# Hydrology and restiration of wet heathland and fen meadow communities

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# Summary

This thesis focuses on the restoration prospects of wet heathland ecosystems within the context of their hydrological functioning. In The Netherlands these ecosystems are limited to the Pleistocene landscape, which is often rich in altitudinal gradients, causing a large variation in site conditions within a short distance. Consequently, a variety of vegetation gradients could develop, along which several endangered plant communities may occur, such as dry heathlands (alliance *Calluno-Genistion pilosae*), wet heathlands (alliance *Ericion tetralicis*), small-sedge communities (alliance *Caricion nigrae*), fen meadows (alliance *Junco-Molinion*), communities of soft-water pools (class *Littorelletea*) and dwarf-rush communities (alliance *Nanocyperion*). Moreover, these communities harbour many endangered and protected plant species. Despite their protection as nature reserves, these remnants of wet heathlands suffer from a loss in biodiversity, mainly as a consequence of desiccation, acidification and eutrophication. Therefore, their restoration is urgent from a nature conservation point of view.

The major part of the research has been carried out in nature reserves in the Pleistocene landscape of the Twente region (eastern Netherlands), in which both degraded and well-developed plant communities of wet heathlands occur. Here, recently several measures have been carried out to restore degraded plant communities. In existing nature reserves sod cutting, hydrological measures or their combination have been applied, whereas in a former agricultural field sod cutting down to the original top soil in combination with hydrological measures has been carried out. The successes and failures of these measures are discussed.

Fen meadows are species-rich and characteristic of wet, slightly acid to neutral and low-productive sites. The larger part of the remaining fen meadows has severely deteriorated; nowadays only 30 ha of well-developed fen meadows remain. Therefore, recently several projects were launched to restore damaged fen meadows. In **Chapter 2** the successes and failures of these projects are reviewed in relation to the existing variation in hydrological systems. Seven hydrological system types have been distinguished, which all provide site conditions required by this community. Nowadays, the best developed fen meadows occur in the Pleistocene landscape of The Netherlands, where they are dependent on base-rich groundwater discharging from local or larger groundwater systems. Fen meadows of the low-lying Holocene landscape usually occur in man-made surface water systems; almost all stands have severely deteriorated. Restoration of fen meadows in the Pleistocene landscape is promising when the hydrology is only slightly disturbed or when hydrological measures are taken in combination with sod cutting. Restoration prospects of fen meadows in the Holocene landscape are low. Until now a complete regeneration of fen meadows has not been realised. Restoration measures failed to restore high pH values in the top soil. It is hypothesised that viable seeds of many target species are lacking in the soil seed bank. In addition, the dispersal capacities of these species seem to be limited.

Successful restoration of fen meadows requires (1) water tables that reach the soil surface during at least six months, and (2) discharging base-rich groundwater in the rooting zone (**Chapter 3**). Such conditions are still present in the Lemselermaten. In this nature reserve an eutrophicated fen meadow stand and a site with a former agricultural grassland and an alder carr were sod-cut. Sod cutting of the former agricultural grassland and of the alder carr suffices to restore this plant community, whereas sod cutting of the eutrophicated fen meadow

was not successful. The unsuccessful restoration of the eutrophicated fen meadow is attributed to the prolonged inundation resulting from the sod cutting. The chemical composition of the deep groundwater supplying the reserve has changed from base-rich and sulphate-poor to base-rich and sulphate-rich, due to the increased manure spraying by farmers in the catchment area. This change might have caused a higher nutrient availability in the rooting zone and therefore may have led to the eutrophication and subsequent degradation of the former fen meadow. This change might also negatively influence the restoration prospects of fen meadows on the longer term, when a new organic top soil layer has build up again.

When hydrological mechanisms are heavily disturbed, as in the nature reserve Stroothuizen, restoration of former fen meadows on the sole basis of sod cutting was not successful (**Chapter 4**). This might be due to high phosphorus concentrations in the top soil, which possibly arise from high mineralisation rates as a result of the disturbance of crucial hydrological processes. Under such conditions restoration of fen meadows is only promising when sod cutting is combined with hydrological measures that counter prolonged inundation and reinforce the discharge of base and iron-rich groundwater. Further, the absence of (viable seeds of) characteristic species might hamper complete restoration of the former fen meadow. Sod cutting, however, did result in the restoration of wet heathlands, small-sedge marshes and ephemeral dwarf-rush communities. The combination of sod cutting and hydrological measures, which was carried out in Staverden, a severely deteriorated nature reserve in the central part of The Netherlands, resulted in the restoration of dry heathlands, small-sedge marshes and a species-rich wet heathland. The successful restoration of this heathland type, which has several species in common with fen meadows, indicates that fen meadows can be restored when (1) appropriate hydrological conditions can be re-created and (2) target species still occur in the vicinity of the restored site, as is the case in Staverden.

The nature reserve Punthuizen is characterised by a complex vegetation gradient, in which fen meadows occur in the upslope part of the gradient (**Chapter 5**). The occurrence of fen meadows in Punthuizen is determined by a local hydrological system, the features and functioning of which are described. During the winter season a pool is formed as a consequence of the absence of a superficial outlet. A concentrated flux of base-rich groundwater is brought up at the margin of the exfiltration part of the pool, whereas downstream infiltration takes place. These processes, which cause a variety in site conditions, and consequently also in plant communities, are phenomena of a local groundwater system. A prerequisite for the functioning of such a groundwater system is the presence of pools during the winter season. When summer groundwater tables, which are being determined by regional features outside the reserve, but which determine the origin and the extension of pools, are too low, measures outside nature reserves have to be taken to restore high summer water tables. In addition, successful restoration of degraded fen meadows determined by the local hydrological system requires sod cutting along the entire gradient. Since relatively small height differences can result in groundwater flow, restoring local hydrological systems on former agricultural areas requires first of all restoration of the relief.

In **Chapter 6** the successes and failures of the restoration of endangered plant communities of wet heathland ecosystems are discussed. Measures were carried out both in existing nature reserves and in a former agricultural field in the Twente region. Sod cutting of degraded sites appeared to be successful in the restoration of fen meadows, small-sedge marshes and wet heathlands when groundwater regime and base status of the soil were still appropriate. Sod cutting in combination with hydrological measures led to the restoration of the required site conditions of communities of the class *Littorelletea*, which indeed re-established, both in an existing nature reserve and in a former agricultural field. Hydrological measures improved the quality of small-sedge marshes. Sod cutting of a another degraded wet heathland and a soft-water pool, where formerly the *Isoeto-Lobelietum* occurred, was only temporarily successful, probably as a consequence of too low water tables. Not only could valuable plant communities be restored, but also many endangered species re-established. In addition, restoration was also favoured by the occurrence of many characteristic species in the soil seed bank and by the presence of these species in the proximity of the restored sites. Life-form and growth-form composition of the successfully restored plots were similar to their well-developed references. Hence, by comparing spectra of life- and growth-form composition we are able to trace the origin of failures in restoration projects.

Initially, the abiotic requirements of wet heathland plant communities and the hydrological processes and hydrological system types which provide for these conditions, are thoroughly discussed in **Chapter** 7. Next, criteria for successful restoration of these plant communities are formulated. It appeared to be impossible to define one single objective criterion for successful restoration. Restoration of low-productive plant communities of wet ecosystems requires first of all the re-creation of appropriate site conditions. Inside existing nature reserves, but also on former agricultural fields, the measures applied were often sufficient in restoring suitable site conditions of wet heathland plant communities. Failures are associated with an unsuitable groundwater regime. Moreover, also other factors may hamper complete restoration. The possible absence of mycosymbionts might explain the limited re-establishment of orchid species in restored fen meadows. Opposite to other plant communities of wet heathlands, the major part of the characteristic species of fen meadows has a short-lived soil seed bank type. Many of the latter species have not re-appeared within ten years after carrying out restoration measures. The best results were obtained when restoration measures were carried out in or adjacent to existing, well-developed fen meadows. In existing nature reserves the results of sod cutting as a restoration measure can be improved (1) by removing the organic top soil precisely down to the mineral top soil, (2) when is sod-cut during late summer or early autumn and (3) by maintaining micro-relief. This way of sod cutting prevents the complete removal of the soil seed bank and stimulates the germination of seeds. Species with a short-lived soil seed bank only re-established when they were still present in the reserves. Apparently, these species have limited dispersal capacities. The dispersal of species might be improved by (1) connection of isolated nature reserves, (2) the design of adequate management schemes and - as a last possible measure - (3) re-introduction. A prerequisite for the restoration and sustainable conservation of wet ecosystems is a proper hydrology. The Dutch policy is aimed at the substantial reduction of the area of hydrologically disturbed wet ecosystems. Although wet ecosystems locally have been restored successfully, I doubt whether policy goals on the restoration of these systems will be reached. In nature conservation several restoration strategies have been developed. In my opinion the approach followed in this study is the most adequate one in centuries old, naturally stabile ecosystems of semi-natural landscapes. Although it is an intensive, rather technological and costly one, it showed to be successful. Therefore, the example deserves to be followed.