ASSESSING ECOLOGICAL CHANGE IN EUROPEAN WETLANDS: HOW TO KNOW WHAT PARAMETERS SHOULD BE MONITORED TO EVALUATE THE DIE-BACK OF COMMON REED (*Phragmites australis*)?

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Abstract

When monitoring is applied as an early warning system for undesired changes, well defined parameters are required that indicate changes in their initial phases. In the case of the die-back of common reed (*Phragmites australis*) the causes, especially in relation to eutrophication, are not clear. A project, called EUREED, is sponsored by the Commission of the European Communities to examine the effects of interaction between eutrophication, water table management and temperature on ecophysiological processes in reed plants and biogeochemical processes in the rhizosphere of reed. Changes in these processes due to ongoing eutrophication are strongly supposed to be involved in the die-back of reed stands. Variability within and between reed populations is examined, because it is assumed that populations with limited genetic variability will be more susceptible to environmental stress than populations that are highly variable, or that are already adapted to high nutrient loading. The results will provide basic knowledge on the effect of ongoing eutrophication on the ecosystem stability of reed vegetation under different water table regimes and temperature conditions. The achieved knowledge will be applicable to monitoring, as well as to the management of European reed marsh vegetation.

Van der Putten, W.H.: **Bewertung ökologischer Veränderungen in europäischen Feuchtgebieten: Welche Parameter sollten für das Monitoring von Schilfsterben (*Phragmites australis*) ausgewählt werden?**

Monitoring als Frühwarnsystem für unerwünschte Veränderungen benötigt klar definierte Parameter, welche Veränderungen bereits in der Anfangsphase aufzeigen. Im Fall des Schilfsterbens (*Phragmites australis*) sind die Ursachen, besonders in Zusammenhang mit Eutrophierung, nicht klar. Das von der Kommission der Europäischen Gemeinschaft unterstützte EUREED Projekt untersucht die Effekte von Interaktionen zwischen Eutrophierung, Management des Wasserspiegels und Temperatur auf ökophysiologische Prozesse in Schilfpflanzen und biogeochemische Prozesse im Schilfwurzelbereich. Änderungen in diesen Prozessen aufgrund fortschreitender Eutrophierung dürften ziemlich sicher für das Schilfsterben verantwortlich sein. Die Variabilität innerhalb und zwischen Schilfpopulationen wird untersucht, da angenommen wird, daß Populationen mit begrenzter genetischer Variabilität anfälliger gegen Umweltstressfaktoren sind als hoch variable Populationen oder solche, die sich bereits an hohe Nährstofffrachten angepaßt haben. Die Ergebnisse zeigen die Auswirkungen beginnender Eutrophierung auf die ökologische Stabilität der Schilfvegetation unter verschiedenen Wasserständen und Temperaturbedingungen. Dieses Wissen steht für Monitoringprojekte und für das Management europäischer Schilfgebiete zur Verfügung.

Van der Putten, W.H.: **Hodnocení změny ekologického charakteru evropských mokřadů: Jak víme, které parametry by měly být monitorovány, abychom vysvětlili odumírání rákosu (*Phragmites australis*)?**

Pokud má monitorování sloužit jako časný varovný systém nežádoucích změn, je třeba zvolit takové parametry, které poukáží na změnu v jej počáteční fázi. V případě odumírání rákosu (*Phragmites australis*), jeho příčiny, zejména ve vztahu k eutrofizaci, nejsou známy. Projekt nazvaný EUREED, financovaný Komisí evropského společenství, má za úkol vysvětlit vliv eutrofizace, výšky vodní hladiny a teploty na ekofysiologické procesy rákosu a biochemické procesy v jeho rhizosféře. Předpokládá se, že změny těchto procesů jsou příčinou odumírání porostů rákosu. Je zkoumána proměnlivost uvnitř a mezi jednotlivými populacemi rákosu, neboť se předpokládá, že populace s nižší genetickou variabilitou jsou více citlivé ke stresu než populace, které jsou vysoce proměnlivé anebo již adaptované ke zvýšenému přísunu živin. Výsledky této studie přinesou základní znalost o vlivu eutrofizace na stabilitu ekosystému rákosové vegetace při různém režimu kolísání vodní hladiny a různých teplotách. Dosažené výsledky budou použitelné při dalším monitorování stejně jako pro menedžment rákosin v Evropě.

REED DIE-BACK: SHORT HISTORY

Ecosystem stability of land-water ecotones is based on a balance between the processes of progress and die-back of the dominant plant species. Nearly 40 years ago, the first frequent substantial retreat of reed belts around many Swiss lakes was reported by HÜRLIMANN (1951). In the late 1960s Sukopp, as well as Klötzli published on this subject and in the 1970's, obvious changes in the littoral vegetation became the subject of common concern (OSTENDORP 1989). In 1989 Volume 35 of Aquatic Botany was dedicated to the reed die-back syndrome. Large scale reed die-back has always been observed in areas with humid and cold climate (*i.e.* in Eastern, Central, and Northern Europe). In the hotter and drier Mediterranean area, reed seems to grow vigorously and to expand, even in eutrophicated areas (J. Kvét, pers. comm.). In Denmark and in Scandinavia on the other hand, reed die-back seems to be less of a problem, and reed is even invading new biotopes with relatively low water level, like sea shore meadows, pastures, and shallow watered lakes and ponds (H.-H. Schierup, pers. comm.). In The Netherlands, reed belts around former estuaries that have been locked off from tidal movements during the Delta-works, have been reduced in size (KUIJPERS & VAN STOKKOM 1985). However, the Dutch area of reed as a whole seems to be unaffected, because reed has invaded new shallow wetlands, such as the Oostvaardersplassen nature reserve (J. Van der Toorn, pers. comm.). These observations suggest strongly that the underlying mechanisms of reed die-back may depend on parameters related to the climate, as well as to the water table management.

The possible causes of reed die-back are reviewed by OSTENDORP (1989). Explanations for the die-back syndrome deal with a variety of reasons, from intensified boat traffic causing mechanical damage, to changing management practices and environmental conditions. With respect to environmental changes, eutrophication is the major factor that has altered growing conditions of reed in most wetlands during the last decades. Because of nutrient enrichment the C/N ratio decreases and the stem lignin content becomes less. Hence, it has been supposed that eutrophication increases susceptibility of reed to environmental stress factors such as waves, wind, grazing, and fungal attacks (DEN HARTOG et al. 1989).

Until now, there is little evidence to clarify the causes of the reed die-back syndrome. A whole complex of short-term as well as long-term changes may have changed the dynamic equilibrium of reed belts towards a gradual retreat (OSTENDORP & KRUMSCHEID-PLANKERT 1993).

Nevertheless, there are strong arguments to suggest that the local instability of reed vegetation may be mainly caused by an interaction between eutrophication and two other major environmental factors, *i.e.* water table fluctuations and temperature. Furthermore, restricted genetic variation within reed populations may be an important constraint of adaption to the dramatic changes in nutrient availability that have occurred during the last decades (NEUHAUS et al. 1993).

Review of literature and expert opinions has lead to five working hypotheses, that are being tested by a multidisciplinary project group (called EUREED), which is sponsored by a research grant from the Environment Programme of the Commission of the European Communities.

EUREED:

This is a project of the European Community to examine the mechanisms of reed die-back in relation to some major environmental factors

The hypotheses examined in the EUREED project group are:

1. Eutrophication causes an imbalance in carbon and nutrient cycling within the reed plants. Especially the uptake of high amounts of nitrogen may disturb the storage of carbohydrates in the rhizomes, which makes the plants more susceptible to unpredictable events like grazing, flooding, insect damage or wave action.

2. Eutrophication reduces gas flow in the reed plants because of reduced aerenchymatous gas space, and it enhances anoxia in the root tips because increased root wall permeability stimulates leakage of oxygen. In combination with critical depths or sudden rises in water level the reed plants may suffer temporarily from anoxia, which will lead to death of living plant parts. In response to wounding and senescence, reed rhizomes and culms readily produce callus which blocks aeration pathways. Volatiles released from dying or decaying regions may induce callus formation elsewhere leading to increased gas-flow resistance, further anoxic damage, and premature stimulation of bud growth, the latter causing a depletion of the rhizomes.

3. Because clonal expansion of reed dominates over establishment from seeds, genetic variation within reed populations will be restricted. The plants, therefore, cannot adapt adequately to site conditions that have changed relatively fast during the last decades, although there may be genetic variation among populations for the trophic status of the site. Both establishment of reed from seeds and seed dispersal of one population to another will be limiting the adaptative capacity of reed.

4. Eutrophication stimulates biomass production which results in an increase of litter production. Depending on the water table regime and the decomposition rate of the litter, the oxidation-reduction potential in the root zone may be reduced, which will lead to adverse soil conditions or compounds that are toxic for the plant roots.

5. Eutrophication may lead to superfluous availability of nitrogen for reed growth if there is an imbalance in the input of nitrogen into the soil system and bacterial transformation of nitrogen to gaseous products. These bacterial processes may depend strongly on water table management, soil temperature, and numbers and characteristics of nitrifying and denitrifying bacteria.

BACKGROUND INFORMATION FOR THE HYPOTHESES OF EUREED

Recent studies make clear that the reed dieback syndrome can be caused by a disturbed carbon/nutrient balance in the plants (CÍZKOVÁ-KONCALOVÁ et al. 1992, KÜHL & KOHL 1992). This can especially be caused by superfluous supply of nitrogen (MARSCHNER 1986, CHAPIN *et al.* 1990, KONCALOVÁ 1990, KONCALOVÁ et al. 1993). In a rhizomatous plant, like reed, the storage of carbohydrates in the rhizomes is essential for emergence of new shoots after the above-ground biomass has disappeared. Such emergence is required in spring, but also after catastrophic events, such as grazing, destruction of shoots by waves, and lodging. If the pool of stored carbohydrates becomes depleted or exhausted, there is a likelihood that the reed would fail to survive particularly in stressed situations. Stress may be caused by e.g. a high, or a suddenly increased, water table, so that the plants will be forced to generate energy from fermentation in order to elevate new shoots to a level where photosynthesis can take place (BARCLAY & CRAWFORD 1982, BRÄNDLE 1985). The reed die-back syndrome usually begins with a retreat from deep water (OSTENDORP 1989), which supports the possible explanation of die-back by exhaustion of carbohydrates.

The reason why reed die-back does not occur in a relatively warm climate may be related to the soil biogeochemical processes, which determine the availability of nitrogen for the reed plants. Under optimal conditions, in non-eutrophicated sites, a large part of the mineral nitrogen in the soil is converted to gaseous products such as NO, N_2O and N_2 (SMITH & TIEDJE 1979, BOWDEN 1987, REDDY et al. 1989). However, when the input of nitrogen exceeds the potential activities of these bacteria, the nitrogen content of the soil will increase, leading to superfluous uptake of nitrogen by the reed plants. By exudation of carbon and release of oxygen, plant roots affect the activity of the microflora in the rhizosphere being involved in the cycling of nitrogen. The size and the composition of the nitrifying and denitrifying bacterial community in the rhizosphere of wetland plants is dependent on the combined inputs of nitrogen, carbon and oxygen in the soil ecosystem as well as on the prevailing temperature. High inputs of carbon might stimulate ammonium production from nitrate in the sediments at the expense of denitrification, *i.e.* losses of gaseous nitrogen. Increased temperature will most likely accelerate the production of gaseous nitrogen products.

Another important consequence of a relatively cold climate is a low turn-over rate of litter which, consequently, accumulates in the sediment. The growth of reeds can be poor in substrates rich in its own litter (VAN DER PUTTEN 1993). Poor growth of reed in its own litter could not be clarified by a shortage of nutrients or by reduced oxidation-reduction potentials. However, since the decay of reed tissue leads to the production of high concentrations of volatile phytotoxines, such as butyric acid, volatile compounds may be involved in poor reed growth at sites where litter accumulates (W. Armstrong and J. Armstrong, pers. comm.). Volatile acids can be transported rapidly via the convective gas-flow path in the plants, so that they may be disadvantageous at all growing points. The adverse conditions caused by litter should be considered as a possible contribution to the reed die-back syndrome, because eutrophication enhances productivity of reed stands which, in its turn, stimulates the production of litter. If more litter accumulates in cold areas than in warm areas, the disadvantageous effect of litter will be more apparent in central and northern Europe than in southern Europe. In cold areas there may be differences between areas with tidal fluctuations and stagnant water levels, as litter rarely accumulates in tidal areas.

Reed cannot survive constant anoxia and an extensive aerenchymatous system provides the plants with an aeration system that enables growth under waterlogged conditions (ARMSTRONG 1978, BRÄNDLE & CRAWFORD 1987, ARMSTRONG & ARMSTRONG 1988). Eutrophication may directly or indirectly lead to reduction of oxygen supply in the growing points of rhizomes and roots. A direct effect of eutrophication may be the reduction of the aerenchymatous gas space within the plants, as this was found to be association with nutrient enrichment in certain *Carex* species (KONINGS & VERSCHUREN 1980, KONCALOVÁ 1990, JUSTIN 1990). Indirectly, eutrophication could lead to anoxia in the below ground growing points of reed, because the increased production of litter may result into an increase of decomposition activity in the soil compartment. When more organic matter can be decomposed by soil bacteria, the demand of oxygen in the rhizosphere will increase, which could enhance radial loss of oxygen from the roots via the permeable root walls. Such loss of oxygen could contribute to the occurrence of anoxia in the growing points if it becomes extensive (W. Armstrong, pers. comm.). If the rhizosphere will not be oxygenated, anaerobic bacteria will become dominant and the oxidation-reduction potential of the soil decreases. Under such conditions phytotoxines may be produced during microbial decomposition (PONNAMPERUMA 1984, LAANBROEK 1990).

As a conclusion, nutrient enrichment of the reed biotope by eutrophication may have various negative effects on reed physiology, which seem to contribute to the die-back of reed stands, *i.e.*: a reduced storage of carbohydrates in the rhizomes, disturbing of the gas flow within reed plants by a reduced development of aerenchymatous gas space and other anatomical changes (callus formation and increased root wall permeability) within the plants, a reduced denitrification resulting in an increased nitrogen accumulation, an increase of radial oxygen losses in the roots, and an increased litter accumulation in the sediment leading to adverse growing conditions. The absence of reed die-back in southern Europe may be due to a greater turn-over rate of the produced litter and to higher bacterial release of gaseous nitrogen from sediment of the reed stands. It could be that tidal water movements in the colder parts of Europe may be beneficial for reed performance, because the litter is removed constantly and soil processes will be stimulated by the cycles of wetting and drying of the sediment.

As reed occurs in a variety of wetland habitats, there will be genetic variability among populations. BJÖRK (1967) showed quite some variation on the ploidy-level (see also GRIME et al. 1988) and KÜHL & NEUHAUS (1993) found variation at DNA-level between clones within populations. However, experimental data on adaptation of reed to the trophic status of the site are lacking. Because after establishment reed usually propagates by clonal spreading, genetic variability within populations will be limited as compared to that between populations. Pilot studies have shown that reed die-back may be associated with a limited genetic variability within populations (J.-G. Kohl pers. comm.). More extensive studies are required in order to verify these preliminary results, and it should be examined whether reed will be genetically variable with respect to the trophic status of the site. Such information is required in order to assess the possibility to restore reed belts by improving genetic variability of the populations.

MONITORING OF WETLANDS IN RELATION TO THE DIE-BACK OF REED

Until now, many examples of observations, field measurements and distribution patterns on sequential airborne images show that *P.australis* is dying back from sites where it was vigorous some years or decades ago. A number of scientists have warned for the retreat of reed, a number of symposia have been dedicated to this subject and measurements for the restoration of reed belts have been suggested (OSTENDORP & KRUMSCHEID-PLANKERT 1993).

However, when monitoring should be regarded as an early warning system (see the contribution of KVĚT & FINLAYSON to this volume) it is questionable whether the case study of the die-back of reed is such a good example. Instead of receiving signals when part of the reed belt has already declined, it would be better to demonstrate which reed stands are susceptible to dying back. Useful parameters to indicate the latter are virtually absent. There are two reasons. First, it is very difficult to prove that a dynamic equilibrium is disturbed Long-term measurements are required to detect trends that can be verified statistically. Second, we do not understand how the ecophysiological, genetical, and soil microbial background affect the dynamics of reed, especially its die-back. When these processes become clarified, which is the aim of the EUREED project, the results can be used

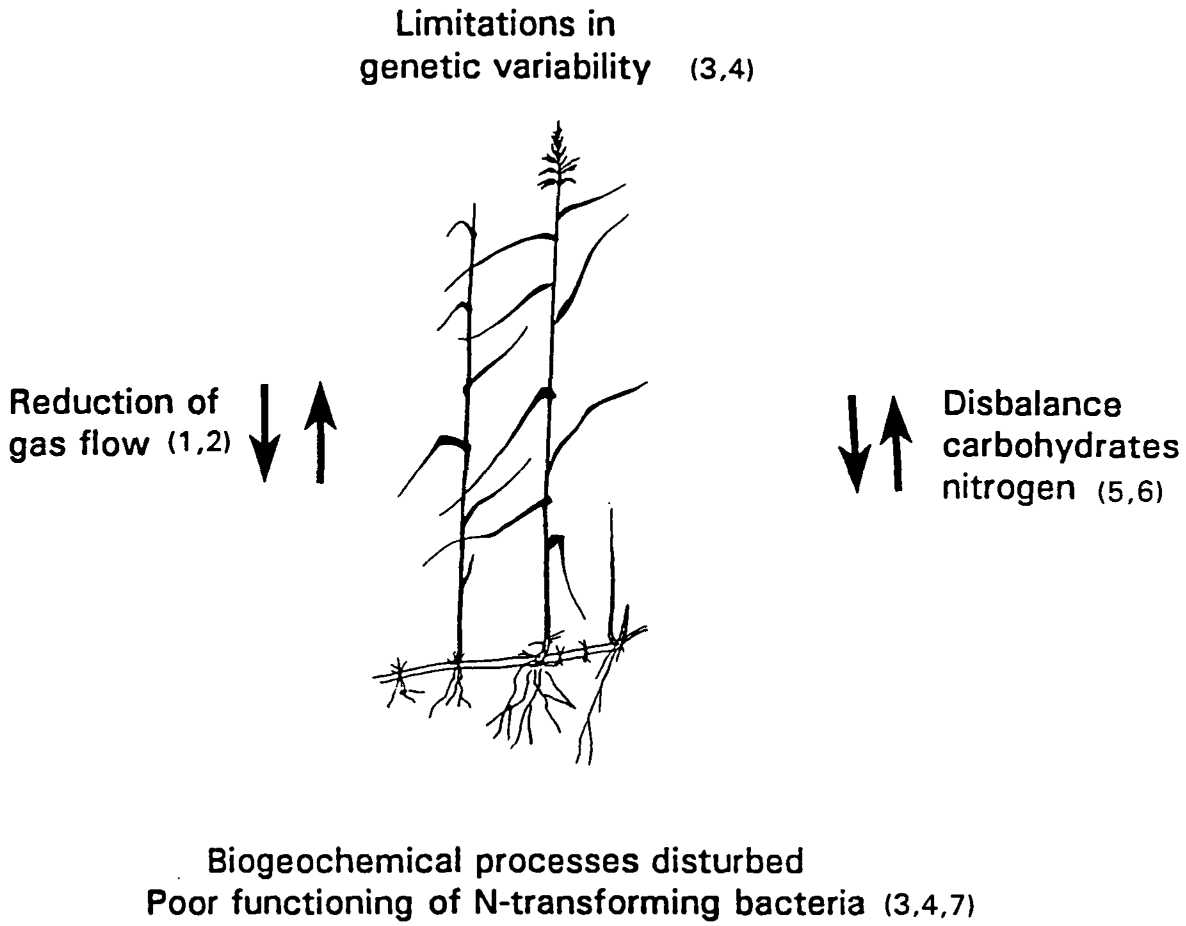

Fig.1. Organisation of research expertise of the participants of the EUREED project. The numbers refer to the participants:

1 University of Hull, Dept. of Applied Biology, Hull, England.
2 Institute of Biology, Dept. of Plant Ecology, Aarhus University, Risskov, Denmark.
3 Humboldt Universität zu Berlin, Institut für Ökologie, Berlin, Germany.
4 Netherlands Institute for Ecological Research, Heteren, The Netherlands.
5 Botanical Institute, Department of Hydrobotany, Trebon, Czech Republic.
6 Institute of Ecology and Botany of the Hungarian Academy of Sciences, Vacratot, Hungary.
7 Department of Biology, University of Évora, Évora, Portugal

to design monitoring strategies for early warning, as well as to develop effective management strategies. The results of EUREED may be important for other wetland species as well, because what is happening to *P. australis* may have happened to endangered wetland species already and may happen to other wetland species in the future.

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