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Groundwater dynamics converted to a groundwater classification as a tool for nature development programs in the dunes

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SUMMARY

Within the European Union, Habitat Directives are developed with the aim of restoration and preservation of endangered species. The level of biodiversity in coastal dune systems is generally very high compared to other natural ecosystems, but suffers from deterioration. Groundwater extraction and urbanisation are the main reasons for the decrease in biodiversity. Many restoration actions are being carried out and are focusing on the restoration of groundwater level with the aim of re-establishing rare species. These actions have different degrees of success. The evaluation of the actions is mainly based on the appearance of red list species. The groundwater classes, developed in the Netherlands, are used for the evaluation of opportunities for vegetation, while the natural variability of the groundwater level and quality are under-estimated. Vegetation is used as a seepage indicator. The existing classification is not valid in the Belgian dunes, as the vegetation observed in the study area is not in correspondence with this classification. Therefore, a new classification is needed. The new classification is based on the variability of the groundwater level on a long term with integration of ecological factors. Based on the new classification, the importance of seasonal and inter-yearly fluctuations of the water table can be deduced. Inter-yearly fluctuations are more important in recharge areas while seasonal fluctuations are dominant in discharge areas. The new classification opens opportunities for relating vegetation and groundwater dynamics.

1. Introduction

Within the European Union, different directives for nature conservation have been established and put into practice for the preservation, establishment and reproduction of endangered or vulnerable species. The most important directives are the Council Directive 79/409/EEC on the Conservation of Wild Birds and the Habitats Directive (Council Directive 92/43/EEC) on the conservation of natural habitats and of wild fauna and flora. They form the basis of the Natura 2000 network. Within this network, the level of biodiversity in coastal dune systems is generally very high compared to other natural ecosystems (Carranza et al., 2008), but suffers from deterioration resulting in loss of biodiversity. The dune system within Europe is divided in several Biogeographical Regions. Within each Biogeographical Region, different habitats are addressed in view of their conservation. The coastal dune system in Belgium makes part of the Atlantic Biogeographical Region that extends from Portugal to Denmark. Threats on the dune system are of anthropogenic origin and are caused by (de-)forestation, farming, intensive grazing, expansion of urbanisation including tourism (Carranza et al., 2008) and other leisure activities (e.g. golf courses) (Houston, 2005), military activities (Houston, 2005; Koskela and Sievänen, 2009), sea defence (Houston, 2005), harbours (Heslenfeld et al., 2004). Changes in land use started in the 19th century and became more important after World War II (Carranza et al., 2008). Moreover, an increase of aerial deposition of pollutants (Herrier and Van Nieuwenhuyse, 2005) causes a deterioration of the dune area. Additional to the former stresses, groundwater extraction is an important issue in the dune ecosystem, especially in the Netherlands and in Belgium where the extraction started in the 19th century. Since the early 20th century, it became more intensive. As groundwater extraction starts, the equilibrium between ecology and groundwater is distorted and the groundwater table is lowered. Slowly, a new ecologically stable equilibrium with a low groundwater table and a dry environment may develop. Biodiversity in this new equilibrium state is less than in the situation without groundwater extraction.

2. Nature development programs

In the 1980s the consciousness of nature preservation arose. Plants are useful indicators to observe possible degradation of

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the ecosystem (Landsberg and Crowley, 2004) although they should be used in combination with other abiotic parameters (Carignan and Villard, 2002). Dune ecosystems in Europe are heavily under stress due to human activities which have resulted in a no longer mobile dune system where the effect of the wind and water on the sand transport is reduced to negligible level. Deterioration of dune ecosystems is counteracted by mowing, grazing and/or sod cutting (Houston, 2005; Grootjans et al., 2002; van Til and Kooijman, 2007).

Especially in the Netherlands, a lot of restoration actions are being carried out and are focusing on the restoration of groundwater level with the aim of re-establishing rare species (Zevenberg, 2011; Van Rijn, 2010). To achieve these goals, in the first place, reduction of groundwater withdrawal is promoted and combined to artificial groundwater recharge with surface water. The restoration of the groundwater level causes a rewetting of the area and wet dune slacks might arise. During decades of groundwater exploitation, however, the groundwater level was low and a nutrient rich dune soil developed unlike the condition before the start of groundwater exploitation. As a result of the rising groundwater table, the development of a monotonous rough vegetation is not an exception (Van Rijn, 2010; Grootjans et al., 2002). Therefore, removal of the top soil either or not combined to mowing or grazing is recommended to realise a nutrient-poor open and wet condition that will remain more or less stable for long time (Van Rijn, 2010; Grootjans et al., 2002), although it is not a guarantee for success (Bakker et al., 2006).

Guidelines for nature conservation and development have been established in the Netherlands since the 1980s with the aim of a fast rewetting of the area. This objective was pursued for about 20 years, from the 1980s till 2000. The aims are based on relict fauna indicating a former wet dune area with seepage at the surface. Nowadays, in recent ecological investigations, many problems are observed due to the fast rewetting: increasing the water table level at a high speed causes a very negative effect. Before the restoration, the water table was at great depth due to groundwater extraction. These conditions are preferable for buck thorn which developed at high speed and occupied most part of the dune area. These shrubs absorbed nitrate and oxygen in their roots which are released in the soil by removal of the shrubs during nature restoration activities. If the water table rises quickly, a nutrient rich soil forms the basis for development of nutrient rich vegetation in the dune area. This forms the basis for studies about the soil compositions in relation with vegetation. Van Bodegom et al. (2006) stated that the composition of the soil before the groundwater table rise is decisive for the re-establishment of the vegetation and a long term of monitoring is recommended.

In Belgium (Flanders), several measures are taken to restore the ecosystem in the dune area. Regulations for urbanisation are set up to protect the dune area. Besides the forced reduction of groundwater exploitation to repair the groundwater table, efforts are made to repair the aeolic dynamics of the dune system. The goals of nature development programmes in Flanders are focused on restoration of the groundwater table as it was in the original state in the 18th century, the so-called Ferraris reference state (after the Ferraris map, 1777–1778). It should however be considered that some human activities cannot be reversed (e.g. acidification and eutrophication due to air pollution) (Cortina et al., 2006). As a consequence, the realisation of the same state as it was in the 18th century is rather opportunistic. Nonetheless, investments for nature conservation should be taken with realistic goals for a new ecological balance and sustainable with the changing environment of the future (Choi et al., 2008). For this purpose, appropriate evaluation methods should be used to evaluate the success of the nature conservation measures.

The implementation of nature restoration activities within Europe is mainly financed by the European Life Nature projects. Because the LIFE projects are seen as "milestones" (Houston, 2005) in the development of techniques and networking to share experiences and prepare guidelines for decision making, it is important to evaluate the evolution correctly, so that mis-management is avoided.

3. Evaluation of nature restoration actions

The nature development programmes have different degrees of success, depending on the aim of the project or wether the evaluation was performed on the long or short term (Bakker et al., 2006). Nature restoration actions in the Netherlands are considered successful if many endangered species (Red List species) re-establish in restored slacks and can maintain large populations for at least several decades (Grootjans et al., 2002; van der Hagen et al., 2008). Ruiz-Jaen and Aide (2005) question if the success of restoration should be measured based on the diversity, the vegetation structure or the ecological processes.

To evaluate the efficacy of nature restoration, many studies have been carried out (van Duren et al., 1998; Bonte and Hoffmann, 2005; Kiehl et al., 2006). An approach based on the relation between hydrodynamics and vegetation in the dune – polder area has been developed at the beginning of the 1990s with the aim of supporting water management in relation to nature conservation. In this context, Nieuwenhuis et al. (1991) developed ecological standards that represent the non-biotic conditions for the plant communities needed to survive. Several zones were set related to the groundwater quality varying from fresh over brackish to salt groundwater, and with respect to infiltration and seepage. Although Nieuwenhuis et al. (1991) emphasise that the result is restricted to their study area in the Netherlands, the relation of their proposed seepage indicator with vegetation has been used in many other Dutch studies in the following years and forms the basis of further classifications.

The principle of using vegetation as seepage indicator is continuing to be a hot topic (Klijn and Witte, 1999), although caution is called for.

Results of our own investigation are confronted with a paradigm. The existing groundwater classes, based on the measured depth of the groundwater table, are not corresponding with the observed vegetation in the study area. Supposed seepage indicator species are not confirmed by our observations. The occurrence of orchids (relict population) is not an indication of seepage, on the contrary: they are found in groundwater recharge areas. If seepage took place, the relict populations might be replaced by nitrofile vegetation. It is our belief that artificially rewetting dune areas should be abandoned, and rather a stand-still principle of groundwater extraction should be handled. The existing groundwater classes, developed in the Netherlands, should not be used for the evaluation of opportunities for vegetation in the Flemish study area, because of the different abiotic conditions (rainfall, nutrients in soil,...) influencing the ecosystem. On top, in the Netherlands, the groundwater level is managed between 0 and 2 m below ground surface (Knotters and Bierkens, 2001). This artificial groundwater level management is not in use at the Belgian dune area.

There is thus a need for a classification addressing the relation between the groundwater dynamics and ecology, whereby the basis for the evaluation should be valid. Many classifications are developed with a focus on groundwater fluctuations and vegetation. In nature development, the vegetation is not only related to the fluctuations of the groundwater level, but also on other aspects