Aspects of Applied Biology ***118***, *2013*
Environmental Management on Farmland

Shifts in functional plant groups in ditch banks under agri-environment schemes and in nature reserves

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Summary

Management of ditch banks of agricultural fields is considered to be a promising and multifunctional application of agri-environment schemes (AES) on farmland. Our previous research has shown that in the Netherlands, there is a small increase in the number of target plant species of AES in ditch banks. However, the productivity and Ellenberg indicator value for nitrogen also increased. This suggests a change in species composition towards more competitive species. This is important, because management mainly focuses on restoring disturbance tolerant species that used to be common in meadows, rather than competitive dominants. In this study we use a large scale dataset of target species composition in ditch banks of nature reserves and ditch banks with and without AES over 10 years to monitor results of functional plant species groups under these different management regimes. Our analyses show that plant functional type composition in ditch banks of agricultural fields indeed shifted towards more competitive species over the last 10 years, independent of AES. In nature reserves, a similar increase in competitive species was observed. The shift towards more competitive species was reflected in the increase of the average height of the vegetation and the increase in species with a leafy canopy structure, whereas species with a semi-basal canopy structure were decreasing. We conclude that current AES does not increase the number of targeted disturbance tolerant species and that more disturbance such as more frequent mowing is required to obtain these species.

Key words: Grassland, C-S-R-strategy, Plant canopy structure, Biodiversity conservation, Farmland, Agrobiodiversity, Riparian management

Introduction

Agricultural landscapes worldwide have faced great losses of biodiversity over the last decades due to intensification of the agricultural practice (Donald *et al*., 2001; Stoate *et al*., 2009). One of the measures widely implemented internationally to halt this decline is the management of waterways neighboring agricultural fields. In Europe, the main instrument to conserve biodiversity in agricultural areas is the implementation of agri-environment schemes (AES). In the Netherlands, the UK and Denmark the management of agricultural ditch banks is a widely applied example of

AES. Ditch banks are very suitable for AES because the number of plant species in ditches can exceed 90% of the total plant species richness on agricultural fields (Herzon & Helenius, 2008; Kleijn *et al*., 2001). Ditch banks form a network of less productive linear landscape elements in the agricultural matrix. Here, biodiversity can be maintained and ditch banks may serve as corridors between isolated species-rich areas such as nature reserves (Herzon & Helenius 2008; Stutter *et al*., 2012). In the Netherlands, for example, the total length of ditches is estimated to be between 300,000 and 400,000 km (Higler, 1994).

However, over the last 10 years this management has not resulted in a substantial increase in the species richness of managed ditch banks compared with regular ditch banks (Blomqvist *et al*., 2009). Previous research has shown that there have been shifts in species compositions in ditch banks over the last 10 years (Blomqvist *et al*., 2009; van Dijk *et al*., in press). The productivity of ditch banks increased, the species composition moved towards species with higher N demand and those species that are dispersed by water. Since recommendations for ditch bank management includes late mowing, both the increase in productivity and higher N demand of the vegetation will likely lead to a shift in the vegetation towards more tall growing highly competitive species. The goal of the management, however, is restoring traditional meadow species such as *Lychnis flos-cuculi*, *Lathyrus pratensis* and *Caltha palustris*. Because these species require disturbance, such as frequent mowing, and lower N supplies it is unlikely that these species are encouraged under current management.

In this research we investigate if there have been changes over the last 10 years in functional species groups of the vegetation in ditch banks with and without AES and in ditch banks located in nature reserves. We expect that competitive species have increased over the last 10 years due to the increase of productivity and increasing N demand of the vegetation. Furthermore we expect that the average plant height and the canopy structure will change towards tall growing species with a leafy canopy structure, because these traits give species a higher competitive capacity.

Material & Methods

Study area

Our research was performed in the Krimpenerwaard area in the Western part of the Netherlands. The Krimpenerwaard area covers 14908 hectares with pastures used for grazing or fodder production for dairy cattle being the most common land use. The landscape consist of long and narrow fields, separated by 1–4 m wide ditches. The total length of ditches in this area is 3927 km. Water levels in the ditches are controlled by the local water board and may vary between 0–50 cm below the surface of the field. The main soil types in the area are peaty soils with some clay soils near the rivers.

AES vs non-AES

AES management in ditch banks encompassed no application of fertilizer, manure or dredged sludge in the first metre of ditch bank, from the edge of the ditch. Mowing and grazing by cattle is allowed, but delayed mowing is recommended for the vegetation to set seed (DLG 2000).

The financial support for the AES is remunerated according to a result-oriented principle in which farmers get paid for the presence of 25 government-selected target plants. These species were selected based on their correlation with plant species richness along ditch banks and could be easily recognized (Jansen *et al*., 1989). Presence of the target species was monitored by farmers in a 100 m long and 1 m wide quadrats. The number of quadrates monitored per farmer is proportional to the number of kilometres of ditch banks managed by that farmer. Quadrats were yearly redistributed over the farmers ditch banks. Monitoring data by farmers were verified in the field by specialists in the first year that farmers started AES. In the following years at least 25% of the quadrats per farmer were verified and quadrats with atypical observations were checked.

To compare quadrats with and without AES, we obtained the monitoring data of 153 quadrats in ditch banks with AES management which were yearly managed and monitored by 20 farmers between the years 2000 and 2009. As control plots we used the data of target plants of 1613 quadrats from 181 farmers collected in the year that they started AES, which is not necessarily 2000. Using this method the control plots are independent from the AES plots. By using farmer selected control plots we also excluded a possible bias of farmers performing AES in their most species rich ditch banks evoked by the result-oriented remuneration (Blomqvist *et al*., 2009).

AES vs nature reserves

Most nature reserves in the Krimpenerwaard are extensively managed grasslands that aim at conserving meadow birds or hay-meadow vegetation. Management is dependent upon the target group; in reserves focused on plants management consists of grazing or haymaking without fertilization, whereas in nature reserves for meadow birds extensive grazing and fertilization with farmyard manure takes place. In the early nineties the creation of protected nature reserves started in this area. The area of reserve increased from 674 hectares in 1999 to 1147 hectares in 2005 and eventually 1410 in 2008. We collected data of total plant species abundance from 122 permanent quadrats in ditch banks of nature reserves in the period 1998–2009. The data were obtained from Zuid-Hollands Landschap, the foundation that also manages the reserves. We included only those quadrats in ditch banks in nature reserves that were monitored at least twice in the period 1998–2009. Quadrats in ditch banks of nature reserves were 50 m long and covered the width of the ditch bank, which averaged 0.49 m ± 0.15 m (average ± SD). To compare between ditch banks with AES and the ones in nature reserves we obtained data of 511 quadrats in ditch banks with AES management, which were managed and monitored by 63 farmers. These quadrats were monitored in the years 2000, 2005 and 2009. We could not include both AES, control and nature reserve ditch banks in one analysis because there were just a few farmers that started AES in 2005 and none that started in 2009.

Functional species groups

To research changes in functional composition towards more competitive species we used the strategy types according to Grime (Grime, 1977); competitive (C), stress tolerant (S) and ruderal species (R). Following this approach, we transformed the strategy type of a certain target species into three quantitative weight variables per target species: the weight of C, S and R type (Hodgson *et al*., 1995). For each quadrat we calculated the weight of the three strategy types based on the abundance of all species, the species present and the presence of the target species. To further understand these changes, we also analyzed shifts in the important competitive traits canopy height and canopy structure (Hodgson *et al*., 1995).

These two properties give plants an advantage in highly competitive habitats (Liira & Zobel, 2000). Canopy height data were based on Canopy height categories of Hodgson (Hodgson *et al*., 1995). These categories were transformed to mean height of a particular category (Mean height of all target species 78 cm ± 71.2 SD). Subsequently we calculated the average canopy height per quadrat based on the abundance of all species, all species present and the target species present. Canopy structure was also based on Hodgson (1995). We calculated the relative abundance of plants that either had a leafy, a semi-basal or a basal canopy structure. We also calculated the values for these three categories based on the species present and the target species present.

Statistics

All statistical analyses were performed using Predictive Analytics Software (PASW) (Version 17.0.03; SPSS/IBM Inc., Somers, NY). For the analysis of the functional species groups in ditch banks with and without AES, we performed a Generalized Linear Mixed Model (GLMM) (Bolker *et al*., 2009) with a normal distribution. We analysed trends in the strategy types based on the presence of 25 target species per quadrat. We added the weight of either C, S or R as the dependent variable. We distinguished between quadrats that were managed continuously between 2000–2009 and grouped them as AES quadrats. Quadrats that were in their first year of management were grouped as control quadrats. Year was added as covariate to the model and management (AES or control), and the interaction year*management as fixed factors. We added farmer as random factor. We subsequently reduced the number of variables in the model based on their significance (type III sum of squares), until we obtained the simplest model with the lowest Akaikes Information Criterion (AIC) and significant terms only.

The data from nature reserves encompassed the species abundance of the total number of plant species present in a quadrat. We analysed the weight of the three strategy types based on the abundance of all species present in nature reserves and plant species presence in in the period 1998–2009. We used a GLMM for the analysis of the weight of the functional species groups per quadrat and average plant height we performed a GLMM with a repeated measures structure. Quadrat was added to the model as subject and year as repeat. The nature reserve in which the quadrats were located was added to the model as random factor to compensate for correlations within nature reserves.

We used a AR1 covariance structure to compensate for correlation among the repeated measures of the quadrats. Year was added as covariate to the model.

To compare nature reserves with AES ditch banks we compared trends in the strategy types based on the presence of the 25 target species. We performed a GLMM with the weight of the strategy type as dependent variable. Management (AES or control), year and their interaction were added as fixed factors to the model. Nature reserve or farmer were added to the model as random factor. Subsequently we reduced the number of variables in the model based on their significance (type III sum of squares), until we obtained the simplest model with the lowest AIC. We did not use a repeated measures design in this analysis, because quadrats in AES ditch banks were not repeated measures.

For the analysis of trends in the canopy structure we repeated the aforementioned analyses using a GLMM with a Poisson distribution and a log-link for the canopy structure categories. For vegetation height we used a GLMM with a normal distribution.

Results

AES vs non-AES

Table 1. *Results of the GLMM analysis (F-values) of effect of year (2000–2009 and management (AES or control) on species number and functional diversity. Significance levels: *P<0.05, **P<0.01, ***P<0.001*

	Competitors	Stress-tolerators	Ruderals	Plant Height	Leafy canopy	Semi-basal canopy
Year	46.592***	43.596***		81.479***	26.136***	
Management					5.970*	
Year*management						

Our results show that over time the number of competitive target species increased (0.28 target species per 10 years while the number of stress tolerators also increased, but less so (0.12 target species per 10 years, Table 1). Following that, the average plant height and the number of target species with a leafy canopy substantially increased. Target plants with a semi-basal canopy did not increase. However, all of the previously mentioned variables showed the same trend in quadrats with and without AES.

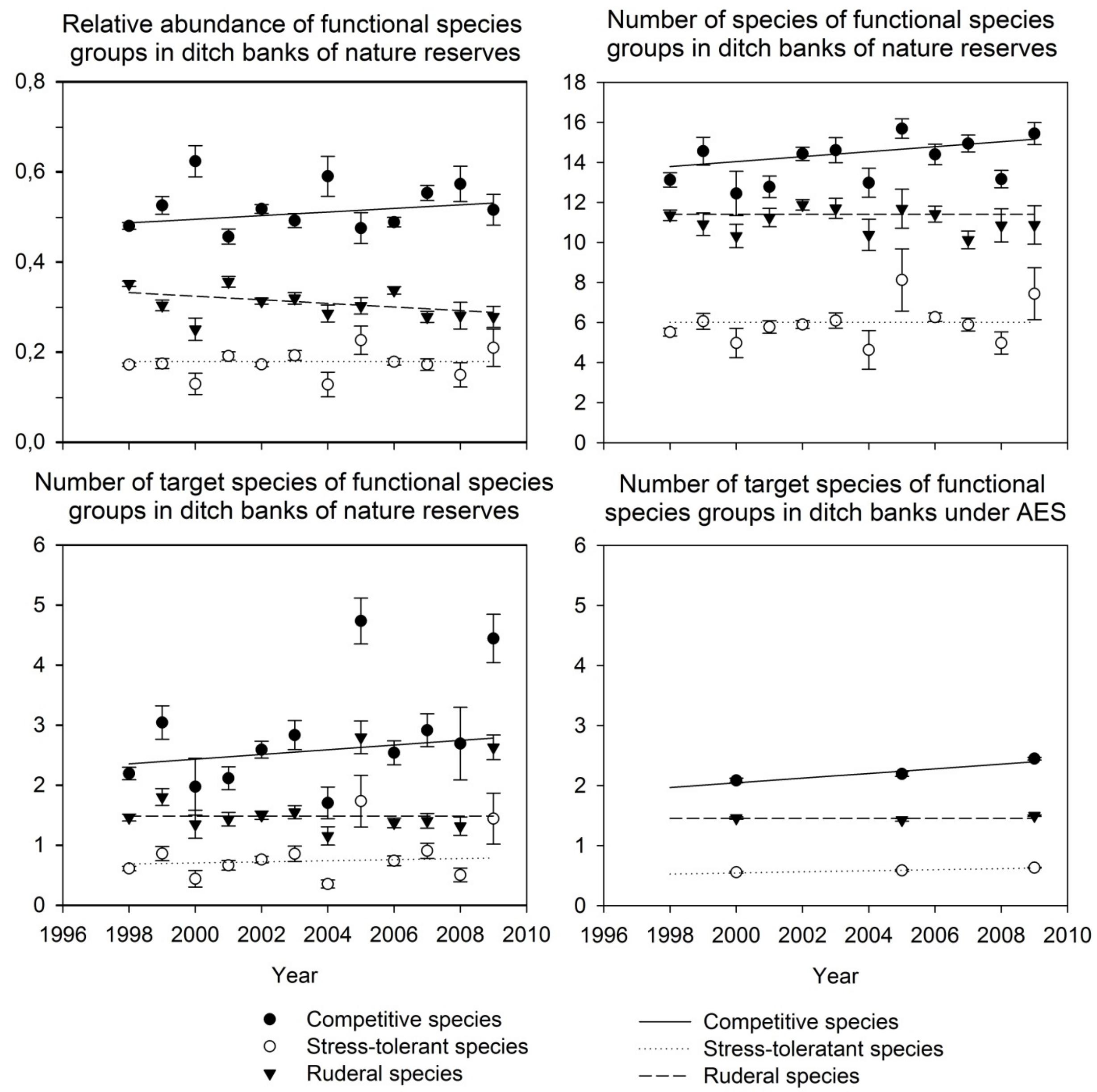

Fig. 1. Changes over time in the functional species groups according to Grime (1977) based on the a abundance, b total species number and target species number in c ditch banks of nature reserves and d ditch banks under AES.. The line represents the predicted values over time determined by performing a GLMM analysis with year as covariate and subsequently removing factors until the simplest model was obtained with significant factors only for abundance and total species number. For target species we performed a GLMM analysis with year, management (nature reserve or AES) and their interaction and subsequently removing factors. Notice that the size of quadrats in nature reserves differs from those under AES.

AES vs nature reserve

Fig. 1a demonstrate that in nature reserve the relative abundance of competitive species was increasing ($F_{1,304}$: 6.989, *P*<0.01) at the cost of ruderal species ($F_{1,304}$: 17.604, *P*<0.001) (Fig. 1). Also, the number of competitive species was increasing (Fig. 1b) ($F_{1,304}$: 10.238, *P*<0.01). Stress tolerant species showed no significant increase in abundance, nor in the number of stress tolerant species. Ruderal species demonstrated a decrease in abundance ($F_{1,304}$: 17.604, *P*<0.001) (Fig. 1a), but there was no change in the number of ruderal species present in nature reserves over time.

When we compared quadrats in ditch banks of nature reserves with quadrats in AES ditch banks we found that nature reserves contained on average more competitive and more stress-tolerant target species ($F_{1,1834}$: 8.431, *P*<0.01, $F_{1,1834}$: 8.331, *P*<0.01, respectively)(Figs 1c & d). We

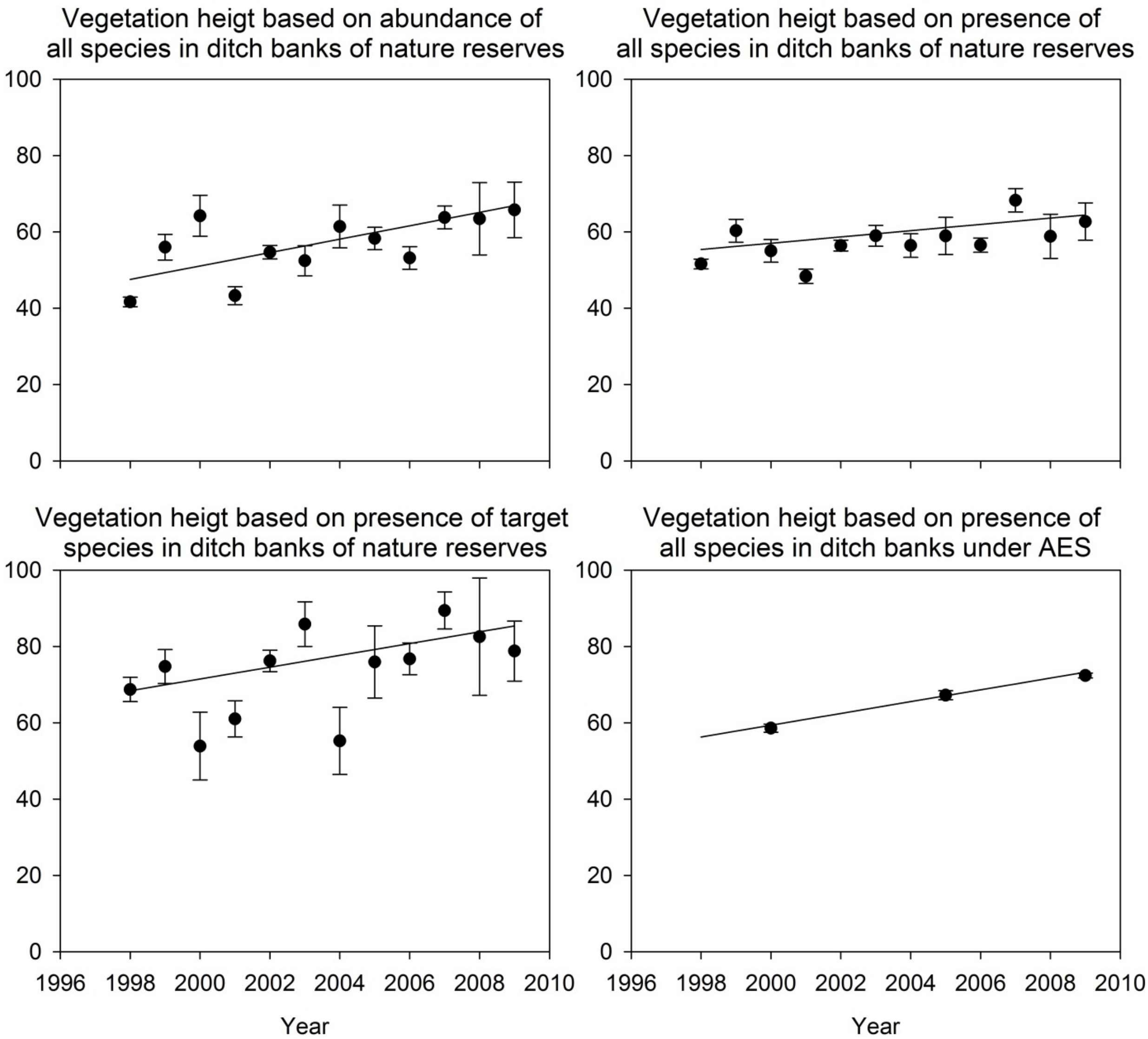

Fig. 2. Changes over time in the vegetation height based on the a abundance, b total species number and target species number in c ditch banks of nature reserves and d ditch banks under AES. The line represents the predicted values over time determined by performing a GLMM analysis with year as covariate and subsequently removing factors until the simplest model was obtained with significant factors only for abundance and total species number. For target species we performed a GLMM analysis with year, management (nature reserve or AES) and their interaction and subsequently removing factors. Notice that the size of quadrats in nature reserves differs from those under AES.

found a significant increase in the number of competitive species in both nature reserves and AES ditch banks ($F_{1,1834}$: 67.505, P<0.001) (Fig. 1d). Stress tolerant species had only a minimal increase in time ($F_{1,1834}$: 25.400, P<0.001), which was also equal in nature reserves and AES ditch banks. Ruderal target species showed no difference nor in numbers present between nature reserves and AES, nor in increase in time.

Fig. 2 demonstrates that in nature reserves there is both an increase in the abundance and the number of tall growing species (respectively $F_{1,304}$: 46.636, P<0.001, $F_{1,304}$: 34.577, P<0.001). This trend is also reflected in the average plant height target species present in both nature reserves and AES ditch banks (Fig. 3) ($F_{1,1834}$: 120.293, P<0.001). AES ditch banks, however, have a lower average plant height of the target species present ($F_{1,1834}$: 19.544, P<0.001).

The canopy structure of the vegetation in nature reserves changed in time to both a higher abundance of species with a leafy canopy (Fig 3a)($F_{1,304}$: 6.478, P<0.05), a higher number

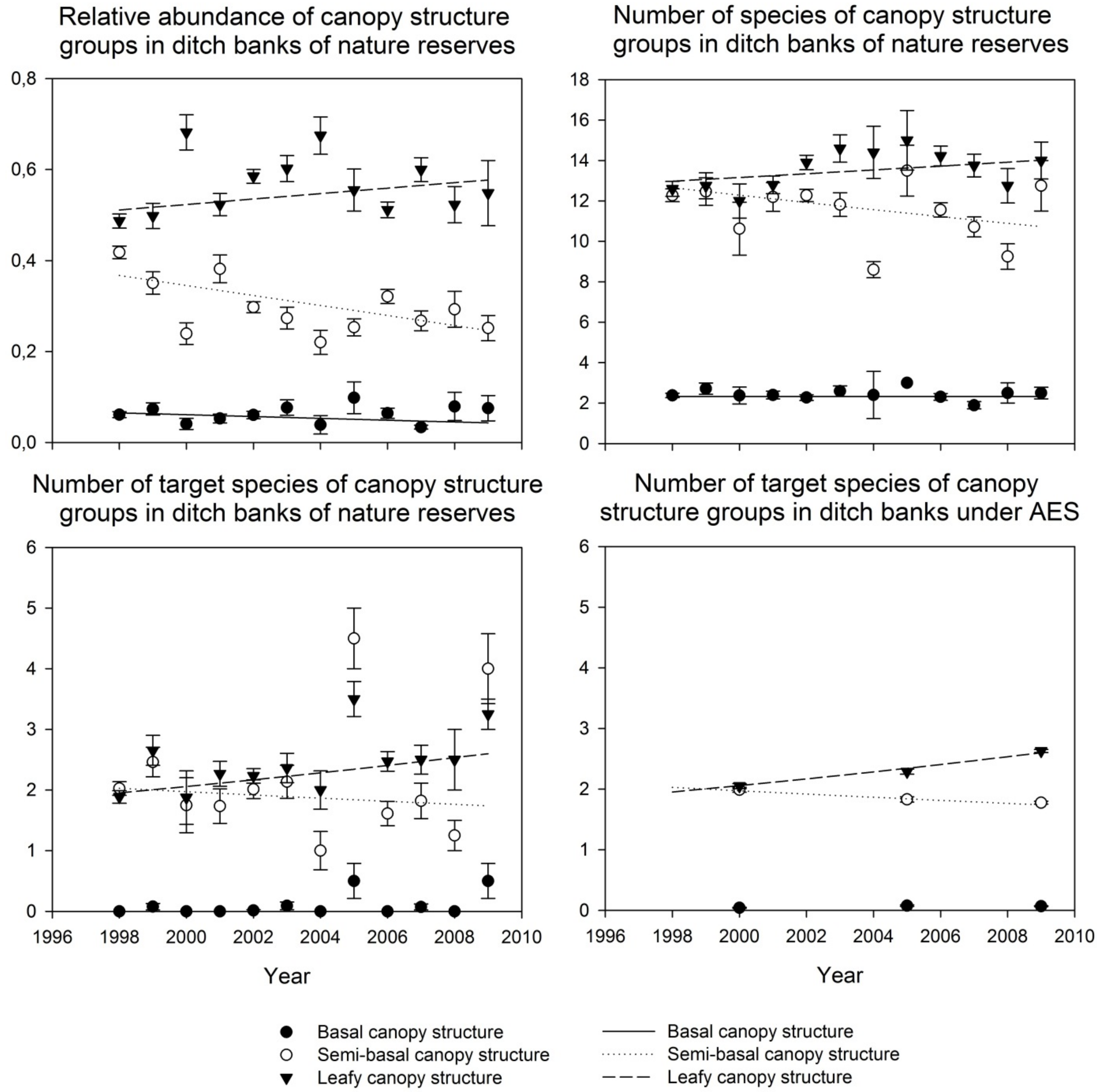

Fig. 3. Changes over time in the canopy structure groups according to Grime (1977) based on the a abundance, b total species number and target species number in c ditch banks of nature reserves and d ditch banks under AES. The line represents the predicted values over time determined by performing a GLMM analysis with year as covariate and subsequently removing factors until the simplest model was obtained with significant factors only for abundance and total species number. For target species we performed a GLMM analysis with year, management (nature reserve or AES) and their interaction and subsequently removing factors. Notice that the size of quadrats in nature reserves differs from those under AES.

of species with a leafy canopy (Fig. 3b)($F_{1,304}$: 3.752, P<0.05) and a higher number of target species with a leafy canopy in both nature reserves and AES ditch banks (Figs 3c and d)($F_{1,1834}$: 40.086, P<0.001)(Fig. 3). While species with a semi-basal canopy decreased both in abundance ($F_{1,304}$: 47.182, P<0.001), total species number ($F_{1,304}$: 13.583, P<0.001) and the number of target species in both nature reserves and AES ditch banks ($F_{1,1834}$: 8.617, P<0.01). Plant species with a basal canopy structure had a decrease in abundance in nature reserves ($F_{1,304}$: 7.274, P<0.01). We found trend in time in the total species number or target species number for this canopy structure. This may be due to the small number of species in this category present in both nature reserves and AES ditch banks.

Discussion

Our analyses show that over the last 10 years mainly competitive target species have increased in ditch banks. This is in line with the increased productivity of ditch banks and the increasing Ellenberg N value of the vegetation that has been observed in previous studies (Blomqvist *et al*., 2009; van Dijk *et al*., in press).

In fact, ditch banks in nature reserves and AES ditch banks both contain a high percentage of competitive target species. The trend towards more competitive species is suggested by the increasing average height of both the vegetation, the species present and the target species present. It is also reflected in the general increase of plants with a leafy canopy both in ditch banks of nature reserves and AES ditch banks.

The increase of competitive, tall growing species with a leafy canopy is at the cost of species with a basal or semi-basal canopy. Plants with a semi-basal canopy are decreasing in abundance and species present in ditch banks of nature reserves and under AES.

Because quadrats in nature reserves were smaller than in AES ditch banks, the number of target species may be higher in ditch banks of nature reserves. However, temporal trends in functional groups, canopy structure and vegetation height are unlikely to be affected by this.

Measures that could be taken to increase the targeted meadow species would be increasing water tables and lowering the nutrient input on the adjacent fields. Also, the sowing of hemiparasitic plants native to these ditch banks, such as *Rhinanthus angustifolius* would lower competition and sward height and increase the number of species (Pywell *et al*., 2004).

Yet, more feasible on highly productive agricultural pastures would be to increase the mowing frequency. Mowing has been shown to decrease vegetation height, independent of soil fertility (Liira & Zobel, 2000) and increase the number of species (Hansson & Fogelfors, 2000).

A second cut in September would also increase the impact of disturbance and would lower the competition leading to disturbance and stress tolerant species, traditional to these meadows rather than the tall-growing more competitive species. In the long-term, frequent mowing should be performed in a phased way, to give the vegetation also the opportunity to set seed (Leng *et al*., 2011).

Acknowledgements

We would like to thank Rianne de Wit for providing data of AES quadrats and Dick Kerkhof for providing data on nature reserves. This research is part of the KBIV strategic research programme “Sustainable spatial development of ecosystems, landscapes, seas and regions” which is funded by the Dutch Ministry of Economic Affairs, Agriculture and Innovation, and carried out by Wageningen University & Research centre.

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