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Structural and functional characteristics of buffer strip vegetation in an agricultural landscape – high potential for nutrient removal but low potential for plant biodiversity

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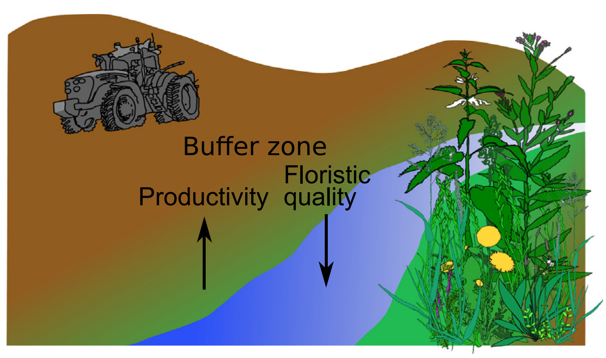
HIGHLIGHTS

- Buffer zones should protect the aquatic environment and vegetation biodiversity.
- We investigated floristic quality, productivity and catchment characteristics.
- Floristic quality in buffer zones is low and productivity is high.
- Both are related to land-use intensity in the catchment.
- Good management would maximize floristic quality while minimizing diffuse pollution.

GRAPHICAL ABSTRACT



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ABSTRACT

Vegetated buffer strips constitute a transition zone between terrestrial and aquatic ecosystems and provide several ecosystem services. Buffer strips are often applied as a mitigation measure against diffuse pollution in agricultural areas, primarily because they may retain nutrients and in this way help protect the aquatic environment. Additionally, they can improve biodiversity in an otherwise homogenous landscape and may therefore have a value in their own right. In the present study, we characterized the structural and functional features of the vegetation in Danish buffer strips using a nationwide dataset to explore: i) their floristic quality in terms of species diversity and conservation value and ii) based on their functional characteristics, their potential to retain nutrients. Moreover, we analyzed how the structural and functional characteristics varied along gradients in the environmental features of the catchment. We found that the floristic quality of the buffer vegetation was generally low, exhibiting an average of only 3.3% of the number of species of conservation interest. Instead, Danish buffer strips were dominated by widespread and productive species that are tolerant of anthropogenic impacts in the catchment. The abundance of highly productive plant species was positively related to high intensity land use, whereas the abundance of stress-tolerant plant species was positively related to low intensity land use. The high productivity of the buffer strips implies a large bio-storage potential, and these areas might therefore offer an opportunity to remove nutrients by harvesting the plant biomass. We discuss how Danish buffer strips could be exploited via appropriate management (e.g. harvesting) to maximize nutrient retention and at the same time improve floristic quality.

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1. Introduction

Riparian areas constitute a transition zone between terrestrial and aquatic ecosystems and form a natural barrier against loss of substances from the terrestrial environment to the adjacent aquatic environments (Osborne and Kovacic, 1993). Along natural, undisturbed streams, these transition zones may host a diverse array of habitats of conservation value, including wet meadows and fens as well as productive plant communities such as hygrophilous tall herb fringes (Natura 2000 code: 6430; Fredshavn et al., 2014). In agricultural landscapes, on the other hand, these zones are often narrow strips, heavily modified due to physical modifications of the streams, including widening and deepening of the stream channel and, furthermore, highly influenced by agricultural practice, including drainage and application of fertilizers and pesticides. Thus, the biodiversity value of the vegetation in buffer strips in agricultural areas is likely to vary with land use intensity. Some studies suggest that riparian buffer areas may show high biodiversity and highlight their need for protection in agricultural landscapes (Corbacho et al., 2003; Naiman et al., 1993), while others suggest that plant diversity is limited and comparable to that found in upland areas, although with contrasting compositional patterns and different species pools (Sabo et al., 2005). Furthermore, it has been suggested that buffer strips may contain many wetland species that are in decline elsewhere (Boutin et al., 2003), though it can be questioned to what extent these species can survive in buffer strips in agricultural areas due to elevated nutrient levels (Dybkjær et al., 2012). The physical characteristics and management of the buffer strips (Crawford and Semlitsch, 2007; Stockan et al., 2012; Stutter et al., 2012) may also be of importance for the biodiversity value. For example, wide buffer zones can provide space for many plant species (Castelle et al., 1994, 1992; McCracken et al., 2012) as natural communities are allowed to develop, reflecting that the influence from agriculture diminishes with the distance to cultivated land. Consequently, wide buffer strips may support a higher diversity than narrow ones (Spackman and Hughes, 1995), which may be of importance for the overall diversity in highly homogeneous, agricultural landscapes.

Buffer vegetation plays a key role for several ecosystem services, especially protection of the aquatic environment (Dosskey et al., 2010; Rasmussen et al., 2011). For instance, the structural and functional characteristics of the vegetation play a role for the ability of the buffer strips to reduce nutrient losses to the aquatic environments, either by trapping sediments and associated nutrients or through assimilation of nutrients from either groundwater or surface runoff, or in suspended sediments (Correll, 1996). It is reasonably well documented that buffer strips are most effective in retaining sediments and nutrients when the slope between the field and the aquatic water body is shallow and the runoff is slow (Barling and Moore, 1994). Also, the buffer strips should have a certain width to effectively retain, for instance, nutrients and pesticides that are preferentially attached to fine sediment (Rasmussen et al., 2011). Additionally, the capacity of the vegetation in buffer strips to store nutrients, the so-called bio-storage capacity, is also likely to depend on the type of vegetation (Dosskey et al., 2010) as differences in growth and biomass allocation patterns may affect the nutrient cycling. Besides trapping and retaining surface runoff and nutrients, the vegetation of the buffer strips also influences stream water temperature (Osborne and Kovacic, 1993), stream bank stability (Dosskey et al., 2010; Welsch, 1991), the input of organic matter to the stream (Correll, 1996; Osborne and Kovacic, 1993; Welsch, 1991), the quality of habitats for invertebrates and other small animals (Barling and Moore, 1994; Crawford and Semlitsch, 2007) and the recreational value for the public (Stutter et al., 2012).

Denmark is an intensively cultivated lowland country; more than 60% of the area is covered by agricultural land and the degree of fragmentation of natural terrestrial habitats is high (Kronvang et al., 2008). Consequently, today, the conservation status is considered unfavourable for 11 out of 17 terrestrial habitat types embraced by the EU Habitats Directive (Fredshavn et al., 2014). Moreover, the ecological quality of aquatic ecosystems is negatively affected by excessive nutrient loadings (Carpenter et al., 1998; Correll, 1998; Scheffer et al., 2001; Smith et al., 1999) that hinder fulfilment of the ecological goals defined by the EU Water Framework Directive (European Parliament and Council, 2000).

In the present study, we used an extensive plant community dataset to explore the potential ecosystem services offered by Danish buffer strips focusing on two important purposes i) providing areas for natural habitats and ii) reducing the influence from agriculture on aquatic ecosystems. Our analyses had particular focus on the functional and structural characteristics of the vegetation in the Danish buffer strips. A trait-based approach was used in order to evaluate to which extent these strips can serve to protect plant diversity and act as a refuge for rare and endangered species and to assess the potential of the buffer strips to retain nutrients and in this way project the adjacent aquatic systems from nutrient loadings. Specifically, we hypothesized that increasing anthropogenic impact is 1) negatively correlated with plant diversity, in particular with the abundance of rare and declining species, and 2) positively correlated with the abundance of productive and competitive plant species that have a high bio-storage potential.

2. Methods

2.1. Study sites

A total of 515 stream buffer strips distributed throughout Denmark were studied in the period 2004 to 2009 as part of the NOVANA monitoring program (Fig. 1a; Friberg et al., 2005; "NOVANA program"). Buffer strips of 2 m width were established in 1992 as part of the Danish water course Act along all natural watercourses with the aim to stabilize stream banks and to reduce influence from agriculture on the aquatic environment. Each study site was defined as a 100 m long reach along the stream channel. Six cross sectional transects, placed perpendicular to the stream channel, were established at 0 (starting point, most upstream), 20, 40, 60, 80 and 100 m from the starting point at each study site (Fig. 1b). The vegetation was registered in 60 plots (10 per transect on both sides of the stream) per buffer strip from the water edge, 2 m up the stream banks (Fig. 1c). In total, 6 m^2 were studied in each buffer strip. All plant species occurring in the plots were recorded and abundance was calculated as the percentage of the area with each species present.

2.2. Structural characteristics

To assess the floristic quality of the buffer strips, we assigned a rarity value to each of the registered species based on information from the Danish Red List (Wind and Pihl, 2004) and different Danish floras (Frederiksen, 2012; Mossberg and Stenberg, 2014). Rarity was divided into five categories: common, declining, relatively rare, rare and endangered species. Furthermore, we assessed plant diversity by calculating Shannon diversity (H), Simpson diversity (D), Pielou's evenness (J) and plant species richness (as total number of species) for each buffer strip.

2.3. Functional characteristics

A trait-based approach was used to characterize the structural and functional characteristics of the buffer strip vegetation. Traits are closely linked with environmental conditions (Göthe et al., 2017) and may give an indication of ecological processes in ecosystems (Lavorel, 2013). In this way, traits can help to further the understanding of trade-offs and synergies between different ecosystem services (Lavorel et al., 2011).

We applied 16 plant traits with a total of 32 attributes to 653 identified plant species. The trait data used in this study is a subset of the LEDA database (Kleyer et al., 2008). Traits and attributes related to productivity, and therefore considered as measures of the bio-storage capacity of