University of Groningen

The state of the art of aquatic and semi-aquatic ecological restoration projects in the Netherlands

Nienhuis, P H; Bakker, J P; Grootjans, A P; Gulati, R D; de Jonge, V N

Published in:
Hydrobiologia

IMPORTANT NOTE: You are advised to consult the publisher's version (publisher's PDF) if you wish to cite from it. Please check the document version below.

Document Version
Publisher's PDF, also known as Version of record

Publication date:
2002

Link to publication in University of Groningen/UMCG research database

Citation for published version (APA):
Nienhuis, P. H., Bakker, J. P., Grootjans, A. P., Gulati, R. D., & de Jonge, V. N. (2002). The state of the art of aquatic and semi-aquatic ecological restoration projects in the Netherlands. *Hydrobiologia*, *478*(1-3), 219-233.

Copyright
Other than for strictly personal use, it is not permitted to download or to forward/distribute the text or part of it without the consent of the author(s) and/or copyright holder(s), unless the work is under an open content license (like Creative Commons).

The publication may also be distributed here under the terms of Article 25fa of the Dutch Copyright Act, indicated by the “Taverne” license. More information can be found on the University of Groningen website: https://www.rug.nl/library/open-access/self-archiving-pure/taverne-amendment.

Take-down policy
If you believe that this document breaches copyright please contact us providing details, and we will remove access to the work immediately and investigate your claim.

Downloaded from the University of Groningen/UMCG research database (Pure): http://www.rug.nl/research/portal. For technical reasons the number of authors shown on this cover page is limited to 10 maximum.

Hydrobiologia **478:** 219–233, 2002.
P.H. Nienhuis & R.D. Gulati (eds), Ecological Restoration of Aquatic and Semi-Aquatic Ecosystems in the Netherlands (NW Europe).
© 2002 *Kluwer Academic Publishers. Printed in the Netherlands.*

The state of the art of aquatic and semi-aquatic ecological restoration projects in the Netherlands*

P.H. Nienhuis[1,3], J.P. Bakker[2], A.P. Grootjans[2], R.D. Gulati[3] & V.N. de Jonge[4]
[1]*Department of Environmental Studies, Faculty of Science, University of Nijmegen, P.O. Box 9010, 6500 GL Nijmegen, The Netherlands*
[2]*Laboratory of Plant Ecology, University of Groningen, P.O. Box 14, 9750 AA Haren, The Netherlands*
[3]*Centre for Limnology, Netherlands Institute of Ecology, Rijksstraatweg 6, 3631 CA Nieuwersluis, The Netherlands*
[4]*Department of Marine Biology, University of Groningen, P.O. Box 14, 9750 AA Haren, The Netherlands*

Abstract

The Netherlands are a small, low-lying delta in W. Europe (42 000 km^2; 50°–54° N; 3°–8° E), mainly consisting of alluvial deposits from the North Sea and from the large rivers Rhine and Meuse. The country was 'created by man'. The conversion of natural aquatic and terrestrial ecosystems into drained agricultural land was a major cultural operation over the past 1000 years. Roughly 55% of the country's surface area is still agricultural land. Some decades ago, The Netherlands' landscape was characterised by an armoured coastline and bridled estuaries, a drastically reduced area of saline and freshwater marshes, fully regulated rivers and streams, and numerous artificial lakes. The aquatic ecosystems beyond the influence of the large rivers, the Pleistocene raised bogs and moor lands, have almost been completely annihilated in the past. Acidification and eutrophication led to the deterioration of the remaining softwater lake vegetation. Last but not least, an artificial drainage system was constructed, leading to an unnatural water table all over the country, high in summer, low in winter. Only very recently, some 25 years ago, the tide has been turned and ecological rehabilitation and restoration of disturbed ecosystems are in full swing now, enhanced by the European Union policy to set aside agricultural land in the Netherlands in favour of the development of 'nature'. The state of the art of aquatic and semi-aquatic ecological restoration projects in the Netherlands is given. Starting from the conceptual basis of restoration ecology, the successes and failures of hundreds of restoration projects are given. Numerous successful projects are mentioned. In general, ecological restoration endeavours are greatly benefiting from progressive experience in the course of the years. Failures mainly occur by insufficient application of physical, chemical or ecological principles. The spontaneous colonisation by plants and animals, following habitat reconstruction, is preferred. But sometimes the re-introduction of keystone species (e.g. eelgrass; salmon; beaver) is necessary in case the potential habitats are isolated or fragmented, or when a seed bank is lacking, thus not allowing viable populations to develop. Re-introduction of traditional management techniques (e.g. mowing without fertilisation; low intensity grazing) is important to rehabilitate the semi-natural and cultural landscapes, so characteristic for the Netherlands. For aquatic ecosystems proper (estuaries, rivers, streams, larger lakes) the rule of thumb is that re-establishment of the abiotic habitat conditions is a pre-requisite for the return of the target species. This implies rehabilitation of former hydrological end geomorphological conditions, and an increase in spatial heterogeneity. The 'bottom-up' technique of lake restoration, viz. reduction in nutrient loadings, and removal of nutrient-rich organic sediment, is the preferred strategy. The 'top-down' approach of curing eutrophicated ecosystems, that is drastic reduction of fish stock, mainly bream, and introduction of carnivorous fish, may be considered as complementary. For semi-aquatic ecosystems (river-fed and rain-fed peat moors, brook valleys, coastal dune slacks) it also counts that the abiotic constraints should be lifted, but here the species-oriented conservation strategy, the enhancement of the recovery of characteristic plant and animal species, is mainly followed. An important pre-requisite for the rehabilitation of the original natural or semi-natural

* NIOO Contribution no. 3054.

vegetation is the presence of viable seed bank. Restoration of salt-marsh vegetation has to deal with a short-lived persistent seed bank, which means that transport of seeds by water currents is important. Isolated softwater ecosystems may rely on the long-lived seeds of the aquatic macrophytes. The paper ends with some notes on the predictability of the outcome of ecological restoration measures and the societal position of restoration ecology as a science. Scientists hold different views on the predictability of restoration measures. A fact is that the predictability of ecosystem development increases, with increasing knowledge of the underlying environmental processes.

Keywords: restoration ecology, ecological rehabilitation, ecological restoration, aquatic ecosystems, semi-aquatic ecosystems, semi-natural landscape, successes, failures, predictability, The Netherlands

Introduction

A unique feature of this book is that it does not artificially separate the aquatic ecosystems and terrestrial ecosystems, as generally encountered in the classical textbooks on ecology. This is more so because many shallow water bodies in the Netherlands mainly show their aquatic status during winter, and their terrestrial status mainly during summer. During the larger part of the year, the plant and animal communities form wetland ecosystems proper, being either partly and temporarily dry or wet. These seasonally changing hydrological characteristics demand many adaptations to the environment of both terrestrial and aquatic plants and animals. The inundation of land results in either water logging of the soil or partial or complete submergence of the shoots of plants, which necessitates for the organisms to possess an 'amphibious' behaviour. Living amphibiously is not usually associated with plants, yet there are many species of higher plants living both on land and in water, and aquatic plants proper that have to adapt to the reverse strategy. The wet–dry ecotone, so characteristic of shallow aquatic systems in the Netherlands, offers an array of interesting ecological problems that need to be overcome, using physiological adaptation strategies. These consist of acclimatisation to flooding and oxygen shortages in non-wetland plants, resulting in increased carbohydrate levels in plant tissues, and the rhizome anoxia tolerance and habitat specialisation in wetland plants (Blom, 1999). Among animals these temporal fluctuations in water levels have led to interesting niche differentiation and colonisation strategies.

There are three major factors to be mentioned that altered the original, natural situation of aquatic ecosystems in the Netherlands. (1) The mild temperate and coastal climate governing the seasonal changes in the Netherlands has led to a hydrological regime of relatively lower water tables in summer and higher water levels during winter. These natural water level changes have been disturbed by management actions of man over the past 1000 years or so. Especially during winter, the water tables are artificially kept to a level as low as possible, in order to facilitate accessibility of low lying grounds early in spring for agricultural use. Another aspect is the general lowering of the water tables by water distraction for manifold purposes, such as drinking water and water for industrial purposes, facilitated by a complicated artificial drainage system, covering the entire country. (2) The conversion of natural aquatic ecosystems into drained agricultural land was a major cultural operation over the past centuries. Inaccessible wetlands and marshes were considered as 'wasteland', and were cultivated. In 1996, the total area of the Netherlands was 41 500 km^2, of which 57% was agricultural land, and 18% was open water; built-up area and infrastructure comprised 11%. The tendency is now to set aside agricultural land, and to increase the total area of (semi-) natural land from 11% now to 17% in 2018 (RIVM, 1999). (3) Compared with the natural and the semi-natural situation massive habitat loss took place, both qualitatively, i.e. the complete disappearance of specific habitats, and quantitatively, the strong decrease in surface area of remaining habitats, owing to numerous causes. The most obvious causes are the regulation of rivers and water courses, the reclamation of wetlands for infrastructure and urban sprawl, pollution with persistent and toxic chemicals, acidification by atmospheric deposits, eutrophication by enriched river water, desiccation (see argument 1), and fragmentation of habitats.

Only very recently, arbitrarily some 25 years ago, there is a marked improvement in the Netherlands in the ecological rehabilitation and restoration of disturbed ecosystems. In this paper, the status of Dutch aquatic restoration projects is given. It is meant as a synthesis of the ten separate papers covering most of the aquatic ecosystems. The paper starts with a historic overview of human impact on, and decline of

Dutch aquatic ecosystems. The conceptual basis of restoration ecology is given, followed by the successes and failures of Dutch restoration projects. It ends with some notes on the predictability of the outcome of ecological restoration measures and the societal position of restoration ecology as a science.

History of human impact

The pristine coastal environment of the Netherlands, i.e. before human impact, was dominated by a continuous sea-level rise since the last glacial period, roughly 10 000–15 000 years ago. During the development of the current landscape of the Netherlands, we may discern three periods: the natural period, the semi-natural period and the cultural period (Bakker & Londo, 1998). The natural period is characterised by the dominance of communities, landscapes and processes without any noticeable human impact. The major patterns in the landscape were largely determined by geological and hydrological factors. Large raised bogs and river-fed peat bogs were formed. Grazing and browsing took place by indigenous herbivores. The rivers and brooks may have shifted their positions several times, as most peat deposits are older than the existing bed of the small rivers. Large aeolian dunes sometimes blocked the course of a river, which then forced its way through sandy ridges, and finally to the sea.

The semi-natural period started when the first agricultural invasion took place about 7000 BP, followed by a second one around 4600 BP. The human tribes grew arable crops in a shifting cultivation system after the clearance of primeval forests. For the greater part, livestock gradually replaced indigenous large herbivores. In medieval times degradation and destruction of the primeval forests continued and large oligotrophic bogs, mesotrophic fens and eutrophic reed swamps were drained, reclaimed and in some places the peat was completely removed for fuel (Grootjans et al., 2002A).

A palaeographic reconstruction of the area of wetlands, some 42 000 km^2, later called 'The Netherlands', roughly 2300 years ago (van Staalduinen et al., 1979) shows wide and unbridled river valleys with freely meandering river branches and floodplains, comprising freshwater marshes and swamp forests, and debouching in an area of fens and peat moors, and closer to the North Sea coastal marshes beyond or under tidal regime. Until about 1000 BP, man lived on the higher grounds beyond the impact of sea- and river-floods, and hardly touched these vast and inaccessible wetlands. During the 11th century, man began to invade the fertile floodplains, and to reclaim wetlands for agriculture, followed by systematic embankment of vast areas.

In the coastal area, dominated by impact from the sea, once the transgression slowed down, some thousands years BP, the salt marshes became suitable for livestock grazing. After further sedimentation, the area became suitable for arable field, and later for permanent settlement. When salt marshes were accreted to dry land, they were embanked if this was economically feasible, and transformed into intensively exploited agricultural land. The reclaiming of land from the sea became a tradition, that would last roughly 1000 years in the Netherlands. Consequently, due to continuous embankments, the present salt-marsh area along the coast of the Netherlands is rather small relative to the surface area of the tidal basins (Bakker et al., 2002).

The start of the cultural period is characterised by intensified human exploitation of all natural ecosystems in the Netherlands. The intensive and exponential human use of European rivers, and among them the Rhine and Meuse catchments covering two-thirds of the country, started more than 500 years ago. Following this the basins lost, step by step, their naturalness and thus also their ecological integrity. The rivers were canalised for the purpose of navigation and regulated by weirs and sluices for water resource control and flood defence, habitats were fragmented and floodplain land was reclaimed for urban and industrial purposes. The basins were treated as sewers carrying waste and drainage away from the urban environment. From the early 1900s, major dam building activities started for both hydroelectric power and drinking water supply (Nienhuis et al., 2002).

In addition to the larger rivers, the lowland streams are the most threatened ecosystems. About 96% of the numerous Dutch brooks and streams are directly impacted by human activities, through changes in the length and transversal profile owing to the canalisation works, through alterations in the discharge pattern, water level, water extraction and drainage, by construction of weirs and other artificial construction works. Changes in the profile and the hydrology of the streams have led to an increase in discharge fluctuations and in the erosive capacities of the streams (Verdonschot & Nijboer, 2002).

Concerning the semi-aquatic and terrestrial ecosystems, the large-scale reclamation and subsequent fertilisation of common grassland and heathland occurred in the early 20th century, when mechanisation in agriculture started. It resulted in the development of the cultural landscape, in which not only the landscape but also the flora and fauna became heavily influenced by man. Indigenous species were eradicated by herbicides and non-indigenous species were introduced (Grootjans et al., 2002a).

The extensive ombrotrophic raised bogs and the minerotrophic peat bogs, mainly formed during the natural and the early semi-natural periods, were heavily exploited during the cultural period, and this process only very recently came to an end. Less than 5% of the original elevated peat-moors are still existing in the Netherlands. The remaining oligotrophic pools in these peat-moors suffer from environmental pollution. Acidification and eutrophication are widely accepted as important factors involved in the decline of softwater lake vegetation in Western Europe. In the 20th century, over 90% of the remaining habitat of Atlantic softwater macrophytes of the Netherlands has locally disappeared because of acidification or eutrophication. In many softwater lakes, precipitation of atmospheric nitrogen compounds above the critical level of 5–10 kg N ha^{-1} yr^{-1} has caused acidification and the accumulation of ammonium. The emission levels of nitrogen compounds in the Netherlands still remain high (Roelofs et al., 2002).

In the Netherlands, the nature of minerotrophic peatland areas has been strongly shaped by the extraction of peat, creating a distinctive pattern of turf ponds (called '*petgaten*' in Dutch), and baulks ('*legakkers*') onto which the extracted peat was deposited to dry. Many of these dams were blown away by storms, thus creating large shallow lakes called broads ('*wieden*'). Numerous former smaller turf ponds gradually became dry land, and the present vegetation is strongly dependent on the type of management. The typical Dutch peatland type, a semi-natural landscape created by anthropogenic activity, comprises many species-rich plant communities and offers an important habitat to waterfowl (Lamers et al., 2002).

The wet dune slack environment holds a special position in the Netherlands, as it is one of the very few natural ecosystems that may emerge during the wind-generated process of dune removal or dune formation. Large scale disturbances of dune slack environments along the Dutch coast started around the mid 1850s, when the vast stock of fresh and good quality dune water became a major source of drinking water production for the large cities. The exploitation of dune water resulted in a lowering of the water table by 2–3 m on average. Lowering of the groundwater levels in the adjacent polder areas, reclamation for agricultural use and afforestation of the dunes with pine plantations were additional factors that contributed to a dramatic decline of wet dune slacks along the Dutch coast. In a later stage surface water from the rivers Rhine and Meuse was infiltrated to serve the ever-increasing demand for drinking water. This input of polluted river water led indeed to elevated water tables in the dune slacks, but at the same time promoted eutrophication (Grootjans et al., 2002b).

There is an old saying: 'God created the world, but the Dutch made their own country'. The question is, whether we should be proud to have shaped our own country. In ecological terms the Netherlands comprise fully regulated rivers and streams, numerous artificial lakes, annihilated raised bogs, an armoured coastline and bridled estuaries, a drastically reduced area of saline marshes, and last but not least, an artificial drainage system and an unnatural water table all over the country: high water levels in summer, and low in winter. Only very recently has the tide been turned (see section '*Ecological restoration: successes and failures*').

Decline of aquatic and semi-aquatic ecosystems

The historical decline of Dutch aquatic ecosytems has now sufficiently been documented in the previous sections. The Lower Rhine and Meuse catchments cover two-thirds of the country. They comprise man-dominated, strongly regulated rivers and streams, including the estuarine stretches, polluted water and sediments, and annihilated and deteriorated ecosystems. In Dutch lakes, eutrophication had resulted in massive blooms of Cyanobacteria, causing light limitation and disappearance of macrophytes and of some species of herbivorous Crustacea. Aquatic bird populations decreased dramatically and bream (*Abramis brama*) became the dominant fish species. The aquatic ecosystems beyond the influence of the larger rivers, the Pleistocene raised bogs and moor lands, have almost been completely annihilated in the past. Acidification and eutrophication have been responsible for the deterioration of the remaining softwater lake vegetation and zooplankton (Gulati & van Donk, 2002; Roelofs et al., 2002).

We recall here only some recently investigated, and less know facts on the river-fed peat bog ecosystems, so characteristic for the Netherlands. In fact almost all river-fed surface waters in the Netherlands, including shallow lakes, ditches and ponds suffer from a number of complex problems (Lamers et al., 2002). The major environmental problems in Dutch aquatic and semi-terrestrial river-fed peatbog systems (fens) are: desiccation, (internal and external) eutrophication, acidification, habitat fragmentation and intoxication. The primary cause for the loss and degradation of fens is desiccation caused by drainage. Land reclamation, the construction of numerous channels and ditches, and the lowering of surface water levels and groundwater tables have led to the severe desiccation of wetlands. In many wetlands, groundwater tables have dropped from a few decimetres to up to more than 1 m in recent decades.

The eutrophication of surface and/or groundwater poses another severe threat to wetlands. The nutrient influx from agricultural areas and sewage has led to a marked increase in the availability of PO_4^{3-} and NO_3^-. To compensate for the shortage of water in nature reserves and agricultural areas, water from the rivers Rhine and Meuse is (directly or indirectly) used on a large scale. Moreover, this river water is characterised by relatively high concentrations of sulphate because of the natural weathering of sulphate containing rocks, anthropogenic dumping and sulphur runoff from agricultural areas. Groundwater and surface water are sulphate-enriched by desiccation and by NO_3^- pollution.

According to Lamers et al. (2002), a much less known causal factor for the deterioration of fens is the enforcement of highly stable water levels. In more natural situations, as in the past, water levels fluctuated throughout the year, being lower in the summer and higher during winter. Current water level regimes in the Netherlands tend to be the opposite: lower winter levels to enable rapid runoff of access water from agricultural land, and relatively high and stable summer levels provide water for growth and evapotranspiration. In most cases, this unnaturally high summer level can only be maintained when allochthonous river water is used. This often leads to internal eutrophication because of enrichment with bicarbonate and sulphate.

Most peatlands along small streams and brooks are fed by a combination of groundwater and surface water, particularly in the Pleistocene parts of the Netherlands. The semi-terrestrial brook valley meadows, traditionally wet in winter and dry in summer, have suffered from anthropogenic impacts. The large-scale reclamation of adjoining heathlands also led to many short cuts in the hydrological cycle, which increased flooding of meadows in the middle- and lower courses of the brook valleys after heavy rainfall. This in turn led to large-scale interference with the apparent hydrological conditions. It often resulted in the complete disappearance of all natural watercourses and in deep drainage of all peat soils. This resulted in subsidence of the peat, increased mineralisation, eutrophication of surface water, replacement of calcareous groundwater by rainwater, and subsequent acidification of the topsoil. All aforementioned processes resulted in a dramatic decrease of species of the former semi-natural landscape. Many plant species became endangered and were restricted to marginal environments in a fragmented landscape (Grootjans et al., 2002a).

Ecological restoration: concepts and theory

The literature

Why should restoration ecology bother about having a conceptual base to work from? It has been pointed out repeatedly that ecological restoration has been, and continues to be, practiced widely without apparent recourse to any background conceptual framework (Allen et al., 1997; Palmer et al., 1997). On the other hand, the practitioners have identified a need for a firm ecological foundation for developing and implementing restoration projects. In addition, it is becoming increasingly apparent that the assumptions underlying many restoration projects have their roots in outdated concepts of how ecological systems function (viz. theories on stability and equilibrium state of ecosystems following disturbance). Hobbs & Harris (2001) held a plea for an ongoing dialog between the conceptual and on-ground aspects of restoration ecology. In their vision, we need to have an up-to-date and comprehensive conceptual framework to provide a context for the activities of restoration ecologists. Setting clear and achievable goals is essential, and these should focus on the target characteristics for the system in the future, rather than on an idealized reference image from the past.

An interesting concept worked out by Hobbs & Harris (2001) is the restoration threshold concept. A general feature of many systems seems to be the potential for the system to exist in a number of different states, and the likelihood that restoration thresholds exist, which prevent the system from returning to a less-degraded state without the input of management effort. The concept was already formulated earlier by Hobbs & Norton (1996), who illustrate their theory with the example of woodlands, currently degraded by grazing, which may recover and regenerate simply by excluding stock. On the other hand, if the system has exceeded a threshold value, removing the degrading influence will not be sufficient to allow transition back to a state suggestive of the original one. For instance, if the grazed woodland is heavily invaded by weeds and the soil structure is altered, exclusion of grazing will not be adequate to promote woodland recovery, and more severe management measures would be needed.

The best known aquatic examples from the Netherlands are described by Scheffer et al. (1993) who group the shallow lakes on the basis of one of the two stable states in which these lakes may find themselves in: the clear-water stage with dominance of submerged macrophytes, benthic diatoms, zooplankton and carnivorous fish, and the turbid-water state with dominance of phytoplankton, especially Cyanobacteria, and of planktivorous/benthivorous fish. The removal of bream from eutrophicated and turbid freshwater bodies, may rehabilitate the lake to its original clear-water situation with aquatic macrophytes. We also know that the reduction of bream standing crop does not always lead to the target situation. Moreover, this grouping of lakes with extreme under-water light characteristics is based on the turbid lakes, which during the restoration process exhibit intermittent periods of improved light climate and increased littoral vegetation rather than a stable situation over several consecutive years (Gulati & van Donk, 2002).

Another example to illustrate the restoration threshold concept is the removal of the accumulated organic sapropelium layer from softwater bodies, in order to restore the original macrophyte vegetation. But again, this recipe does not always work, because oxidation of the sandy sediment and a process of oligotrophication are pre-requisites for the development of the waterplants (Roelofs et al., 2002). In other words, the restoration threshold concept seems theoretically sound, but in practice many of the Dutch ecological restoration projects have gone along a pathway of trial and error: learn from the failures and try to understand the rationale behind the successes.

Whisenant (1999) has suggested that two main types of restoration thresholds are likely: one that is caused by biotic interactions, and the other caused by abiotic limitations. If the system has degraded mainly due to biotic changes (such as grazing-induced changes in vegetation composition), restoration efforts need to focus on biotic manipulations which remove the degrading factor (e.g. the grazing animals) and adjust the biotic composition (e.g. replant target species). If, on the other hand, the system has degraded due to changes in abiotic features (such as through soil erosion or contamination), restoration efforts need to focus first on removing the degrading factors and repairing the physical and/or chemical environment. In the latter case it would serve no use focusing on biotic manipulations, without first tackling the abiotic problems (Hobbs & Harris, 2001). Similar ideas were put forward by Grootjans et al. (1996) and Bakker & Londo (1998).

In fact, Hobbs' & Harris' (2001) conceptual ideas are not as new and original as they are considered to be. It was already Southwood (1977), who hypothesised that ecological theory predicts that the medium, the physical habitat, rather than the organisms, determine the structure of ecosystems. The habitat provides the template on which evolution processes forge the characteristic life-history strategies. Thus, through the effects of habitat conditions on the fitness of individual organisms in geological time, certain combinations of adaptations for survival and reproduction are assumed to be selected. According to Moss (2000), it is a consequence of Southwood's (1977) strictly ecological theory, that emphasis on individual, in policy terms often charismatic species, may be counter-productive for the conservation of aquatic ecosystems. Aquatic ecosystems provide many of the fundamental biogeochemical services upon which the continuity of life depends, and this provides a strong argument for conservation of the functional values in aquatic systems through whole-system reconstruction rather than following the philosophy of terrestrial species-oriented conservation (Moss, 2000).

An example from the Rhine Action Programme may illustrate this line of thinking. The euphoria about 'the salmon is back in the Rhine' (ICPR, 2000) provokes the wrong impression. No wonder that the salmon is back in the Rhine after stocking the tributaries of the river with hundreds of thousands of young individuals. The salmon returns to the Rhine when the fish is able to migrate from the sea to its upstream spawning areas, finding the proper resting habitats, feeding items etc. on its way. Weirs in the harnessed rivers are still preventing this. Maintenance of migratory salmonid stock may require major moderation of forestry, and operations around the spawning rivers;

moreover, conditions in estuaries or on the open sea will affect the recruitment and survival of the stock. According to De Groot (2002), to place much emphasis on recent observations of an odd salmon is, in fact, misleading. Many of the declines of anadromous species can not be attributed to a single factor, such as the construction of dams, pollution, de-watering of streams or sand and gravel extraction. It is better not to single out one causal factor for the decline, as most factors do not necessarily act singly, but rather in concert. The chain of required habitats forms the template for the return of the salmon.

The Dutch applications

Which ecological concepts have been applied during the restoration processes of Dutch ecosystems? Did the authors of this book refer to the restoration threshold concept? These questions will be answered further in this section. Concerning the restoration of estuarine and coastal ecosystems, both Bakker et al. (2002) and de Jonge & de Jong (2002) stress the restoration of abiotic habitat conditions as a pre-requisite for the return of the desired species. Bakker et al. (2002) define restoration measures as an attempt to bring back the destroyed habitats to an original state. In the context of salt-marsh restoration this implies, changing the present state of agriculturally intensified sites into the former, more natural ones. The effects of restoration management can only be measured after setting the targets for both abiotic and biotic factors. The conditional abiotic targets are to restore hydrological, geomorphological and saline, tidal conditions. Once this 'new' tidal regime has been restored, the biotic targets will be reached with namely, livestock grazing or without human interference, viz. a zonation of characteristic plant and animal communities, integrating the suitability of a-biotic conditions and plant traits, comprising the entire series from pioneer community to mature salt marsh vegetation. Defining targets and monitoring the effects of ecological restoration should be strongly interrelated. According to Bakker et al. (2002), monitoring the ecological developments in the field is a pre-requisite for the evaluation of the effects of ecological restoration measures.

De Jonge & de Jong (2002) go even a step further in their ambitions to restore the estuarine systems. The development of coastal ecosystems is the result of complex processes of large-scale and small-scale functional relations. Consequently, restoration of these systems has to be realised primarily by influencing the acting processes, and this is the only way to a sustainable preservation or recovery of ecological elements. Focusing only at one particular species (e.g. breeding terns) or a specific habitat (e.g. salt marsh) easily ends up in a sort of 'bio-agriculture' where the natural processes have been mainly excluded. Such an approach does not exclude the species or mono-habitat oriented strategy, but one should be conscious of the limitations and the unpredictability of such a biotic repair.

As said above, de Jonge & de Jong (2002) stress the need for a thorough knowledge of the processes responsible for ecosystem functioning in restoration projects. Large interventions in ecosystem processes without the proper knowledge about the long-term consequences might have severe, and often unexpected side-effects. Three examples: a reduction in tidal range of only 10% in the Oosterschelde estuary caused the tidal areas to erode severely, and an increase of salinity by only 2‰ in the Grevelingenmeer resulted in the total disappearance of the eelgrass ecosystem including the accompanying fishes and birds. The deepening of the most shallow parts in the main shipping channel in the Westerschelde estuary by about 2 m resulted in significant geomorphological changes in the sand and mud flats.

According to Nienhuis et al. (2002), Verdonschot & Nijboer (2002) and Gulati & van Donk (2002), river and stream restoration and lake restoration in the Netherlands should preferably start with lifting the abiotic constraints in favour of biotic rehabilitation. The excavation of new side channels in the river basins is a good example of successful habitat restoration, because this was followed by a striking increase of aquatic biodiversity (Schropp & Bakker, 1998). Besides lifting the restoration threshold of the abiotic limitations, the Dutch river managers have also focussed on the introduction of keystone species (beaver, stork, salmon), reared specially for such re-introductions.

Holistic ecological theories to promote river catchment management are available in the literature (Townsend, 1996). A common aim of rehabilitation projects is to make the river more natural, and 'naturalness' has become an important element of the international enhancement ethos (de Waal et al., 1998). However, what is considered 'natural' nowadays, might not have had the same qualification centuries ago. Is a floodplain overgrown with hardwood and softwood floodplain forests more 'natural' than floodplain pastures, bordered by hawthorn hedges and studded with cows? This means that each rehabilitation process needs a reference image, i.e. a picture of the former state or condition of the river. The second and possibly the most important step in any rehabilitation scheme is to define a target image and associated project objectives. Such an target image sketches an optimal solution for the river and its floodplains, considering the present conditions, opportunities and constraints.

Although the theoretical concepts for river rehabilitation are predominantly catchment oriented, rehabilitation projects rely heavily on local and regional planning policies. The planning and implementation of rehabilitation schemes is mainly done at the level of the regional water boards, and participation of municipalities and local interest groups is important. For practical reasons, many habitat restoration projects in river basins in the Netherlands start from the 'stepping stone' concept (Cals et al., 1998). This concept is based on the assumption that local management projects should be set up along the longitudinal axis of the river at regular distances, in such a way that a connected chain of nature reserves comprising favourable conditions for the (potential) plant and animal species will be developed. The use and application of ecological theory and empirical knowledge are increasingly playing a role in the rehabilitation schemes, mainly focusing on nature conservation and restoration strategies, i.e. restoring habitat diversity and hence species diversity. Older plans for river rehabilitation were mainly based on physical (hydrological and geo-morphological) criteria, the more recent ones, in contrast, fully involve ecological criteria (Nienhuis et al., 2002).

Lake restoration has proven to be the most successful in 'whole lake experiments' e.g. by the reduction of the external phosphorus loading by more than 50%, and by flushing the lake with water high in calcium and bicarbonate to reduce internal P-loading from the sediments. Additional measures, called biomanipulation or 'active biological management', i.e. drastic reduction of the fish stocks, mainly bream, has led in a number of cases to rehabilitation of the clear water state of the lake. A drawback, however, is that without additional measures such as the introduction of piscivorous fish (e.g. pike), the bream removal should be repeated once every 5–10 years. Again, a combination of abiotic habitat oriented and biotic species oriented measures appeared to be most successful (Gulati & van Donk, 2002).

Grootjans et al. (2002a,b) and Lamers et al. (2002) focus in the restoration projects, respectively dealing with the biotic communities in brook valleys and coastal dune slacks, and river-fed peat moors, predominantly on the vegetation and individual plant species. Herein they follow the terrestrial species-oriented conservation tradition, without ignoring the abiotic demands necessary for a successful restoration (cf. Moss, 2000). According to Grootjans et al. (2002a,b) in the Netherlands success of a restoration project is almost always judged by whether or not a restored site provides good growing conditions for rare or endangered plant or animal species. Thus, a restoration project is considered a success if many 'Red List species' establish themselves at the restoration site and can maintain large populations for at least several decades. Successful restoration is analogous to constructing a field museum for preserving the living part of a lost cultural heritage.

Lamers et al. (2002) stress that fen restoration aims at the recovery of original plant communities and their fauna, often semi-natural, as known from the times before undesirable anthropogenic disturbances occurred, such as desiccation or eutrophication. Restoration should, as Grootjans & van Diggelen (1995) stated, 'be aimed at restoring the fen system', and not at 'restoring fen species'. Restoration ecologists do not use a pre-historic concept for most fen types, but rather a cultural-historical concept, involving as a benchmark the semi-natural landscape of the 19th century or the beginning of the 20th century. Already in 1945, Westhoff (1945) initiated the idea that not only the so-called natural, but also the semi-natural systems in the Netherlands are well worth conserving. The concept implies the re-establishment of traditional management measures.

Ecological restoration: successes and failures

Recent experiences

Strikingly, ecological restoration in the Netherlands is a very young branch of science, which is not more than 25 years old, and in many cases the endeavours are much more recent. Arbitrarily the mid 1970s can be pointed out as turning point regarding the prevention and abatement concerning water pollution and eutrophication. The reduction of point source emissions appeared to be the most effective measure, and toxic heavy metals and persistent organic micro-pollutants where the first chemicals to be banned. Freshwater ecosystems benefited markedly from drastic reductions of the phosphorus emissions. Nitrogen sources, the limiting nutrients in marine ecosystems, appeared much more difficult to combat. The present situation is much better than that 25 years ago, although emissions from diffuse sources and from the polluted sediments of many surface waters are difficult to overcome in restoration projects.

Estuaries, rivers and smaller streams

Ecological restoration in the coastal zone and in the estuaries has been reviewed by de Jonge & de Jong (2002) and by Bakker et al. (2002). Remarkably, nearly all coastal restoration measures in the Netherlands are related to the recently realised engineering works or are their side effects. The Delta Works in the SW Netherlands, executed between 1957 and 1986, were designed to close off the large Rhine-Meuse estuaries from the North Sea for safety reasons, viz. to avoid recurrence of the flooding disaster in 1953. The execution of the Delta Works deprived the region of its estuarine transition zones: the brackish water habitats almost completely disappeared (except in the Westerschelde estuary). It is now clear, some 15 years after the completion of the Delta Works, that ecologically speaking the closure of Haringvliet, Veerse Meer, Grevelingenmeer, and the partial closure of the Oosterschelde have resulted in ecosystems that for one reason or the other do not fulfil the expectations. The negative developments that occurred were generally unexpected, affirming the difficulties of predicting developments after such large scale interventions. Various major schemes are now underway to restore the brackish-water gradients. Smaller, purely technical rehabilitation projects, such as fish passages, can not be regarded as a serious restoration attempt of a former habitat because these actions were restricted to a few specific elements in the foodchain.

Continuous sea level rise, due to global warming, forced the Dutch coastal managers to re-fix and armour the dune ridges along the Dutch coastline. Only very recently have the natural 'walking dunes' been re-introduced, although the stability of these systems can be questioned because of the limited spatial scale of the projects.

As stated by Bakker et al. (2002), salt marshes are threatened ecosystems, having until recently decreased in surface area continuously owing to civil engineering schemes. In order to increase the salt-marsh area, two options are at present in operation, viz. de-embankment of the summer polders while maintaining and reinforcing the main levee, the seawall between land and sea, and an increase in the effects of saline seepage landwards of the seawall by top soil removal. Both the options include the 'natural' restoration of salt-marsh communities (target communities) in former, intensively used agricultural sites. The general policy in the European Union is to set aside the low quality agricultural land, implying that the restoration of salt marshes and halophytic plant communities has recently become a realistic option in the Netherlands. Restoration of salt marshes or halophytic plant communities can not rely on a viable soil seed bank, which might reflect the vegetation prior to embankment. This is caused by the fact that the majority of salt-marsh plant species have a transient or short-term persistent seed bank. Hence, the success of restoration mainly depends on the dispersal of propagules from elsewhere. The development of a salt marsh at the former arable fields takes more time than at the former pastures. Livestock grazing is necessary to maintain a species-rich salt-marsh plant community and the coexistent fauna at the small scale. At the scale of e.g. the entire Wadden Sea area, the combination of both grazed and ungrazed salt marshes contribute to biodiversity.

Nienhuis et al. (2002) reviewed the ecological rehabilitation of Dutch large rivers, particularly that of the Lower Rhine catchment. In the past 25 years, the water quality and – to a lesser extent – the sediment quality, have been improved considerably, hence leading to improvement of biotic diversity. The rehabilitation of the lost or disturbed ecosystems started some 15 years ago. The established boundary conditions for restoration projects are protection against flooding and transport by cargo ships. The use and application of ecological criteria are increasingly playing a role in the rehabilitation schemes. Ecological rehabilitation focuses mainly on nature conservation and restoration strategies, i.e. exploiting the hydrodynamic and morphodynamic potentials of the flowing rivers, and introducing a semi-natural grazing regime by large herbivores. Particularly the creation of new secondary channels contributes to the restoration of riverine habitat diversity and heterogeneity, and hence to species diversity.

The assessment of a number of rehabilitation projects along the Lower Rhine has led to the conclusion that no general patterns have emerged concerning 'success' or 'failure' of specific restoration measures. The assessment based on the 14 scrutinized projects out of some 30 projects in progress, is positive. Recent projects benefited from the experience gained during the earlier projects (viz. in Duursche Waarden the connection of isolated freshwater pools with the main river channel in 1989). All projects started with the dominance of cultivated, over-fertilised and levelled grasslands or maize fields. The actual values of nature in all areas within a few years improved by increasing the spatial heterogeneity by re-introduction of larger hydro-dynamical and morphodynamic forces. This was achieved by excavation of sediment and dredging of silted-up river branches and excavation of secondary channels, in combination with extensive grazing by cattle on the fallow land. These measures enlarged the actual values of nature in all areas within a few years. The water quality in surface water bodies in the floodplains is rather negative, owing to retarded seepage of fertilisers via groundwater. The highly dynamic river Waal offers the best possibilities for the restoration of natural sandy levees and back swamps. It will be very difficult to rehabilitate the hardwood floodplain forests under the present management conditions. A further recovery of the river biota depends on continued repression of pollution, an increase in the morphological dynamics, and the development of the original natural habitats (Nienhuis et al., 2002).

According to de Groot (2002), there are chances for the recovery of some of the anadromous fish species (a.o. the twaite shad population) in the SW Netherlands, when the estuarine gradients will be restored. The return of the sturgeon is unlikely. The salmon, once fished in large numbers, is now the subject of restocking programmes in Germany. Encountering a stray specimen of salmon can be attributed only partly to these programmes. Restocking programmes need to be considerably improved before noticeable success is to be expected.

Postma et al. (1996) made an inventory of the present and past status of riverine landscapes in the Netherlands, classified as ecotopes. At present roughly 75% of the surface area of the river floodplains of the Rhine is cultivated land, either dominating grassland (pastures), fields or built-up area. The current government policy in the Netherlands is to decrease the acreage of cultivated land, to set aside or to abandon agricultural land and to stimulate the development of natural grassland and floodplain forests. The reference image dating back some centuries, shows dominance of hard- and softwood floodplain forests (roughly 60–70%), and this is in sharp contrast with the present situation, where only less than 5% of the floodplain forests is left. The target image shows an intermediate position, a strong stimulus for natural grasslands, brushwood and floodplain forests, at the expense of classical agricultural land. The aim of the government is the doubling of the area of natural landscape along the large rivers to 30 000 ha in 2010.

The Netherlands, rich in water, still has numerous deteriorated streams and brooks, and the techniques of stream restoration are being quickly developed. In 1991, 70 projects were in progress, in 1993 the number increased to 170, and in 1998 to 206. Both hydrological and morphological measures, as well as biological measures are being taken. The catchment oriented measures involve an increase of the water retention capacity of the stream, or the revival of lost inundation areas. The morphological measures deal with the construction of fish ladders, pools, wooded banks, the creation of new meanders and adaptations of stream profile width and depth. The introduction of species – fish; aquatic plants – that occurred in the stream in the past, is considered as an additional measure (Verdonschot & Nijboer, 2002).

Lakes, fens and bogs

Lamers et al. (2002) reviewed the restoration of Dutch mineral-rich peatlands with either surface peat accumulation or submerged peat accumulation. Although some fens are brackish (8.5–85 mmol Cl l^{-1}; mainly in the western part of the Netherlands), the majority are freshwater systems. The focus is mainly on aquatic and semi-terrestrial fens. Lowland fens differ from ombrotrophic mires (bogs) in that the biogeochemical processes in their top layer are strongly influenced by the influx of mineral-rich groundwater or surface water. The assumption that this implies meso- or eutrophic conditions is incorrect. The mineralisation rates and nutrient availability are not necessarily lower in the raised-bog plant communities compared with the fen plant communities. The uptake of nutrients, rather than their availability, appears to form the principal constraint for plant growth in bogs. Fen restoration aims at the recovery and conservation of characteristic, often semi-natural fen systems (flora and fauna), by restoring the hydrology, hydrochemistry and the sediment considered optimal for the fens under restoration.

In contrast to the larger lake types (cf. Gulati & van Donk, 2002), the reduction of turbidity in the small fen lakes by external or internal measures appeared to be often unsuccessful. Such lakes remained turbid or the decrease in turbidity was short lived after taking the measures, and the submerged plant communities did not develop. In the hypertrophic lakes, turbidity is the only possible stable situation. Biomanipulation will only work after PO_4^{3-} concentrations are reduced to a level in which two alternative stable states, the clear water and the other turbid, are possible (Lamers et al., 2002).

Softwater pools and lakes are found scattered over the higher, Pleistocene parts of the Netherlands. These waters possess a highly characteristic vegetation adapted to limited carbon availability. The vegetation of shallow softwater lakes in the Netherlands is strongly endangered, due to atmospheric sulphur- and nitrogen deposition, local eutrophication, habitat fragmentation, afforestation and drainage. Removal of the nutrient-rich, anoxic, organic sediments is a pre-requisite to the restoration of these lakes. In the acidified or acid-sensitive lakes, additional measures against acidification are required. A controlled supply of calcareous, nutrient-poor water is preferable to direct liming. Most softwater macrophytes produce long-lived seeds and regeneration of soft water macrophytes via the seed bank can recur even after 20–40 years of absence in the vegetation. Removal of the recently accumulated matter from eutrophicated softwater lakes strongly stimulates the germination of viable seeds from the seed bank, and the lakes can be completely recolonised by softwater macrophytes within a foreseeable period. Oxidation of the sediment and oligotrophication of both water layer and sediment and the presence of a broad riparian zone are important pre-requisites (Roelofs et al., 2002).

Semi-aquatic brook valleys and dune slacks

Grootjans et al. (2002a) reviewed the restoration of semi-aquatic and terrestrial brook valleys, habitats closely connected to the aquatic peat moor and fen systems, discussed by Lamers et al. (2002). Until recently, restoration measures in brook valley meadows in the Netherlands consisted of re-introducing traditional management techniques such as mowing without fertilisation and low-intensity grazing. In the Netherlands, additional measures, such as rewetting and sod cutting, are now carried out on a large scale to combat negative influences of drainage and acidifying influences by atmospheric deposition. An analysis of successful and unsuccessful projects shows that restoration of brook valley meadows is most successful if traditional management techniques are applied in recently abandoned fields that had not been drained or fertilised. Successful projects have been executed at sites that have been least affected by intensive agriculture and drainage. Thus, the restoration projects should be initiated preferably in areas which have not been affected by drainage and still have some relics of meadow species in the vegetation. The availability of reference communities is, indeed, an acute problem in target areas where intensive fertilisation has taken place for a long time, soil degradation has occurred, and where practically all target species have disappeared in both the existing vegetation and the seed bank.

According to Grootjans et al. (2002b), several environmental conditions influence the recovery and consequent stability of young dune slack ecosystems. These conditions are most favourable when the soil is nutrient-poor and fairly well buffered (pH>6), prolonged flooding with base-rich surface waters occurs, and when the soil remains moist during dry summers, preferably provided by an additional flow of calcareous groundwater from adjoining dune areas. Less favourable conditions occur when a rapid acidification of the top layers occurs during succession, resulting in a fast accumulation of organic matter, or when the dune slack is infiltrated with nutrient-rich (river)water, enhancing eutrophication, hence counteracting the natural nutrient-poor situation. An important pre-requisite for restoration success of the dune slack vegetation is, of course, the presence of a seed bank. The better the development of the seed bank is, the greater guaranty that Red List species (the criterion for success!) will show up during the early stages of succession.

Ecological restoration, predictability and society

Ecological restoration and predictability

What can we learn from the aforementioned successes and failures? Firstly, the abiotic conditions should be restored to establish the target communities. Secondly, the target species must be present or able to arrive at the target sites. It is important to realise the constraints in ecological restoration projects (Bakker & Berendse, 1999). The experimental introduction of target species may show that after initial emergence, these species disappear again (van Duren et al., 1998). Abiotic constraints may comprise, e.g. a too low buffer capacity in seepage water, or acidification or eutrophication from atmospheric deposition. Successes on the re-establishment of softwater macrophytes suggest that a number of species is still present in the long-term persistent soil seed bank, indicating former plant communities. Unfortunately, many other species only have a transient or short-term persistent seed bank (Thompson et al., 1997). This means that ecological restoration needs dispersal of propagules from elsewhere, which can be difficult to accomplish in the present fragmented landscape. Case studies reveal that dispersal, even over a distance of a few kilometres, may be a constraint (Verhagen et al., 2002). In fact, data on seed dispersal are mainly lacking; a database on dispersal of plant species, sustained by experimental evidence, would give insight in potential distribution patterns.

Do we have enough knowledge to predict the outcome of ecological restoration projects? The sequence of prediction, monitoring and evaluation is essential in ecological restoration projects. When a prediction comes through, apparently the researcher and the manager have convincing ecological knowledge of the ecosystem involved. In fact, it is more interesting when a prediction does not hold. In those cases, research is needed to understand the mechanisms and learn the constraints in the ecosystem, at the benefit of future predictions of both manager and researcher. It is important to distinguish between targets dealing with the rehabilitation of structural components such as plant communities or the restoration of processes such as the reduction of nutrient availability. Top soil removal or the introduction of grazers may never be a goal in itself.

There is an ongoing discussion among ecologists in the Netherlands about the predictability of ecological restoration measures. Theoretical modellers (Huisman, 2000a,b) disagree with the overall predictability of ecological systems. The determining factor is not the type of ecosystem but the number of interactions between the different species. The more complex the system the greater is the chance for ‘chaotic competition’, leading to large fluctuations in the structure of the biotic community. The multi-species phytoplankton communities are often used as examples to illustrate this ‘chaos’ hypothesis. Theoretical ecologists argue that the creditability of ecology would be at stake if too definite predictions are made, and the calculation of probabilities that certain species will maintain themselves in specific habitats would be more reliable than the statement that certain species will re-appear after specific management measurements. From their focus nature development is as un-predictable as the weather: the general sequence of the developments is, of course, predictable: spring, summer, autumn and winter may be foreseen, but the day to day distribution or intensity of rain, sunshine, fog, etc. can not be forecasted. The same is true for ecological restoration projects: supposing that the proper environmental steering variables have been restored, large-scaled succession patterns can be predicted, but small-scaled distribution patterns, both in space and in time, and the answer to the question which species composition finally would prevail, are largely not predictable.

Lamers & Roelofs (2000) contest the assumption that the species composition is not predictable, and that instead the main lines of succession and development of a (plant) community can be forecasted. The major challenge is to assess the proper steering variables, that determine the major processes in the ecosystem. Our inability to explain the ecological processes in the past has often been attributed to insufficient knowledge of the proper steering variables. ‘Chaotic competition’ is invariably used as a pretext to accept failures in the ecological restoration projects. This is an inevitable consequence of insufficient application of ecological theory, starting with the ill-founded hypotheses, and mainly based on trial and error. Such an approach may easily lead to a ‘laissez faire’ policy, and hence to non-repairable damage of ecosystems. The way an ecosystem evolves in response to restoration measures, is largely predictable, provided the main environmental variables are known in enough detail. This will, however, not provide an exact blueprint of the expected species composition and biodiversity. The successful restoration of oligotrophic fens and species-rich fen meadows are mentioned as examples. The management aim was to get back these ecosystems, without expecting a resurgence in the abundance or distributions of the species that had disappeared.

The above discussion is also an ongoing phenomenon in the international literature on ecosystem restoration (Ehrenfeld, 2000; Zedler, 2002). For example, according to Zedler (2000), the restoration of aquatic ecosystems is more complex than implied by early concepts of ecosystem degradation and restoration. Degradation involves many paths of change in species abundances and ecosystem functions, and restoration is at least as complex. Furthermore, models developed for one wetland type appear not to be easily applicable to other types (Ehrenfeld, 2000). Ecological theory has much to offer to the practitioner, but the predictions remain vague. Predictability should improve if generalities are sought where the restoration context and specific restoration actions are held constant. To date, there are too few studies to draw generalizations from within the context of one specific ecosystem type, let alone between the different types and landscape settings. According to Zedler (2000), there is a great need for more habitat-specific advice, such as that which recently became available for riverine wetlands and tidal wetlands (Middleton, 1999; Zedler, 2002).

In this context of predictability in rehabilitation endeavours a study of de Melo et al. (1992) on the rehabilitation of aquatic ecosystems is illustrative. Lake restoration theory (Shapiro & Wright, 1984) is based on the prediction that an increased piscivore abundance will result in a decrease in planktivore abundance, and an increase in zooplankton abundance, as well as an increased zooplankton grazing pressure leading to reductions in phytoplankton abundance and improved water clarity. De Melo et al. (1992) contested this irrefutably accepted trophic cascade 'law' in the generalist literature, which is used worldwide as a lake management tool (cf. Hosper, 1997 for restoration practice in the Netherlands). De Melo et al. (1992) examined 50 papers published between 1961 and 1989, documenting 44 independent food-web biomanipulations in ponds and lakes. The trophic cascade of these 44 case studies revealed data for 118 response cells (relations between trophic levels). Fifty-two represented complete agreement with the predictions of the top-down models. Twenty-one represented complete disagreement and 45 were undecided. On first examination, these results might seem to augur well for the top-down hypothesis; however, a more detailed analysis casts doubts on this conclusion. The undecided or equivocal results showed that the confounding effect was most apparent at the zooplankton–phytoplankton link in the food web. This relationship is dominantly determined by factors, such as the climatic conditions, macrophyte presence and the palatability of the phytoplankton algae, and not by planktivore-mediated alterations. Far from being 'clearly confirmed' (cf. Carpenter, 1988), biomanipulation is clearly at the stage of 'paradigmal crisis' sensu Kuhn (1962). According to de Melo et al. (1992), far too many questions remain unanswered to presently advocate biomanipulation as a justifiable management strategy for lake rehabilitation.

Gulati & van Donk (1989) who reviewed a series of papers on biomanipulation in fresh-water ecosystems and estuaries in the Netherlands, reached similar conclusions as de Melo et al. (1992). The 'top-down' remedial factors to alleviate eutrophication of lake ecosystems can perhaps be considered as complementary to the 'bottom-up' technique of lake restoration, viz. reduction in allochthonous nutrient loading, especially of phosphorus. Thus, this complementary approach of lake restoration may have surprises as well as successes in store for us.

Ecological restoration and society

Ecologists from policy-oriented state institutes are forced to express themselves carefully about the successes and failures of restoration projects, in accordance with the current national policy. 'Failures' of ecological restoration projects are preferably not published: dirty linen should not be washed in public, isn't it? Failures might be interpreted as shortcomings of the national policy, and this will cause damage to the Ministry.

Ecologists from universities and independent research institutes may allow themselves a more critical and independent approach, but their 'truth' is not seldom coloured with emotion, because of the links with organisations for nature conservation. Ecological restoration projects rather frequently suffer from conflicting economic arguments which are weighed against environmental arguments. Ecologists from both sides, conservation ecologists *versus* policy oriented ecologists, are easily opposing each other, particularly when a major political problem is to be debated. The point is that both parties should uphold their scientific integrity.

A well-known and endlessly debated example is the effect of large-scale bottom trawl fishing on marine bivalves, cockles, in the Wadden Sea, an international nature reserve of great size and standing. Large sucking devices, based on the vacuum cleaner principle, plough the bottom of the Wadden Sea, and destroy benthic habitats, such as natural mussel banks and seagrass beds, hence lowering habitat and species diversity. The massive harvest of cockles jeopardises the food quantity of benthos-eating waders and ducks. Ecological restoration of seagrass beds is also negatively influenced by the cockle fishing industry (de Jonge et al., 1996; van Katwijk, 2000). Of course these fishing activities are not allowed unrestrained: closed areas have been demarcated where cockle fishing is forbidden. Interpretation of the adverse effects of cockle harvesting is hampered by natural events such as heavy storms and severe winter frost.

Long and emotional discussions have been published in 'Bionieuws' (1998), the bi-weekly magazine of professional Dutch biologists, concentrating on the pitfalls of 'type I and II statistical failures' that may be made in discussions on conservation biology. The controversy between the shell-fishermen and their department of civil servants, and the nature conservationists and their home front is a reality. The 0-hypothesis states that cockle fisheries has no negative ecological consequences for the Wadden Sea. The type I failure, i.e. to wrongly conclude that there is a negative effect, should statistically be kept as small as possible. The burden of proof is on the side of the ecologists. The type II failure, i.e. to wrongly conclude that there is no effect, while there is indeed an effect, is even more dangerous. The likely chance that a negative effect is wrongly diagnosed is considerable, because the spatial and temporal variability in the system is large. Unsatisfactory research results and a too small number of samples lead frequently to massive type II failures. In simple terms: following a type I failure, the innocent goes to jail; following a type II failure, the villain does not go to jail. Thus, statistically and scientifically both type I and type II failures should be kept as small as possible.

Nature conservationists argue that the burden of proof should be put on the side of the licencees. The Dutch parliament allowed shellfisheries to exploit the cockle resources in the Wadden Sea, without turning the burden of proof onto the shell-fishermen. Cockle fishers argue that the 0-hypothesis has been rejected some time ago. Shell-fish fisheries has always some effect, but the question is whether this effect negatively influences the predatory bird population. The shell fishermen may not disturb the Wadden Sea to such an extent that the Habitat Directive of the European Union is abused. Cockle fishers argue that they are not responsible for the decline in numbers of migratory birds and cockles; this phenomenon is said to be mainly ruled by natural factors such as storms and severe winters.

This discussion makes clear that conservation biology and restoration ecology are more than 'hard' science only. The distinction between scientific and political arguments, consultation of and communication with stakeholders, public acceptance, and the willingness to pay for measures, either by public or private parties, are finally decisive for the progress of the project. Van Diggelen et al. (2002) edited a series of congress papers on ecological restoration, and they reached roughly the same conclusions.

References

Allen, E. B., W. W. Covington & D. A. Falk, 1997. Developing the conceptual basis for restoration ecology. Restorat. Ecol. 5: 275–276.

Bakker, J. P. & F. Berendse, 1999. Constraints in the restoration of ecological diversity in grassland and heathland communities. Trends Ecol. Evol. 14: 63–68.

Bakker, J. P., P. Esselink, K. S. Dijkema, W. E. van Duin & D. J. de Jong, 2002. Restoration of salt marshes in the Netherlands. Hydrobiologia 478/Dev. Hydrobiol. 166: 29–51.

Bakker, J. P. & G. Londo, 1998. Grazing for conservation management in historical perspective. In Wallis de Vries, F. M., J. P. Bakker & S. E. van Wieren (eds), Grazing and Conservation Management. Kluwer Academic Publishers, Dordrecht.: 23–54.

Bionieuws, 1998. Type I en II: over ecologische effectstudies, beslistheorie en een symmetrische bewijsvoering. Bionieuws 4,5,6 &7 (in Dutch).

Blom, C. W. P. M., 1999. Adaptations to flooding stress: from plant community to molecule. Plant Biol. 1: 261–273.

Cals, M. J. R., R. Postma, A. D. Buijse & E. C. C. Marteijn, 1998. Habitat restoration along the river Rhine in the Netherlands: putting ideas into practice. Aquatic Conservation: Mar. Freshwat. Ecosystems 8: 61–70.

Carpenter, S. R., 1988. Transmission of variance through lake foodwebs. In Carpenter, S. R. (ed.), Complex Interactions in Lake Communities. Springer: 119–138.

De Groot, S. J., 2002. A review of the past and present status of anadromous fish species in the Netherlands: is restocking the Rhine feasible? Hydrobiologia 478/Dev. Hydrobiol. 166: 205–218.

De Jonge, V. N. & D. J. de Jong & M. M. van Katwijk, 2000. Policy plans and management measures to restore eelgrass (*Zostera marina* L.) in the Dutch Wadden Sea. Helgol. mar. Res. 54: 151–158.

De Jonge, V. N. & D. J. de Jong, 2002. Ecological restoration in coastal areas in the Netherlands: concepts, dilemmas and some examples. Hydrobiologia 478/Dev. Hydrobiol. 166: 7–28.

De Melo, R., R. France & D. J. McQueen, 1992. Biomanipulation: Hit or myth? Limnol. Oceanogr. 37: 192–207.

De Waal, L. C., A. R. G. Large & P. M. Wade (eds), 1998. Rehabilitation of Rivers. Principles and Implementation. Landscape Ecology Series, Wiley & Sons, Chichester.

Ehrenfeld, J. G., 2000. Defining the limits of restoration: the need for realistic goals. Restor. Ecol. 8: 2–9.

Grootjans, A. P. & R. van Diggelen, 1995. Assessing the restoration prospects of degraded fens. In Wheeler, B. C., S. C. Shaw, W. J. Fojt & R. A. Robertson (eds), Restoration of Temperate Wetlands. Wiley & Sons, Chichester: 73–90.

Grootjans, A. P., L. F. M. Fresco, C. C. de Leeuw & P. C. Schipper, 1996. Degeneration of species-rich Calthion palustris hay meadows; some considerations on the community concept. J. Veg. Sci. 7: 185–194.

Grootjans, A. P., J. P. Bakker, A. J. M. Jansen & R. H. Kemmers, 2002a. Restoration of brook valley meadows in the Netherlands. Hydrobiologia 478/Dev. Hydrobiol. 166: 149–170.

Grootjans, A. P., H. W. T. Geelen, A. J. M. Jansen & E. J. Lammerts, 2002b. Restoration of coastal dune slacks in the Netherlands. Hydrobiologia 478/Dev. Hydrobiol. 166: 181–203.

Gulati, R. D. & E. Van Donk, 1989. Biomanipulation in the Netherlands: applications in fresh-water ecosystems and estuarine waters-an introduction. Hydrobiol. Bull. 23: 1–42.

Gulati, A. D. & E. van Donk, 2002. Lakes in the Netherlands, their origin, eutrophication and restoration: state-of-the-art review. Hydrobiologia 148/Dev. Hydrobiol. 166: 73–106.

Hobbs, R. J. & D. A. Norton, 1996. Towards a conceptual framework for restoration ecology. Restorat. Ecol. 4: 93–110.

Hobbs, R. J. & J. A. Harris, 2001. Restoration Ecology: Repairing the Earth's Ecosystems in the New Millennium. Restorat. Ecol. 9: 239–246.

Hosper, S. H., 1997. Clearing lakes, an ecosystem approach to the restoration and management of shallow lakes in the Netherlands. Ph.D. Thesis, University of Wageningen.

Huisman, J., 2000A. Natuurontwikkeling is even onvoorspelbaar als het weer. Bionieuws 17 (in Dutch).

Huisman, J., 2000B. Ecologen moeten hun hand niet overspelen. Bionieuws 19 (in Dutch).

ICPR, 2000. Rhine 2020 Programme for Sustainable Development and Action Plan 2005. International Commission for the Protection of the Rhine, Koblenz.

Kuhn, T. S., 1962. The Structure of Scientific Revolutions. Univ. Chicago.

Lamers, L. P. M. & J. G. M. Roelofs, 2000. Natuurontwikkeling is wel goed te voorspellen. Bionieuws 18 (in Dutch).

Lamers, L. P. M., A. J. P. Smolders & J. G. M. Roelofs, 2002. The restoration of fens in the Netherlands. Hydrobiologia 478/Dev. Hydrobiol. 166: 107–130.

Londo, G., 1997. Natuurontwikkeling, Backhuys Publishers, Leiden (in Dutch).

Middleton, B., 1999. Wetland Restoration, Flood Pulsing, and Disturbance Dynamics. John Wiley & Sons.

Moss, B., 2000. Biodiversity in fresh waters – an issue of species preservation or species functioning. Envir. Cons. 27: 1–4.

Nienhuis, P. H., A. D. Buijse, R. S. E. W. Leuven, A. J. M. Smits, R. J. W. de Nooij & E. M. Samborska, 2002. Ecological rehabilitation of the lowland basin of the river Rhine (NW Europe). Hydrobiologia 478/Dev. Hydrobiol. 166: 53–72.

Palmer, M. A., R. F. Ambrose & N. L. Poff, 1997. Ecological theory and community restoration ecology. Restorat. Ecol. 5: 291–300.

Postma, R., M. J. J. Kerkhofs, G. B. M. Pedroli & J. G. M. Rademakers, 1996. Een stroom natuur. Natuurstreefbeelden voor Rijn en Maas. Watersysteemverkenningen 1996: 1–102, RIZA-nota 95.060 (in Dutch).

RIVM, 1999. Milieucompendium 1999. Het milieu in cijfers. Rijksinstituut voor Volksgezondheid en Milieu (RIVM) en Centraal Bureau voor de Statistiek, Bilthoven, Heerlen (in Dutch).

Roelofs, J. G. M., E. Brouwer & R. Bobbink, 2002. Restoration of aquatic macrophyte vegetation in acidified and eutrophicated soft water wetlands in the Netherlands. Hydrobiologia 478/Dev. Hydrobiol. 166: 171–180.

Scheffer, M., S. H. Hosper, M. L. Meijer, B. Moss & E. Jeppesen, 1993. Alternative equilibria in shallow lakes. Trends Ecol. Evol. 8: 275–279.

Schropp, M. H. I. & C. Bakker, 1998. Secondary channels as a basis for the ecological rehabilitation of Dutch rivers. Aquatic Conservation: Mar. Freshw. Ecosyst. 8: 53–59.

Shapiro, J. & D. I. Wright, 1984. Lake restoration by biomanipulations. Round Lake, Minesota – the first 2 years. Freshwat. Biol. 14: 371–373.

Southwood, T. R. E., 1977. Habitat, the templet for ecological strategies. J. anim. Ecol. 45: 337–365.

Townsend, C. R., 1996. Concepts in river ecology: pattern and process in the catchment hierarchy. Ergebn. Limnol. 113, Large Rivers 10: 3–21.

Thompson, K., J. P. Bakker & R. M. Bekker, 1997. Soil Seed Banks in North West Europe; Methodology, Density and Longevity. Cambridge Univ. Press, Cambridge.

Van Diggelen, R., A. P. Grootjans & J. A. Harris, 2001. Ecological restoration: State of the Art or State of the Science? Restorat. Ecol. 9: 115–118.

Van Duren, I. C., R. J. Strykstra, A. P. Grootjans, G. N. J. ter Heerdt & D. M. Pegtel, 1998. A multidisciplinary evaluation of restoration measures in degraded Cirsio-Molinietum fen meadows. Appl. Veg. Sci. 1: 115–130.

Van Katwijk, M. M., 2000. Possibilities for restoration of Zostera marina beds in the Dutch Wadden Sea. PhD Thesis University of Nijmegen.

Van Staalduinen, C. J., H. A. van Adrichem Boogaert, M. J. M. Bless, C. J. W. Doppert, H. M. Harsveldt, H. M. van Montfrans, E. Oele, R. E. Wermuth & W. H. Zagwijn, 1979. The Geology of the Netherlands, Meded. Rijks Geol. Dienst 31–32.

Verhagen, R., J. Klooker, J. P. Bakker & R. van Diggelen, 2001. Restoration success of low-production plant communities on former agricultural soils after top-soil removal. Appl. Vegetation Sci. 4: 75–82.

Verdonschot, P. F. M. & R. C. Nijboer, 2002. Towards a decision support system for stream restoration in the Netherlands. Hydrobiologia 478/Dev. Hydrobiol. 166: 131–148.

Westhoff, V., 1945. Biologische problemen der natuurbescherming. In Verslagen van de Natuurbeschermingsdag van de NJN te Drachten: 18–30 (in Dutch).

Whisenant, S. G., 1999. Repairing damaged wildlands: a process-oriented, landscape-scale approach. Cambridge University Press, Cambridge.

Zedler, J. B., 2000. Progress in wetland restoration ecology. TREE 15: 402–407.

Zedler, J. B. (ed.), 2001. Handbook for Restoring Tidal Wetlands. Marine Science Series, CRC Press.