Long-term vegetation change (1966-2006) on calcium-poor coastal sand dunes in the Netherlands related to nitrogen deposition, and the evaluation of restoration management. Rita Ketner-Oostra & Karlè Sýkora

Abstract. The results of a long-term study reveal disastrous effects of atmospheric nitrogen deposition on biodiversity in calcium-poor dunes. Restoration of lichen-rich sand-dune communities seems to be promoted by in-blowing sand.

Until the mid-1970s the dry coastal calcium-poor dunes on the West Frisian Islands in the Dutch part of the North European coastal dunes were famous for their lichen-rich pioneer grasslands, developed in the course of primary succession in the xeroseries. The greater part of the older dune slopes was covered by a short grassland, dominated by grey hairgrass (*Corynephorus canescens*) and sand sedge (*Carex arenaria*) and rich in the lichen genera *Cladonia* and *Cladina*, the latter called reindeer lichens. These lichen-rich 'grey dunes' were especially well developed on the island of Terschelling. Moreover, lichens that are usually epiphytic, such as *Bryoria fuscensens*, *Evernia prunastri*, *Hypogymnia physodes*, *H. tubulosa*, *Pseudevernia furfuracea* and *Usnea* spp., grew on moss carpets, but also on open sites with only *Corynephorus canescens*. According to Natura 2000, within Europe, the Netherlands has a special responsibility for this habitat type.

Changes in nutrient-poor ecosystems caused by air pollution since the 1970s

Changes in the flora, both of phanerophytes and cryptogams, in dry oligotrophic habitats, have been partly correlated with acidification caused by the high emission of SO_2. That emission declined considerably from the end of the 1970s onwards. However, since then, the increased dry and wet atmospheric deposition of nitrogen (NH_4-N, NO_3-N and organic compounds) has been the main polluting factor throughout the Netherlands as a result of intensified livestock farming, the so-called bio-industry, and industrial output.

In the central part of the country in 1990 the mean nitrogen deposition was 50 kg N ha^{-1} and for the West Frisian islands it was estimated to be 20 kg N ha^{-1}. From 1990 N deposition gradually decreased, to a mean value of 40 kg N ha^{-1} in the central part in 2001, but near areas with high livestock concentrations the N deposition is still high. Nutrient enrichment increases the productivity in nutrient-poor ecosystems, enabling more competitive species to oust species that are characteristic of these ecosystems (Bobbink et al., 1998).

Results of long-term vegetation studies (1966-2006)

The vegetation composition in the 1966-1972 period, a time with a relatively low deposition of atmospheric N, was compared with that in the 1990-1996 period, a time in which the increased deposition had clearly left its mark. The changes in lichen diversity were presented in Ketner-Oostra & Sýkora (2004).

The initial stage of the *Corynephorus*-grassland with mainly pioneer lichen species on slightly decalcified sand, was only present in the 1960s. In the 1990s the early succession stages with *Cladonia* species could still be found, but these were usually accompanied by *Campylopus introflexus*. This neophytic moss is adapted to acid open sand, and invaded both coastal and inland dunes, reducing the area of open sand and the lichen richness in both ecotopes (Biermann & Daniëls, 1997).

In the 1960s, epiphytic lichens were pre-eminently growing terrestrial in the next successional stage. This phenomenon is comparable with epiphytes becoming

terrestrial in other treeless regions, as has been observed at the alpine and arctic timberline. The succession from the *Corynephorus*-grassland to the dune heaths went in the 1960s through a moss-rich stage with *Dicranum scoparium*, which was also very lichen-rich with many *Cladonia* and *Cladina* species, including the normally epiphytic lichens.
In the 1990s, the disappearance of the *Bryoria* and *Usnea* spp. from the *Corynephoru*s-grassland and the severe decline in presence and cover of the *Hypogymnia* spp. were probably mainly a consequence of their intolerance to NH_3, as evidenced by their decline in epiphytic habitats in the Netherlands. The study of the moss-rich succession stages made clear the dominating position of *Campylopus introflexus*. The current expansion of this invasive moss might be one of the aspects of an accelerated vegetation succession.
In the 1960s lichen diversity in the studied plant communities as a whole was very high: 45 lichen species. Nevertheless, in the 1990s we found that when *C. introflexus* was losing vitality through desiccation and/or being covered by green algae, it could act as a substrate for many common humicolous and aero-hygrophytic lichen species. Some pioneer species like *Cetraria aculeata* and *Cladonia foliacea* were also present. All the lichen species mentioned seemed to establish as 'secondary pioneers' on these withering moss carpets (Ketner-Oostra & Sýkora, 2004).
At present, due to grass encroachment, the formerly lichen-rich dune grasslands have been replaced by the community of relatively tall graminoids *Ammophila arenaria – Carex arenaria* with several species of the *Corynephorus*-grassland.

Evaluation of former restoration management in the calcium-poor coastal dunes
Kooijman & Besse (2002) studied the effect of EGM restoration management (Effect-oriented measures against acidification and eutrophication) on the Dutch nutrient-poor grass-encroached stabilized dunes from 1991 untill 1999. Large-scale management in 15 former blow-outs on Terschelling was rather successful, but the duration in which the sand was still blowing seemed restricted. However, on the superficial layer of the accumulated sand a lichen-rich pioneer vegetation established (Ketner-Oostra & Sýkora, 2004). Sand blowing in from foredunes north of Hoorn after shoreface nourishment is maintaining the lichen-rich V.-C. in the older dunes (Ketner-Oostra, 2001).
The effect of a wildfire in 1993 on a vegetation with dominance of tall graminoids was monitored for eight years, using large continuous transects on two dune slopes. These results are compared with those of the same transects in the lichen-rich vegetation in l966 and the vegetation of 1990. After the fire, a lush vegetation of relatively tall graminoids with an abundant moss cover developed. In 2001 the vegetation was still very dissimilar from the lichen-rich vegetation in l966 (Fig.1). It is concluded that fire alone will not change dunes dominated by relatively tall graminoids into open lichen-rich grasslands in an area with heavy aerial nitrogen deposition (Ketner-Oostra et al., 2006).

Conclusion. Burning or removal of the topsoil is not sufficient to regain biodiversity as long as the current N emission still greatly exceeds the critical deposition values for these nutrient-poor ecosystems. The crucial factor to assure the restoration of the former lichen-rich sand-dune communities seems to be in-blowing sand.

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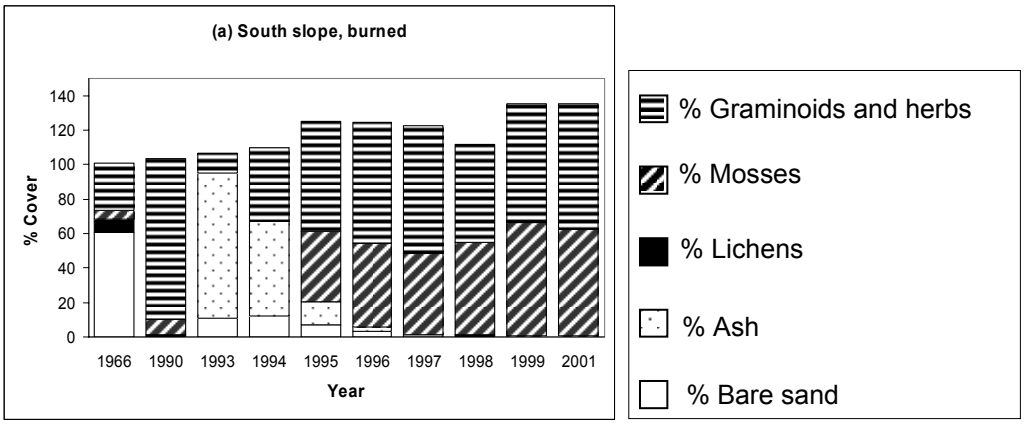

Fig. 1. Changes in cover of different vegetation elements, bare sand and ash (1966-2001). From: Ketner-Oostra et al., 2006.