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Biogeosciences Discussions

Interactive comment on "Effects of long-term flooding on biogeochemistry and vegetation development in floodplains – a mesocosm experiment to study interacting effects of land use and water quality" *by* A. M. Banach et al.

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Responses to the specific comments of the Referee #3 There are three major aspects that the authors should pay attention to or comment on: (i) It is not clear in the manuscript why such a long period of inundation was chosen, and to what extent this is representative of or related to the expected naturally occurring summer flood scenarios. More background information of this experimental approach would also help to evaluate the suitability of the mesocosm design for the goals of this study.

We have removed the lines about summer flooding, including the first part of the abstract, and now stress the fact that we studied the effects of permanent shallow flooding (marshland creation) as a possible measure to reduce flooding risks, including the changes in the last paragraph of the introduction in which we explained the rationale of choosing this period of time by changing the last paragraph of the introduction:

'The aim of this study was to investigate the possibility for the creation of permanently flooded wetlands (marshes) along rivers, in relation to flood water quality (NO3-, SO42-) and soil use (level of fertilization in the past). This measure is one of proposed strategies to counteract flooding risks; next to the creation of temporarily flooded areas for water storage during flood peaks which was investigated in our previous work (Banach et al., 2009b) and that of others (Antheunisse & Verhoeven, 2008). In order to study the effects of long-term flooding under controlled conditions, for which much less information is available in literature, a mesocosm design using intact sods was used. A period of 9 months was chosen as a minimum period necessary in order to cover both winter, spring, summer and autumn. The results with respect to biogeochemistry (especially C, Fe, P, N and S cycling) and vegetation development will be discussed in relation to water management and nature management. In addition, we will compare both management strategies.'

(ii) Display and description of the results of the statistical analysis: In their study, the authors created a comprehensive set of chemical data and did a thorough statistical analysis of the potential correlation and interaction between different parameters. However, due to the high number of parameters and treatments involved, it is sometimes rather difficult for the reader to follow the main results of the statistical analysis. This could be improved by a graphical display of the most important correlations and relationships or by summarizing results in a flow scheme or model of the observed dynamics. The tables containing the results of statistical analysis could be provided as supporting material.

We chose to provide the statistical tables that show interactions between inundation, land use, and water quality. After making a conceptual scheme, we realized that the most important findings were in the text and this scheme about these multiple interactions did not provide additional information or clarification. Therefore, instead, we strongly extended our Conclusions part, to clarify the most important findings:

'Our study showed that the effects of long-term inundation of meadows, as in projects aiming at the restoration of marshes along rivers to increase water storage capacity, are strongly determined by the interactions between land use (level of fertilization) and water quality. The actual effects on biogeochemistry and vegetation will, in addition, strongly depend on the actual flooding duration and frequency, the flooding season and the water level. We tested the creation of a permanently, shallowly flooded situation throughout the year, as this is one of the possible measures to combine the reduction of flooding risks for the population and the restoration of marshes along rivers. These results differ from those of short-term summer flooding (Banach et al., 2009b) where flooding itself had the most striking effects on plant ecophysiology and soil biogeochemistry, regardless water quality. As the rate of the different biogeochemical processes and the growth of plants are both significantly influenced by temperature, winter flooding will have much less effects (e.g. Beumer et al., 2008; Loeb et al. 2008b).

Our work emphasizes the important role of land use (level of fertilization). For heavily fertilized soils, desired vegetation development only seems possible if sulphate and nitrate levels in the surface water are low as in less polluted rivers (Lamers et al., 2006). This means that for intensively used agricultural areas, water quality seems to be even more important than for other areas, which is rather unexpected. Strikingly, development of sedge fens was possible for less fertilized soils even at higher sulphate and nitrate levels, although plant biodiversity was still relatively low (partly due the absence of plant dispersal in our experiment) and peat formation is less probable due to still high levels of nutrients, presumably leading to high decomposition rates. Especially if water quality of rivers is still unfavourable with respect to sulphate and nitrate, restoration measures should concentrate on those areas that do not show a history of heavy

fertilization.

(iii) Discussion of the effects of flooding, land-use history and water quality on the species composition of the vegetation: The authors emphasize the role of plant species composition for both soil chemistry (oxidized rhizosphere) and soil structure (subsidence versus land accretion through peat formation). Here, the authors should explain in more detail the key features of the plant functional groups (herbs, grasses, Carex) with regard to the expected response to flooding, and if the results obtained in this study agree with their expectations. The discussion of changes in plant species composition is mostly restricted to functional groups, although the raw data for a more profound analysis are available (table 2). The information about how individual species were affected could be used in a statistical analysis employing methods such as Canonical Correspondence Analysis to point out more precisely which parameters might be responsible for changes in a particular group or species. Finally, they should comment on to what extent vegetation development may have been influenced by the rather small size of the mesocosms (limitation to root development and coexistence of species) and by the isolation of the mesocosms from their natural situation. Nine months of flooding is a long period, and not all of the original species can be expected to adapt to these conditions by natural plasticity. Under natural conditions, regeneration from the seed bank or input of plant fragments or diaspores supplied by the river water would also contribute to changes in species composition, where especially the second factor is excluded in the mesocosm experiment. For several species, regeneration via these mechanisms would also take more time than one season. This should be commented on.

We agree with the referee and changed the text in the Discussion (section 4.3) to:

'Herbs, the most abundant plant group on the studied meadows were most sensitive to flooding as could be expected for this terrestrial species group lacking specific adaptations to flooding (Van Eck et al., 2004; Banach et al., 2009a); 8 out of 26 species disappeared. Carex species and some of the grass species in the control flooding treatment were tolerant to flooding, as could be expected from their specific traits including the ability to oxidize their rhizosphere.

The vegetation response to permanent flooding, however, appeared to be strongly influenced by the interactions between soil use and water quality. The long term vegetation development after years of hydrological changes may, however, diverge because of succession related to long-term competition between plants, dispersal of diaspores and herbivory, processes that could not be included in the present experiment.'

We agree that a more profound analysis of the responses of the individual species would provide very valuable information, but the presence or absence of species and the highly variable number of individuals within groups made it very difficult to use a Canonical Correspondence Analysis. We kindly refer to Banach et al. 2009a, showing the flooding response of the individual species present in this area. Our experiment, however, showed that land use and water quality were very important in determining the species composition in addition to the actual species traits.

p. 3268, l. 10-11: As mentioned above, it should be explained in more detail why the creation of permanently flooded wetlands along rivers was studied instead of choosing a design more similar to natural conditions of flood regime with episodic inundation.

We explained this by adapting the last paragraph of the introduction: 'The aim of this study was to investigate the possibility for the creation of permanently flooded wetlands (marshes) along rivers, in relation to flood water quality (NO3-, SO42-) and soil use (level of fertilization in the past). This measure is one of proposed strategies to counteract flooding risks; next to the creation of temporarily flooded areas for water storage during flood peaks which was investigated in our previous work (Banach et al., 2009b) and that of others (Antheunisse & Verhoeven, 2008). In order to study the effects of long-term flooding under controlled conditions, for which much less information is available in literature, a mesocosm design using intact sods was used. A period of 9 months was chosen as a minimum period necessary in order to cover both winter,

spring, summer and autumn. The results with respect to biogeochemistry (especially C, Fe, P, N and S cycling) and vegetation development will be discussed in relation to water management and nature management. In addition, we will compare both management strategies.'

p. 3269, l. 17-18: Does "natural light and temperature conditions" mean that diurnal and seasonal changes of light and temperature were adjusted to in-situ conditions? This should be explained in more detail.

We added: ' . . ., under natural light and temperature (ranging between 5-41°C during the experiment) conditions following the outside diurnal and seasonal changes of light and temperature.'

p. 3269, l. 24-25: Was the water exchanged once in a while? What was the total amount of N and P added to the sods via inundation with artificial river water?

We adapted the sentence: 'The sods were kept inundated at 20 cm above soil level for 9 months (January till November) and if necessary adequate volumes of floodwater were added to maintain the desired water column.'

Phosphate was not added to the sods, and nitrate was added with the surface water at the concentration indicated in the Material and Methods.

We added: 'The control (Cfl) had pristine river water quality characterized by low levels of nutrients (Tab. 3), without the addition of phosphate.'

p. 3271, l. 25-26: Why was vegetation harvested twice during the experiment? Please explain.

We answered this question by adding: 'Vegetation and algae were harvested 6 months after the onset of submergence and at the end of the study to be able to quantify biomass production rather than standing stock' in Vegetation description part.

P. 3276, l. 18-20: It seems strange that biomass of flooded plants from the pasture was comparable to Cm, while the pasture plots were only covered by 39% compared to 93% in the corresponding control Cm. This should be explained.

The vegetation on the pasture was dominated by tall Carex plants which did not cover the total surface of the aquaria whilst Cm controls were dominated by a dense herb-dominated vegetation. These differences are shown in figure 6.

We changed L4 on P3276 to: 'Cm sods had a high number of individual small plants for herbs, grasses (GxI) and Carex species, with a relatively low biomass.'

p. 3279, l. 27: "Unexpectedly, the presence of high concentrations of nitrate in the surface water did not prevent P mobilization, as is known to occur in fens related to blocking of Fe reduction by the presence of this more favourable electron acceptor." What could be the explanation for the observed discrepancy?

We added to the end of this paragraph: 'This can probably be explained by the fast depletion of nitrate due to the stagnant situation, even though nitrate was supplied to keep the water levels constant.'

p. 3280, l. 5-10: The authors should discuss in more detail by which mechanisms they expected vegetation to adapt to long-term flooding, and why herbs were the most sensitive to flooding.

We added: 'Herbs, the most abundant plant group on the studied meadows were most sensitive to flooding as could be expected for this terrestrial species group lacking specific adaptations to flooding (Van Eck et al., 2004; Banach et al., 2009a); 8 out of 26 species disappeared. Carex species and some of the grass species in the control flooding treatment were tolerant to flooding, as could be expected from their specific traits including the ability to oxidize their rhizosphere.'

p. 3280, l. 23: "It was, however, clear that land use was the main determinant for the development of target (Carex) vegetation: : :" What could be the mechanisms underlying this relationship?

We agree that this is unclear and changed the sentence to: It was, however clear that land use, leading to the above-mentioned effects, . . .' . This refers to increased algal development and accumulation of phytotoxic compounds, as explained in the text above.

Table 2: Is "average abundance" given in number of individuals or in percent cover?

Abundance is expressed in % - we added the units to the caption of the Table 2.

Technical comments: Check references in the text for tables 4b, 5a, 5b, 6a, 6b. Such table numbers cannot be found among the tables in the manuscript.

We carefully checked all references to all tables and changed them accordingly.

Interactive comment on Biogeosciences Discuss., 6, 3263, 2009.