g·dm^3. However, it might have resulted from an unknown accidental factor, difficult to identification now. Coagulants may also influence planktonic organisms in a physical way. In this study physical influence was observed especially at concentrations of 0.10 g·dm^3, when sticky fluffs formed in water and covered *Daphnia*, thus impairing their moving potential and often cutting them off from algae gathered at the bottom of the baker. The fluffs lay on the baker bottom till the very end of the experiment.

A possible significant factor for coagulants introduction into water is water pH value, and more specifically its fluctuations. Worth noticing is that pH of PIX 113 and PAX 18 formulations is near 1. Some researchers reported pH jumps at concentrations of coagulants even lower than applied in this study (Wang et al. 2005). Observations made during this study did not confirm fears for sudden and substantial pH fluctuations. At the concentrations applied, pH changes were small and similar to daily fluctuations observed in natural waters. However the "initial" pH after 7 days of algae incubation was relatively high, what must have resulted from intensive primary production (bakers were illuminated for 24 h a day). Similar conditions occur during the day in summertime in eutrophic lakes, especially during algal blooms. But restoration works are conducted in spring and autumn periods, when pH oscillates slightly around 7.0. In such conditions, introduction of a coagulant may reduce water pH to value below 6 and influence aquatic biota in water column. Excessive doses of coagulants may contribute to density reduction and elimination of some plankters, which might lead to further disturbance in the already upset ecological balance of the revitalised aquatic system. Worth remembering is that zooplankton is the group which exerts pressure on phytoplankton developing in spring (Kajak 2001). We must stress, however, that elimination of some organisms from various groups needs not to be an unequivocally negative phenomenon. On one hand it would spell, e.g., weaker pressure on phytoplankton and poorer food source for fish, but on the other hand it could create favourable conditions for settlement or return of species that disappeared due to eutrophication and deterioration in habitat conditions. Such a situation was reported by Pietrzak and Czachorowski (2004) for lake Długie, where restoration was followed by an increase in *Trichoptera* biodiversity, including also species typical for running waters. Possibly, similar phenomenon might also occur in other groups of organisms, e.g., in plankton, and such a situation would be advantageous for the revitalised lake.

Phosphorus inactivation with ready-made iron and aluminium coagulant preparations is a relatively new method and there is scarce information on its long term effect on aquatic biota. This information is especially scarce for the aluminium coagulant, which was the less harmful for *Daphnia* in this study. Aluminium is known to exert toxic effects on aquatic biota, its toxicity increasing along with pH decrease (Gostomski 1990, Poléo et al. 1997, Wauer et al. 2004). At higher pH this metal may cause chronic toxicity to aquatic biota (including *Daphnia magna*) with effects noticeable much later (Exley 1996). We cannot exclude such a situation in our study. Methodology used in this experiment does not provide information on long term effect of coagulants on aquatic biota, but the results of our study indicate necessity for further investigation, including both laboratory and field research. Further investigation is necessary if we want to get reliable information concerning lakes, because *Daphnia magna*, although an excellent test organism, is not representative for typical limnoplankton (Koivisto 1995). Therefore the result of this study is just a signal of relationship existing between lake restoration activities and aquatic biota. We believe that the relationship should be thoroughly examined to increase the effectiveness of restoration works.

CONCLUSIONS

This experiment revealed that coagulants PAX 18, PIX 113 and ferrous sulphate exerted adverse effect on *Daphnia magna* Straus juveniles, increasing along with coagulant concentration. The influence was manifested by reduction in body mass increments comparing to the control group and by increased mortality. Ferrous sulphate appears to have been the most toxic compound, while aluminium formulation – PAX 18 – was the less harmful. To reduce adverse effects of coagulants, their single doses used for lake restoration are recommended not to exceed the lowest level from this experiment, i.e., 0.03 $g \cdot dm^{-3}$.

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WPŁYW KOAGULANTÓW UŻYWANYCH DO REKULTYWACJI JEZIOR NA *DAPHNIA MAGNA* STRAUS

Streszczenie

Badano wpływ koagulantów żelazowych i glinowych (PIX 113 i PAX 18) oraz siarczanu żelaza II, używanych do rekultywacji jezior, na wzrost i śmiertelność wioślarki *Daphnia magna* Straus. Stwierdzono, że dodanie do wody koagulantów w stężeniach porównywalnych ze stosowanymi na jeziorach rekultywowanych powoduje istotny spadek przyrostu biomasy *Daphnia* w stosunku do wyników otrzymywanych w próbach bez koagulantów. Zjawisko to jest wprost proporcjonalne do stężenia koagulantu. Najbardziej toksyczny okazał się siarczan żelaza II, najmniej – PAX 18. Obecność koagulantów żelazowych powoduje również śmiertelność skorupiaków na poziomie od 4% do 36%.