Ecological characteristics of small farm land ponds: associations with land-use practices at multiple spatial scales.

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Ecological characteristics of small farm land ponds: associations with land-use practices at different spatial scales.

ABSTRACT

Despite their restricted surface area, small farm land ponds often have a high conservation value because they contribute significantly to regional biodiversity and contain rare or unique species. For this reason, the creation of new ponds has become a widely applied practice in many countries. Information on the effects of land use on farm land ponds is very scarce. Farm land ponds differ from larger ponds, lakes and rivers in many aspects and can therefore be expected to be affected by land use via other mechanisms operating at different spatial scales. We here present a study on 126 ponds distributed over the entire territory of Belgium (surface area: 30.500 km^2). We assessed variables related to turbidity state and vegetation complexity and related them to land use variables assessed at several spatial scales ranging from the pond edge up to 32 km^2 circular areas. According to redundancy analysis, trampling by cattle and percentage cover of nearby crop land were positively associated with turbid state related variables. Conversely, ponds with high coverage by forest in the immediate neighborhood tended to be associated with the clear water state. Multiple regression analysis demonstrated a negative effect of trampling and coverage by crop land on vegetation complexity. Effects of crop lands and forest were strongest at the local scale (< 200 m radius) which indicates that adverse external influences can most efficiently be mitigated at a small scale. Based on these results we suggest several recommendations for pond construction and conservation.

Key Words: vegetation complexity; turbidity; crops; trampling; cattle; water plant

1. Introduction

Small farm land ponds are often very numerous in agricultural areas. Although created to serve agricultural purposes (e.g., providing drinking water to cattle; irrigation) they are generally considered to be of high conservation value. Despite their small surface area, farm land ponds may contribute significantly to regional biodiversity because they support heterogeneous communities of aquatic organisms and often contain rare or unique species (Oertli et al., 2002; Williams et al., 2004; Nicolet et al., 2004). In many regions, however, this type of ponds is highly threatened due to eutrophication, chemical pollution or physical destruction (Heath and Whitehead, 1992; Boothby, 2003). Despite their abundance, biological importance, and threatened status, there is a general lack of knowledge on the structure, diversity and functioning of these systems, and how they are affected by anthropogenic influences (Wood et al., 2003; Williams et al., 2004).

Small farm land ponds are expected to be different from larger ponds and lakes in several aspects (see also Søndergaard et al., 2005; Scheffer et al., in press). They have a smaller volume to edge ratio, which on the whole leads to a higher proportion of littoral zone, a higher impact of shading effects from surrounding trees and a more direct exchange of matter and organisms with the locally surrounding terrestrial matrix. Furthermore, the mechanisms that create resuspension of sediments (and associated nutrient recycling) in ponds differ from those in lakes. Small ponds have lower wind fetch and most often lack large sediment resuspending benthic fish (Scheffer et al., 2003) while in many regions they may be more affected by the wading of cattle. Small size is also correlated with shallow depth, which may tend to allow better light conditions for vegetation, a more intensive benthic-pelagic coupling (Tessier and Woodruff, 2002), and a higher probability to dry out during summer.

Land use can affect aquatic ecosystems via multiple processes that act at different spatial scales, ranging from the short-distance local scale to that of entire valleys (Allan et al., 1997; Johnson et al., 1997; Buck et al., 2004). Consequently, a good knowledge of the spatial scales at which different processes operate is essential to better understand the impact of land use practices on the functioning and ecological characteristics of water bodies, and forms the basis for an efficient integrated catchment management. The creation of new ponds has become a common practice in many countries (Davies et al., 2004; Louette and De Meester, 2005; Søndergaard et al., 2005). A good understanding of the spatial scales at which land use affects ponds is essential for the mitigation of land use effects on existing ponds and the development of efficient location selection strategies for the creation of new ponds (Davies et al., 2004).

This study presents the results of a large scale survey on the ecological characteristics of 126 small farm land ponds that were selected according to a gradient of surrounding land use intensity within the context of agricultural landscapes. The aims of the study were to (1) assess some key biotope characteristics of the ponds that quantify turbidity status (Scheffer, 1998) and structural complexity of the aquatic vegetation; (2) to reveal the associations between these pond characteristics and different types of land uses, (3) to identify the scale at which land use influences operate, and (4) to derive recommendations for management and conservation purposes.

2. Methods

2.1. Study area

Agricultural practices are diverse in Belgium. The northern and central parts of the country (Flanders) are dominated by agricultural landscapes. Forest patches are scarce, fragmented and small, and the land use is generally intensive (predominantly pastures and crop lands with tillage, often combined with intensive cattle raising). In contrast, land use in the southern part of the country (Wallonia) is more extensive and is predominantly characterized by forests and pastures, in addition to crop cultures.

2.2. Study site selection

We surveyed a total of 126 farm land ponds. Because we aimed at studying the association between pond characteristics and land-use practices on a relevant spatial scale, we selected ponds distributed over almost the entire Belgian territory (approx. 30,000 km^2; Fig. 1). We mainly focused on small ponds that provide drinking water for cattle. Land use data are typically geographically structured and show a high degree of spatial autocorrelation (Johnson and Gage, 1997). Such spatial structure may seriously impede the study of associations between land-use and ecological features of water bodies. We therefore tried to uncouple land use and geographical position by selecting the study ponds according to an a priori defined spatial design: (1) first, we selected 42 clusters of ponds distributed over the Belgian territory; clusters were chosen such that each cluster contained several ponds that were located within a circular area of approximately 20 km^2 and covered a broad gradient in land-use; (2) second, to maximally avoid collinearity between the land-use data and geographical position, we selected three ponds within each cluster along a maximal gradient of surrounding agricultural land use intensity, ranging from intensive use (crop lands), over intermediate (extensive) use to pristine (mostly situated in protected nature areas). Special care was taken that only land use was applied as selection criterion, and not the aspects of the ponds themselves (e.g. macrophyte cover, water transparency).

2.3. Sample collection

The ponds were sampled twice: once during the summer of 2003 (during the second half of July, August or the first half of September) and once during the spring of 2004 (during May or June). On each sampling occasion, we measured pH and conductivity with standard electrodes. Water transparency was not determined with a Secchi disk but with a Snell tube because pond depths were shallow. Depth-integrating water samples were collected in an open water zone of the pond using a tube sampler (length 1.5 m; diameter 75 mm) and kept in the cold (4°C) and dark until further analysis. Contact with vegetation or the bottom substrate was carefully avoided during sampling. We also estimated the percentage cover of seven different combinations of vegetation types, defined as: (1) submerged, (2) floating, (3) emergent, (4) submerged + floating, (5) submerged + emergent, (6) floating + emergent and (7) submerged + floating + emergent. Water depth was measured with a graduated stick along two perpendicular transects at distance intervals of 1 m. The thickness of the silt layer was measured from the profile of sediment cores (2 replicates) taken in the central part of the ponds.

2.4. Sample analysis

The water samples served for the assessment of the concentration of chlorophyll a, nutrients (total phosphorus and nitrates), alkalinity and some major ions (calcium, chloride and sulphate ions, water hardness). Sulphates, chlorides, calcium, alkalinity and hardness were measured following standard methods according to the Hach Water Analysis Handbook (HACH, 1992). Nitrate concentration in GF/F filtered water samples was determined with a Technicon autoanalyser III. Total phosphate concentration was measured with the ascorbic acid method after perchlorate digestion (Murphy and Riley, 1962). Chlorophyll *a* concentrations were spectrophotometrically determined.

2.5. Vegetation complexity

Because of the physical structure it provides, aquatic vegetation can be considered as a key determinant of biotope complexity within lentic water bodies. Vegetation has repeatedly been shown to mediate trophic interactions between different organism groups (Jeppesen et al. 1997) and is potentially important as a determinant of aquatic biodiversity (Scheffer 1998; Declerck et al. 2005). The dominance of aquatic plants over phytoplankton is strongly dependent on the light regime in the water column and sediment characteristics. Intensive land use practices are a potential source of nutrients, sediments and herbicides, and may thereby have adverse affects on the abundance, complexity and richness of pond vegetations. We therefore quantified vegetation complexity within each pond using three characteristics of the aquatic vegetation: (1) the richness of observed plant taxa (taxonomic resolution: genus level; NOT); (2) the number of different growth forms present (e.g., submerged, floating, emergent vegetation; NGF), and (3) the Shannon-Wiener diversity calculated from the cover fractions of eight different biotope types, i.e. the seven combinations of vegetation types (see Sampling, above) and the open water zone (SWBT).

2.6. Land use data

Land use cover variables were assessed at seven different spatial scales. The percentage cover of land use types was estimated for circular areas with center at the location of the ponds and a radius ranging from 50 m over 100, 200, 400, 800, and 1600 m to a maximum of 3200 m (corresponding to total surface areas of 0.008, 0.03, 0.125, 0.5, 2, 8, and 32 km^2, respectively). The land use types discerned were (1) crop land, (2) meadows and pastures, (3) forest and (4) urban areas. Coverage data were obtained through the application of the GIS software package ArcView GIS 3.2a (ESRI, Inc.). For the Flemish territory, we used topographical raster maps of the National Geographic Institute (1978-1993; scale: 1/10,000) and the land use coverage database of Flanders (2001; resolution: 15 m). For the Walloon region, topographical and land use data were derived from the PICC (Projet Informatique de Cartographie Continue; 1995-2000; scale: 1/1000) and from the soil occupation database of the Walloon region (Direction de l’Observatoire de l’Biotope et de la Géomatique du Ministère de la Région Walonne;1988-1989; 1/50.000), respectively.

In addition, we made a visual assessment of nearby crop land presence independently from the GIS-dataset. This was done in the field at the time of sampling by reporting the presence or absence of crop land within concentric circles of 10, 20 and 100 m around the pond. Trampling by cattle was assessed using a simple score system (none, low, intermediate, high or very high degree of trampling of the pond edges; TRAMPLING).

2.7. Data analysis

The summer of 2003 was exceptionally dry; 27 of the 126 ponds dried out during August and September. Data analysis was therefore confined to the remaining 99 permanent ponds that kept water during both sampling periods (i.e., summer 2003 and spring 2004). Preliminary analyses indicated a high degree of correlation between spring and summer values for the majority of the variables. All further analyses were therefore done on the averaged values of the spring and summer data.

Our data analysis attempted to evaluate the effect of different land use types on pond characteristics and to assess at which spatial scales such effects are most prominent. For these analyses, we focused on two types of pond variables: (1) variables that are related to the clear water/turbid state (“CT-variables”) (Scheffer, 1998), and (2) variables related to the vegetation complexity. Standardized PCA-analysis on the entire set of measured pond variables indicated a high degree of collinearity among CT-variables: water transparency, concentration of phytoplankton chlorophyll a, total phosphorus, thickness of the silt layer on the pond sediments, and the percentage of pond surface covered by aquatic vegetation. Due to this high collinearity (Appendix 1) and to avoid problems related to multiple testing, we choose to analyze this entire CT gradient in function of land use rather than performing an analysis for each variable separately. In contrast, variables related to vegetation complexity were analyzed separately.

The association between land use variables and the CT-variables was investigated in four steps. We first explored for spatial patterns in the CT-dataset. Two-dimensional geographical co-ordinates were used to generate the terms of a cubic trend surface regression (Borcard et al., 1992). Using the manual forward selection procedure of CANOCO v4.5 (Lepš and Šmilauer, 2003), we constructed a most parsimonious spatial redundancy analysis model (RDA) for the CT-dataset (Borcard et al., 1992).

Secondly, we identified the spatial scales at which different land use variables show the strongest association with the CT-variables. For each of the seven spatial scales, we assessed the contribution of the percentage cover of each land use type to the variation in the CT-dataset with separate RDA-analyses. We also evaluated the contribution of crop presence in the immediate vicinity of ponds as determined from visual observations. TRAMPLING and the variables of the spatial model were specified as co-variables in all these analyses to partial out their effects.

Third, we aimed at estimating the independent contribution of each variable category to the variation in CT-variables. This was done for the spatial scale at which the strongest effects of land use variables were found in the previous analyses (i.e. the spatial scale corresponding with a 100 m-radius circular area). An RDA-model was constructed of the variables TRAMPLING, the spatial variable Y^3 and the four land use cover variables. The contribution of each variable category to the variation in the CT-dataset was assessed with variation partitioning (Borcard et al., 1992).

Finally, we tried to identify the subset of explanatory variables best explaining the CT-dataset. For this a forward selection procedure was performed on the entire set of explanatory variables corresponding with all spatial scales (10 to 3200 m radii). For each of the variables retained, we estimated both the marginal and conditional effects on the CT-variables.

The three vegetation complexity variables were analyzed with multiple regression analysis. In analogy to the RDA-models, a most parsimonious spatial model was first constructed for the vegetation complexity variables using forward variable selection. The significance of the association between vegetation complexity and individual land use types was then evaluated upon inclusion of these spatial variables in the multiple regression models.

The CT-variables were logarithmically transformed prior to analysis. Land use variables were logit-transformed, whereas crop presence/absence and TRAMPLING remained untransformed. All RDA-analyses were carried out with the program CANOCO v4.5 (Lepš and Šmilauer, 2003). Significance levels were assessed with 999 random Monte-Carlo permutations (n = 999; full model). Multiple regression analyses were performed with the software package STATISTICA v6.

3. Results

3.1. Pond characteristics

The studied ponds were generally very small and shallow. The surface area of the 99 permanent ponds ranged between 12 and 3674 m^2 (Table 1) and 90 % of the ponds were smaller than 400 m^2. Maximum depth averages ranged between 0.18 and 1.6 m. The set of ponds displayed a large variability for the studied variables (see Table 1) and represented both turbid hypertrophic ponds devoid of water plants and with high amounts of phosphorus, chlorophyll a and silt, as well as vegetated ponds with clear water.

3.2. Pond characteristics and land use

Partial standardized RDA analyses revealed significant explanation of variation in the CT-variable dataset by the percentage cover of forest and crop land (Fig. 2). There were no significant effects of both urbanized area and pastures. The level of statistical significance of this association strongly depended on the spatial scale considered (Fig. 2). The effect of forest cover was significant when estimated for circular areas with surfaces of 0.008, 0.03, 0.125, and 0.5 km^2 around the ponds (radii of 50, 100, 200, and 400 m, respectively) but not for larger areas. The effect of percentage cover of crop lands was significant for surface areas with radii of 50 and 100 m. Both land use variables explained most variation for areas with a radius of 100 m. The maximum amount of variation in CT-variables explained by forest land (4%) was higher than that for crop land (2.3%). Use of crop presence/absence data for areas with 10, 20 and 100 m radii resulted in similar percentages of explained variation as for forest cover data (approximately 3.5%; Fig. 2).

A RDA-model with the variables TRAMPLING, the spatial variable Y^3 and the four land use cover variables derived from 100m-radius areas, was highly significant (p = 0.001) and explained in total 21% of the variation in the CT-dataset (Table 2). According to variation partitioning performed on this model, the four land use variables jointly contributed 34% of this total explained variation (p = 0.019; Table 2). The variable TRAMPLING alone was responsible for a highly significant contribution of 41% to the total explained variation (p = 0.001). Latitude (Y^3) explained 11% of this variation (p = 0.036), whereas the variation explained in common amounted to 14%.

Application of a forward selection procedure on the entire set of explanatory variables derived for all spatial scales (10 to 3200 m radii) retained four variables: TRAMPLING, percentage forest cover in a 200 m-circular area, crop presence/absence in a 20 m-circular area, and the spatial variable Y^3 (Table 3). TRAMPLING and crop presence/absence were negatively associated with clear water conditions (Fig. 3a,b) whereas forest cover showed a positive association with clear water conditions (Fig. 3c). The CT-variables showed a significant association with latitude: ponds tended to become increasingly turbid towards the north of the study area (Fig. 3d).

3.3. Vegetation complexity and land use

Number of vegetation growth forms (NGF) was the only index of vegetation complexity that was related to one of the spatial variables (Y^3; $r = 0.21$, $p = 0.038$) and to the presence or percentage cover of adjacent crop land (Fig. 4). NGF was significantly related to crop land presence/absence within 20 and 100 m radius areas, to crop land cover within 0.125 km^2 areas and to crop land cover within 0.03 and 0.5 km^2 areas upon exclusion of the spatial variable Y^3 from the regression model. With the exception of associations between urban area in 2 and 40 km^2 areas and growth form number (r_p-values > 0.2; p-values < 0.05), there were no other associations between variables of land use cover and vegetation complexity.

Of all land use variables, TRAMPLING had the highest impact on vegetation complexity. TRAMPLING showed significant, negative correlations with all three vegetation complexity variables and had the highest standardized regression coefficients in multiple regression models on vegetation complexity variables (Table 4).

4. Discussion

Our study of 99 small farm land ponds spread over the Belgian territory revealed significant associations between surrounding land use and pond variables that are related to turbidity status or vegetation complexity. Ponds frequently visited by cattle or located near crop land were characterized by relatively high values of turbidity related variables (e.g., total phosphorus, chlorophyll a concentrations, silt on the sediments), lower water transparency and sparser aquatic vegetation. Conversely, ponds at locations with high forest cover showed the opposite pattern. Ponds with high disturbance by cattle also contained a lower number of abundant water plant taxa, a lower number of water plant growth forms and a lower diversity of aquatic vegetation types. Effects of land use cover were less pronounced on these indices of vegetation complexity, although we also observed a negative association between crops in the immediate vicinity of ponds and the number of plant growth types.

Degree of trampling by cattle seemed to have the highest impact on both turbidity and vegetation complexity related variables. The effect of cattle on permanent ponds probably operates via mechanisms that differ intrinsically from those that govern the terrestrial zones of temporary wetlands (e.g. Marty, 2004) and probably resemble more those exerted by large benthic fish on ponds and lakes (Scheffer et al., 2003). Cattle can directly increase turbidity of ponds by resuspending sediments and increasing bank erosion. Cattle may also indirectly contribute to increased water turbidity by stimulating phytoplankton growth through an increased nutrient input via defecation and urination and via an enhancement of internal eutrophication (nutrient release from the sediments). As a side effect, this increased turbidity can enhance dominance of phytoplankton over water plant vegetations through increased light limitation. Finally, the abundance, taxon richness and structural complexity of water plant vegetations may also be adversely affected by cattle through direct physical damage as a result of trampling and grazing. Although we observed only negative effects of cattle on aquatic vegetation, we cannot exclude the possibility that a moderate disturbance by cattle may promote botanic diversity in individual cases, for example in ponds where the vegetation tends to be dominated by one single invasive species.

The negative association between the proportion of crop land and the ecological quality of ponds is in line with the results of former studies on rivers, lakes and man-made reservoirs (Jones et al., 2004). Crop agriculture, especially row-crop farming with frequent tillage and the intense application of fertilizers, leads to high soil erosion and high nutrient and sediment export rates. This may ultimately result in increased nutrient loads adversely affecting water plant cover and richness in favor of phytoplankton.

Conversely, clear water state related variables of ponds tended to be positively associated with the proportion of forest cover. This result was not an artifact resulting from the negative correlation between forest cover and crop land cover, because the forest signal remained significant upon inclusion of crop land cover as co-variable in the RDA-models. The effect of forest cover may result from reduced wind action on the surface of the ponds, limiting resuspension of sediments. Although important in lakes, however, wind resuspension may perhaps not be so important in the type of small-sized water bodies studied by us because of their lower wind fetch. More likely, forest cover may be correlated with the intensity of exploitation within land use categories. Agricultural land use (fertilizer and herbicide use, stock density of cattle) on crop lands and pastures is possibly less intensive in highly forested areas than in areas with low forest cover. The presence of forest may then indicate an overall lower intensity of agricultural activity in the area.

The amount of variation in CT-variables and vegetation complexity variables that was explained by the percentage cover of crop land and forest showed a strong decline with increasing spatial scale. Crop land presence/absence data in the immediate vicinity of ponds as assessed by visual observation (circular areas with radii up to 100 m) explained more variation than percentage cover data obtained by GIS application. The percentage of land covered by crops explained more variation in CT-variables when derived for a 100 m-radius area than for larger spatial scales. For forest cover the effect was strongest for a 200 m-radius area. These results suggest that the most important land use effects on ponds operate at relatively small rather than at large spatial scales, and that inputs of nutrients and possibly also pesticides mainly originate from local surface water run-off rather than from atmospheric deposition or major ground water flows. It should, however, be noted that the variation in the estimates of the different types of land use cover decreased with increasing spatial scale. A reduction of this variation may also to some extent have hampered the detection of land use effects at these larger spatial scales.

Although highly significant, the amount of variation in CT- and vegetation complexity variables explained by land use variables was rather low. Because of their isolation, ponds are very heterogeneous systems. Apart from land use, they can be influenced by a multitude of other factors as well (e.g., management history, geological context, water chemistry, hysteresis). These factors may create a lot of variation that acts as noise when we want to extract the impact of general land use related patterns. The explanatory power of the land use variables may also have been weakened because of several additional reasons. First, land use can have long-lasting effects on ecosystems, whereas we used rather recent land use data which do not necessarily reflect historic effects. Indeed, Harding et al. (1998), for example, have convincingly shown that past land use may serve as a better predictor of the present state of ecosystems than recent land use data. Secondly, we used rather coarse land use categories, each of which may cover widely different practices. The category "crops", for example, includes different types of cultures that require different levels of treatment intensity (e.g., corn versus wheat). These considerations and the fact that the associations between land use practices and some crucial pond characteristics in our study were still statistically significant and conform with the expectations based on insights yielded by former studies (Jones et al., 2004), suggest that the extent of the impact of land use in our study may have been underestimated.

5. Recommendations with respect to management

Our results have important implications with respect to the management of existing ponds and the creation of new ponds. First, the observations indicate that the conservation of clear water and high vegetation complexity in both existing and newly created ponds can be successful, even in landscapes dominated with crop lands. Although we have not differentiated between different types of crop land, we expect this to be especially true if the agricultural practices exercised at these crop lands are of low or moderate intensity. Furthermore, in contrast to the situation in rivers, and probably also in lakes, efforts to reduce adverse external land use influences might already be effective when applied at a local scale (e.g., by the adjustment of adjacent land use, the use of buffer zones). The creation of new ponds should preferentially take place at a distance of more than 200 m away from crop land. The access of cattle is best restricted or impaired although we perceive some dilemma with respect to this issue. Most ponds of the type we studied were originally created and maintained as drinking ponds for cattle. Enforced exclusion of cattle from ponds may eliminate their agro-economical reason of existence and may lead to their degradation on a longer term due to lack of maintenance. In the larger ponds, restriction of access for cattle to a limited section of the pond may reduce the impact of cattle. Alternative sources of water supply for cattle (e.g., through mechanic drinking infrastructure) may also help in fulfilling the needs of farmers but external financial support will most often be required to ensure a sustained maintenance of the ponds.

With the CT- and vegetation complexity variables we aimed to evaluate the effects of land use on variables that reflect important ecological characteristics of ponds. These variables should, however, not necessarily be considered surrogate variables for biodiversity. Although there are many reasons to believe that the potential for local biodiversity is higher in the presence of an abundant and structurally complex aquatic vegetation, recent studies have suggested that concordance in biodiversity among different groups of aquatic organisms generally tends to be low (Declerck et al., 2005). If the conservation management of ponds aims at increasing or maintaining the biodiversity of specific groups of organisms, it is still to be preferred to evaluate the effect of land use and conservation measures on data collected for these target groups. Furthermore, in cases where groups of ponds can be managed at a regional level, the attention should be focused on B- and y-diversity rather than on a-diversity (see Williams et al., 2004). Despite the negative effects of cattle on water transparency and vegetation complexity, the access of cattle to a subset of these ponds may even contribute to an increased diversity of pond biotopes at the regional scale.

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References

Allan, J.D., Erickson, D.L., Fay, J., 1997. The influence of catchment land use on stream integrity across multiple spatial scales. Freshwater Biology 37, 149-161.

Boothby, J., 2003. Tackling degradation of a seminatural landscape: options and evaluations. Land Degradation and Development 14, 227-243.

Borcard, D., Legendre, P., Drapeau, P., 1992. Partialling out the spatial component of ecological variation. Ecology 73,1045-1055.

Buck, O., Niyogi, D.K., Townsend, C.R., 2004. Scale-dependence of land use effects on water quality of streams in agricultural catchments. Environmental Pollution 130, 287-299.

Davies, B.R., Biggs, J., Lee, J.T., Thompson, S., 2004. Identifying optimum locations for new ponds. Aquatic Conservation: Marine and Freshwater Ecosystems 14, 5-24.

Declerck, S., Vandekerkhove, J., Johansson, L., Muylaert, K., Conde-Porcuna, J.M., Van der Gucht, K., Martinez, C.P., Lauridsen, T., Schwenk, K., Zwart, G., Rommens, W., Lopez-Ramos, J., Jeppesen, E., Vyverman, W., Brendonck, L., De Meester, L., 2005. Multi-group biodiversity in shallow lakes along gradients of phosphorus and water plant cover. Ecology 86, 1905-1915.

Francis, D.R., Foster, D.R., 2001. Response of small New England ponds to historic land use. Holocene 11, 301-312.

HACH., 1992. Water Analysis Handbook. The Hach Company, Loveland, Colorado.

Harding, J.S., Benfield, E.F., Bolstad, P.V., Helfman, G.S., Jones, E.B.D., 1998. Stream biodiversity: the ghost of land use past. Proceedings of the National Academy of Sciences of the United States of America 95, 14843-14847.

Heath, D.J., Whitehead, A., 1992. A survey of pond loss in Essex, South-East England. Aquatic Conservation-Marine and Freshwater Ecosystems 2, 267-273.

Hynes, H.B.N., 1975. The stream and its valley. Internationale Vereinigung für Theoretische und Angewandte Limnologie Verhandlungen 19, 1-15.

Jeppesen, E., Søndergaard, Ma., Søndergaard, Mo., Christoffersen, K., (Eds.) 1997. The structuring role of submerged water plants in lakes. Ecological Studies Series 131, Springer, New York, USA.

Johnson, L.B., Gage S.H., 1997. Landscape approaches to the analysis of aquatic ecosystems. Freshwater Biology 37, 113-132.

Johnson, L.B., Richards, C., Host, G.E., Arthur, J.W., 1997. Landscape influences on water chemistry in midwestern stream ecosystems. Freshwater Biology 37, 193-208.

Jones, J.R., Knowlton, M.F., Obrecht, D.V., Cook, E.A., 2004. Importance of landscape variables and morphology on nutrients in Missouri reservoirs. Canadian Journal of Fisheries and Aquatic Sciences 61, 1503-1512.

Knoll, L.B., Vanni, M.J., Renwick, W.H., 2003. Phytoplankton primary production and photosynthetic parameters in reservoirs along a gradient of watershed land use. Limnology and Oceanography 48, 608-617.

Lepš, J., Šmilauer, T., 2003. Multivariate analysis of ecological data using CANOCO. Cambridge University Press, Cambridge.

Louette, G., De Meester, L., 2005. High dispersal capacity of Cladoceran zooplankton in newly founded communities. Ecology 86, 353-359.

Marty, J.T., 2004. Effects of cattle grazing o diversity in ephemeral wetlands. Conservation Biology 19, 1626-1632.

Murphy, J., Riley, J.P., 1962. A modified single solution method for the determination of phosphate in natural waters. Analytica Chimica Acta 27, 31-36.

Nicolet, P., Biggs, J., Fox, G., Hodson, M.J., Reynolds, C., Whitfield, M., Williams, P., 2004. The wetland plant and macroinvertebrate assemblages of temporary ponds in England and Wales. Biological Conservation 120, 261-278.

Oertli, B., Joye, D.A., Castella, E., Juge, R., Cambin, D., Lachavanne, J.B., 2002. Does size matter? The relationship between pond area and biodiversity. Biological Conservation 104, 59-70.

Roth, N.E., Allan, J.D., Erickson, D.L., 1996. Landscape influences on stream biotic integrity assessed at multiple spatial scales. Landscape Ecology 11, 141-156.

Scheffer, M., 1998. Ecology of shallow lakes. Chapman and Hall, London, UK.

Scheffer, M., Portielje, R., Zambrano, L., 2003. Fish facilitate wave resuspension of sediment. Limnology and Oceanography 48, 1920-1926.

Scheffer, M., Zimmer, K., Jeppesen, E., Butler, M.G., van Geest, G.J., Hanson, M.A., Søndergaard, M., Declerck, S., De Meester, L. In press. Small biotope size and isolation can promote species richness: second-order effects on biodiversity in shallow lakes and ponds. Oikos.

Søndergaard, M., Jeppesen, E., Jensen, J.P., 2005. Pond or lake: does it make any difference? Archiv für Hydrobiologie 162, 143-165.

Tessier, A.J., Woodruff, P., 2002. Cryptic trophic cascade along a gradient of lake size. Ecology 83, 1263-1270.

Townsend, C.R., Arbuckle, C.J., Crowl, T.A., Scarsbrook, M.R., 1997. The relationship between land use and physicochemistry, food resources and macroinvertebrate communities in tributaries of the Taieri river, New Zealand: a hierarchically scaled approach. Freshwater Biology 37, 177-191.

Townsend, C.R., Downes, B.J., Peacock, K., Arbuckle, C.J., 2004. Scale and the detection of land-use effects on morphology, vegetation and macroinvertebrate communities of grassland streams. Freshwater Biology 49, 448-462.

Verschuren, D., Johnson, T.C., Kling, H.J., Edgington, D.N., Leavitt, P.R., Brown, E.T., Talbot, M.R., Hecky, R.E., 2002. History and timing of human impact on Lake Victoria, East Africa. Proceedings of the Royal Society of London Series B-Biological Sciences 269, 289-294.

Williams, P., Whitfield, M., Biggs, J., Bray, S., Fox, G., Nicolet, P., Sear, D., 2004. Comparative biodiversity of rivers, streams, ditches and ponds in an agricultural landscape in Southern England. Biological Conservation 115, 329-341.

Wood, P.J., Greenwood, M.T., Agnew, M.D., 2003. Pond biodiversity and biotope loss in the UK. Area 35, 206-216.

Figure captions

Fig. 1 - Map of Belgium with the location of sampled pond clusters (circular symbols). Each cluster contained three small farm land ponds that were located within a circular area of approximately 20 km^2. The ponds within clusters were selected along a gradient of land use intensity, ranging from relatively natural areas to areas with intensive agricultural activities.

Fig. 2 - Contribution of major land use variables to the total variation in CT-variables in function of spatial scale as estimated from partial RDA-models (with the spatial variable Y^3 and TRAMPLING as co-variables). Filled symbols: land use cover estimated via GIS-applications using land use maps. Open symbols represent crop land presence/absence as observed from visual inspection. *: $p < 0.05$; **: $p < 0.01$.

Fig. 3 - Conditional effects of land use variables and latitude on the CT-variables (cf. Table 3). The Y-axes of the graphs represent the sample scores of the first principal axis of a partial standardized PCA performed on the CT-variables (except Fig. 3d for which an unconstrained PCA was applied). Positive PCA-scores indicate turbid conditions, whereas negative PCA-scores clear water conditions. TRAMPLING: degree of trampling by cattle (Fig. 3a); CROP P/A (20 m): presence or absence of crop land in the immediate vicinity of the pond (radius of circular area: 20 m; Fig. 3b); FOREST (200 m): percentage of land covered by forest in a 200 m radius circular area around the pond (Fig. 3c); Y^3:

variable of the spatial model, with Y being latitude (Fig. 3d). Note the logit-scale of forest cover in Fig. 3c. Error bars equal twice the standard error of the mean.

Fig. 4 - Partial correlation coefficients of the three vegetation complexity variables with crop land in function of spatial scale. The effects of TRAMPLING and the spatial variable Y^3 were partialled out, except for NGF, for which results are also shown without correcting for Y^3. Filled symbols represent crop land cover as estimated from GIS-applications using land use maps. Open symbols represent crop land presence/absence as observed from visual inspection in the field. *: $p < 0.05$.

Table 1. Summary statistics and variable abbreviations for morphometric variables and clear water/turbid state related variables (CT-variables) assessed for 99 Belgian farm land ponds.

			Median	Minimum	25 percentile	75 percentile	Maximum
Morphometric variables							
	Surface area (m^2)	AREA	147	12	62	265	3674
	Depth maximum (m)	DEPTH	0.71	0.18	0.46	0.92	1.6
CT-variables							
	Transparency (m)	TRANSP	0.21	0.4	0.15	0.28	0.56
	Total phosphorus (mg P L^{-1})	PTOT	0.83	0.07	0.44	2.08	19.07
	Chlorophyll a (µg L^{-1})	CHLa	21	1	6	109	1455
	Silt (m)	SILT	0.28	0	0.13	0.50	1
	Vegetation cover (%)	VEGCOV	55	0	15	90	100

Summary statistics based on the averages of the summer (2003) and spring (2004) data.

Table 2. Variation partitioning on an RDA-model relating CT-variables with major categories of land use cover, degree of trampling by cattle and latitude (Y^3, with Y being latitude). The land use cover variables in this model represent 0.03km^2 circular areas around the ponds (radius: 100 m).

Explanatory variables	Co-variables	% of total variation	% of explained variation	*F*	*p*
Entire model					
CROPS, FOREST, URBAN, PASTURE, TRAMPLING, Y^3		21		3.988	0.001
Variation partitioning					
CROPS, FOREST, URBAN, PASTURE	Y^3,TRAMPLING	7.2	34	2.065	0.019
TRAMPLING	CROPS, FOREST, URBAN, PASTURE, Y^3	8.6	41	9.747	0.001
Y^3	CROPS, FOREST, URBAN, PASTURE, TRAMPLING	2.4	11	2.705	0.036
Explained in common		2.8	14		

Table 3. Marginal and conditional effects of land use and latitude (Y^3, with Y being latitude) on CT-variables as determined by standardized RDA-analysis. Only land use and spatial variables retained by the forward selection procedure are included in the model

Entire RDA-model: Total amount of explained variation: 20%; $F = 5.870$; $p = 0.001$.

	Marginal Effects			Conditional effects			
Explanatory variables	% of total variation	*F*	*p*	% of total variation	% of explained variation	*F*	*P*
TRAMPLING	10.9	11.68	0.001	8.5	42	0.804	0.001
FOREST (200 m)	5.8	5.83	0.001	3.0	15	3.421	0.014
CROP P/A (20 m)	5.3	5.37	0.002	2.9	14	3.351	0.022
Y^3	3.6	3.55	0.020	2.0	10	2.256	0.060

FOREST (200 m): percentage of land covered by forest in a 200 m radius circular area around the pond; CROP P/A (20 m): presence or absence of crop land in the immediate vicinity of the pond (radius of circular area: 20 m).

Table 4. Multiple regression analysis results with the three vegetation complexity variables as dependent variables and trampling by cattle, percentage cover of crop land and latitude (Y^3, with Y being latitude) as independent variables.

Dependent variable		β	*Std.Err.*	*t (91)*	*p*
Number of growth forms	Intercept			11.95	<0.001
	TRAMPLING	-0.361	0.096	-3.76	<0.001
	CROPS (200 m)	-0.208	0.103	-2.01	0.048
	Y^3	-0.105	0.103	-1.02	0.311
	Entire model: R^2= 0.19; *F (3.91)* = 7.05; $p < 0.001$				
Number of observed taxa	Intercept			9.25	<0.001
	TRAMPLING	-0.318	0.101	-3.17	0.002
	CROPS (200 m)	-0.077	0.109	-0.71	0.481
	Y^3	-0.039	0.108	-0.36	0.722
	Entire model: R^2= 0.11; *F (3.91)* = 3.63; $p< 0.015$				
Shannon diversity in biotope types	Intercept			8.21	<0.001
	TRAMPLING	-0.224	0.104	-2.17	0.033
	CROPS (200 m)	0.023	0.112	0.20	0.839

Y^3	-0.029	0.111	-0.26	0.797

Entire model: $R^2 = 0.05$; $F(3.91) = 3.63$; $p < 0.17$

CROPS (200 m): percentage of land covered by crops in a 200 m radius circular area around the pond.

Fig. 1

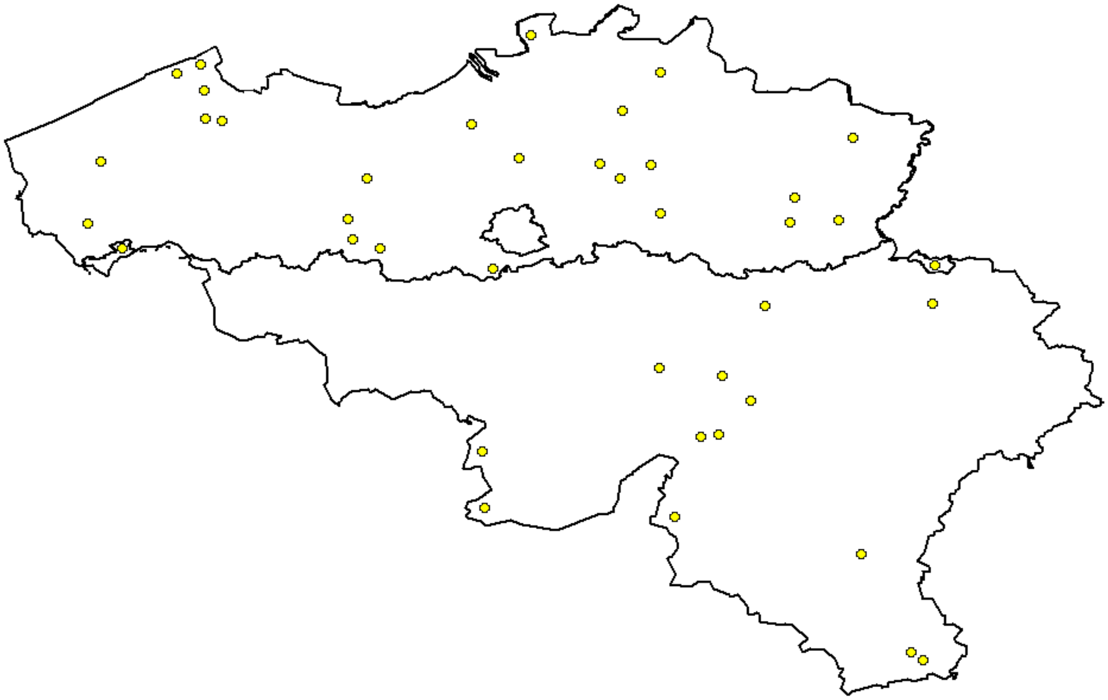
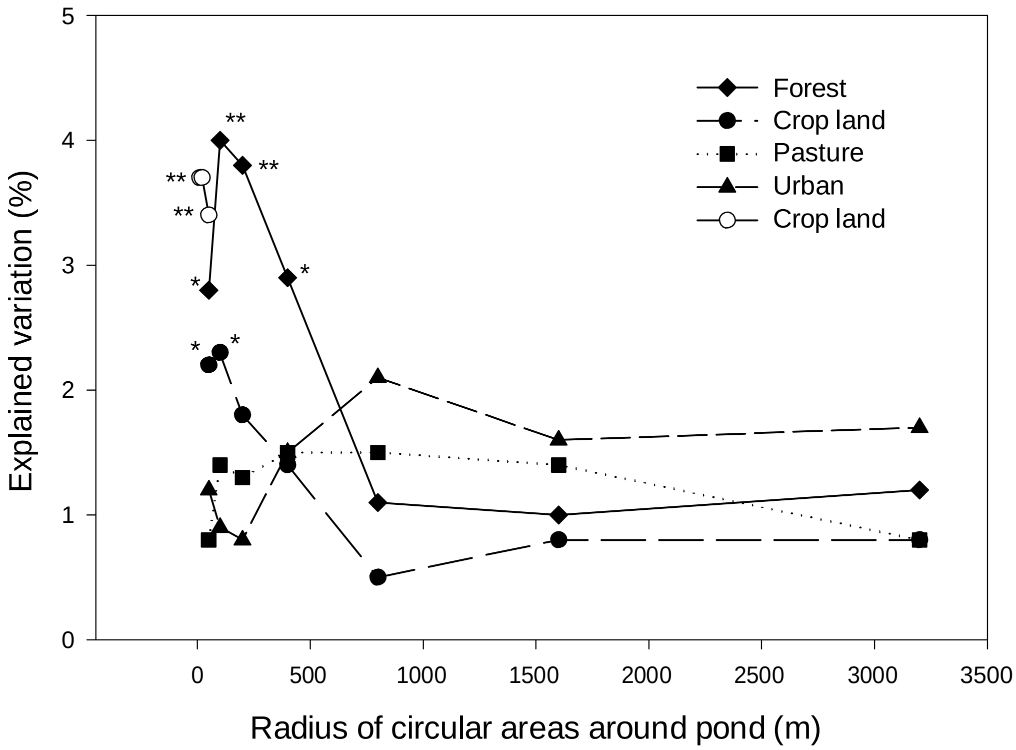


Fig. 2



5
4
3
2
1
0
0
500
1000
1500
2000
2500
3000
3500
Explained variation (%)
Radius of circular areas around pond (m)
Forest
Crop land
Pasture
Urban
Crop land
**
**
**
**
*
*
*
*

1

Fig. 3

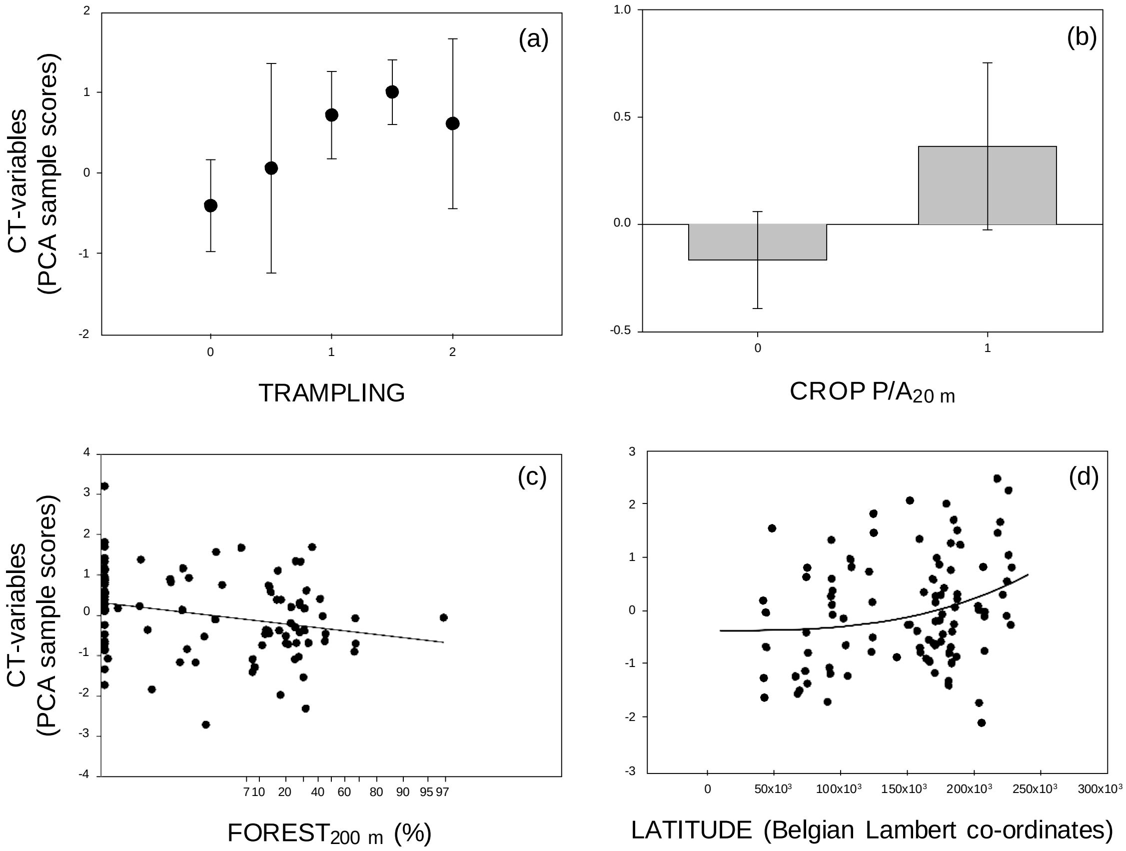
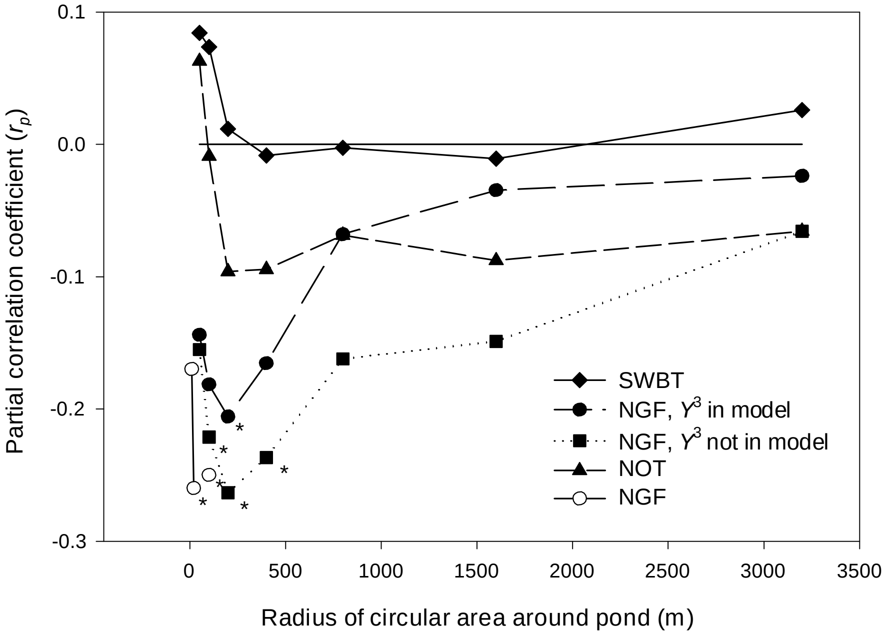

(a)
(b)
(c)
(d)
CT-variables (PCA sample scores)
TRAMPLING
CROP P/A20 m
FOREST200 m (%)
LATITUDE (Belgian Lambert co-ordinates)
2
1
0
-1
-2
1.0
0.5
0.0
-0.5
4
3
-3
-4
7 10 20 40 60 80 90 95 97
0
50x10³
100x10³
150x10³
200x10³
250x10³
300x10³

Fig. 4


Partial correlation coefficient (r_p)
0.1
0.0
-0.1
-0.2
-0.3
0
500
1000
1500
2000
2500
3000
3500
Radius of circular area around pond (m)
SWBT
NGF, Y^3 in model
NGF, Y^3 not in model
NOT
NGF
*
*
*
*
*
*

APPENDIX 1

Results of standardized Principal Components Analysis on variables related to the clear water/turbid state of ponds (CT-variables).

Results of standardized Principal Components Analysis on CT-variables. TRANSP: water transparency as measured with Snell tube; PTOT: total phosphorus content of water column samples; CHLa: chlorophyll concentration representing phytoplankton; VEGCOV: total fraction of pond surface covered by vegetation (submerged + floating + emergent); SILT: total thickness of the silt layer in the middle of the pond.

	PCA1	PCA2	PCA3
Eigen values	0.49	0.19	0.13
Loadings			
TRANSP	-0.85	0.11	0.11
PTOT	0.69	0.06	0.68
CHLa	0.77	0.21	-0.04
VEGCOV	-0.66	-0.42	0.41
SILT	0.46	-0.84	-0.15

Biplot of the standardized Principal Components Analysis on the CT-variables.