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Summary of results

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# Abstract

Within the Danube Delta in Romania large, natural areas have in the past been reclaimed to be used for forestry, agriculture and fisheries. Since the political revolution of 1989, a change has occurred in the management objectives for large parts of the Danube Delta and some of these reclaimed areas have been selected for ecological restoration. This report deals with ecological restoration in the Dunavăţ/Dranov region, in the southern part of the Danube Delta. In this region there are several former fish-ponds of large size (> 1000 ha), with potentially high natural value. The aquatic ecosystem of one of these former fish-ponds, namely Holbina II, was observed to change during the mid-nineties from a highly diverse mesotrophic state to one of turbidity with low natural value. The objective of this report is to summarise all research related to the ecological restoration of these fish-ponds, in particular Holbina II, conducted over the past decade. Based on this review, some recommendations have been formulated.

Holbina II is, in common with the other fish-ponds, surrounded by a dike and almost isolated from Danube river water. There are only a few culverts and in some years there have been breaches in the dike. Previous studies had suggested that it was this isolated character of the fish-pond which was mainly responsible for its observed eutrophication. However, the water of the Danube river has high levels of nutrients and allowing this water to enter the restoration area untreated was expected to enhance eutrophication. It was hypothesised that reed beds might act as natural filters, reducing levels of nutrients. The idea was thus to restore and maintain mesotrophic conditions within Holbina II by flushing the basin with such filtered water. Several hydrological and ecological studies were implemented in order to find out whether such measures were feasible.

The main result to emerge was that reed beds proved during summer to be a source of phosphate, the most important nutrient. This was contrary to the hypothesis. Another important finding was that the aquatic ecosystem in Holbina II had spontaneously reverted to a clear water state in 2002. Given the prevailing concentrations of phosphate, both clear and turbid states are possible. The ecosystem is inherently unstable and may switch from the clear water state to the turbid water state, and then back again.
For the ecosystem in Holbina II there are two possible ecological target states consistent with the management objectives. In the short term, it is recommended that the current 'clear water' state be retained as the ecological target. The alternative ecosystem state that might be advocated, the 'black-water' state, would require for its realisation measures implying important regional consequences. These consequences need to be weighed in political debate against the benefits of restoring habitat for rare organisms.

Given that the ecosystem state of Holbina II was recently favourable from a biodiversity point of view, given the inherent instability of the ecosystem, and given current uncertainties concerning the effects of hydraulic works for ecological restoration, it is recommended that the authorities implement no immediate ecological restoration measures unless these measures can be accompanied by systematic

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# Contents

# 1. Introduction

The restoration of wetlands is a topic that rightfully attracts international attention. All over the world, wetlands are under pressure from economic developments that have lead to a loss of valuable habitat, altered hydrological dynamics and a decline in species diversity. Rapidly increasing populations and growing demands for water and land have led to the degradation of many river systems. Wetlands have important hydrological and biogeochemical functions and provide habitat and food web support for a wide array of organisms. These functions have great value for human society, e.g. in the form of recreational and commercial fishing. Wetlands also contribute to the maintenance of water quality, reduction in global warming and have an important aesthetic value. Ecological restoration may result in a regaining of lost ecological functions, contributing to biological diversity and, in many respects, to human society itself.

### 1.1 Ecological restoration in the Danube Delta

Research for ecological restoration is one of the main topics in the scientific co-operation between scientists from the Romanian Danube Delta National Institute DDNI, officials from the Romanian Danube Delta Biosphere Reserve Authority DDBRA and the Dutch Institute for Inland Water Management and Waste Water Treatment RIZA. Within the framework of this co-operation, attention was paid between 1993 and 1996 to the conservational status of the Holbina/Dunavăț area (5,630 ha; figure 1.1 and 1.2) in terms of its ecological restoration. This resulted in a strategy for research and restoration, defined in 1995 and published in 1996 (Drost *et al.* 1996).

The overall aim for the Holbina/Dunavăț area is to protect and maintain populations of species and habitats with high ecological value, and to carry out ecological restoration works where the natural or the semi-natural character of areas has been lost as a result of human activity (Baboianu & Goriup 1995). This report aims at summarising the results of research carried out within this framework in 1996, 1997 and 1998, in conjunction with an additional field survey in 2002.

### 1.2 Danube river, Danube Delta and Dunavăț-Dranov region

The Danube is the second largest river, after the Volga, on the European continent. The Danube flows west-east from the Schwarzwald mountains in Germany to the Black Sea in Romania (Figure 1.1). It has a catchment area of 800,000 $km^2$, covering parts of Germany, Switzerland, Austria, Slovakia, the Ukraine, Moldova, Hungary, Slovenia, Croatia, Bosnia, Serbia, Bulgaria and Romania. The Danube has a total length of 2,860 km. It has an average discharge into the Black Sea of 6,350 $m^3$/second. The river is fed partly by melting water from alpine snow and partly by rain water from less elevated mountainous regions. Large, low-lying parts of the catchment area have a continental climate with moderate rainfall-deficits in summer and substantial agricultural irrigation water demands.

The Danube Delta is one of the largest intact deltas of the European continent. It covers 418,000 ha, of which 344,600 ha lie in Romania. Only marginal human settlement occurs in the Delta. There are no more than approximately 15,000 inhabitants and this number is presently declining. Most of the Delta territory consists of reed marshes and shallow lakes. The Delta is divided into various hydrological complexes by the three Danube river branches and by fossil beach bars. Mineral wetland soils prevail in the upstream half of the Delta. The downstream part of the Delta is dominated by huge peat complexes.

The Dunavăț/Dranov region (c 19,000 ha, Figure 1.2) is one such peat area, lying as it does between two more or less parallel water courses: the Dunavăț Danube Branch in the north-west and the Dranov creek in the south-east. The 'Holbina/Dunavăț area for ecological restoration' (Figure 1.2) is situated in the Dunavăț/Dranov region and consists of three former fish-farm basins that have been identified for ecological restoration:

Holbina I: 1,270 ha,
Holbina II: 3,100 ha,
Dunavăț II$^{1+2}$: 1,260 ha.


*fig 1.1*
*Danube Delta, Dunavăț/Dranov region (hatched) and Holbina/Dunavăț area (encircled). The inset gives the catchment area of the Danube river.*

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*fig 1.2*
*Dikes and artificial canals in the Dunavăţ/Dranov region. The fishponds are indicated as follows: DI, $DII_{1.2.3.4}$, for the Dunavat basins and HI an HII for the Holbina basins, respectively.*

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The present report gives answers to these questions, in so far as they could be achieved. A short history of the former fish-ponds is given in Box 1. In Chapter 2 an inventory is given of the main stakeholders and their objectives. Chapters 3 and 4 describe the results of hydrological studies related to the Razim/Sinoie complex. Chapter 5 deals with the filtering marshes and in Chapters 6 and 7 are described ecological developments in the former fish-ponds. Conclusions are drawn from these results in Chapter 9 and the recommendations for ecological restoration works are summarised in Chapter 10.

*Overview over (part of) the northern section of Holbina II, looking towards the north-east*

## Box 1

## Short history of Holbina II and other fish-ponds in the Dunavăţ / Dranov region

The fish-ponds in the Dunavăţ/Dranov region in the Danube Delta were constructed in the 1970s. This involved the creation of large, isolated basins (Figure 1.2) surrounded by ring-dikes and separated from each other by major canals. Fish-farm construction also involved the dredging of additional smaller canals within the basins and the construction of pumping stations and culverts with shut-off valves for water exchange with the surrounding canals. Holbina II is one of the four major fish basins in the Dunavăţ/Dranov region. The other basins are Holbina I, Dunavăţ I and Dunavăţ II. Holbina II and Dunavăţ II are further subdivided into sub-basins using minor dikes. Inside Holbina II, the peat soil has locally been removed by burning.

The exploitation of the fish-ponds involved cyclic water level management, including a complete draw-down once in every three years. The energy required for pumping the water out of the basins was supplied to the pumping stations by a high-tension electrical power-line carried on pylons. Water levels were manipulated to improve the efficiency of harvesting and feeding conditions for the fish. In addition, the ponds were stocked with fingerlings and reed regeneration was stimulated by burning and cutting. Emerging reed serves as food for some species of commercially exploited fish. Harvest levels of fish have reached the order of 200-400 $kg.ha^{-1}$ under these conditions. However, this type of management is no longer in use because the required electricity is too expensive. Besides, the necessary infrastructure has largely been destroyed.

Since the political revolution in 1989, the policy for the area has changed from being one of exploitation of the fish-ponds to that of ecological restoration. The basin of Holbina II was already taken out of production in 1989. In that year, the dikes had been opened and these were not repaired until 1996. By 1995 Dunavăţ $II_{1+2}$ had also been withdrawn from use. The basins Dunavăţ I, $II_{3\,\&4}$ continued to be used as a fish farm, at least until the middle of the nineties (Drost *et al.* 1996).

*Within the former fish ponds, there is an extensive canal system*

*For several years during the past decade, Holbina II has been connected to the surrounding canal system by breaches in the dike. In the year 2002, for example, there were 4 small breaches in the ringdike of this type*

### 1.3 Past and present policies concerning the Danube Delta

The Romanian administration has over recent decades pursued an active policy of development concerning the economic potential of the Danube Delta. Reclamation has led to natural areas being put to productive use, divided over fish-farms (40,600 ha), agricultural polders (40,400 ha) and forestry polders (8,700 ha). Semi-natural pasture has come into being on river levees and fossil beach bars covering some 29,200 ha.

The new administration that came into being after the revolution in 1989 has recognised the value of the natural areas in the Danube Delta. It has adopted a policy of nature conservation and ecological restoration. A new authority (the Danube Delta Biosphere Reserve Authority - DDBRA) was established to implement this new policy in the Danube Delta, formally underwritten by the Law on the Danube Delta Biosphere Reserve (Law 82, 1993). The DDBRA is assisted in its tasks by the Danube Delta National Institute - DDNI. Both Authority and Institute are funded by central government. An important impulse to their activities was given by a grant from the Global Environment Fund (US$ 4.5 million) to support biodiversity conservation in the Danube Delta. The Holbina/Dunavăț area is mentioned explicitly as an area for ecological restoration in the final project document of this GEF-Danube Delta Biodiversity Project (World Bank 1994).

### 1.4 Scope of this report

This report represents a summary of the research conducted within the framework of ecological restoration in the Dunavăț/Dranov region, with particular focus on the maintenance of high natural values in the former fish-pond Holbina II. The current report is a follow-up to the publication by Drost *et al.* (1996). The provisional problem analysis given in that publication for ecological restoration of the fish-ponds is as follows:

*'The essential action for ecological restoration is to connect the former fish-ponds with the surrounding open waters by opening the ring-dikes around the fish-ponds. However, the aquatic ecosystems inside the ring-dikes were of great value from the biodiversity point of view. The flooded fish-pond Holbina II contained large areas with mesotrophic clear water systems. The canal water outside the ring-dikes had elevated nutrient contents (especially in phosphorus). Strong flushing of the fish-ponds with this eutrophic water was supposed to undo the mesotrophic conditions. This would cause a shift to turbid water conditions and to domination by algal blooms, with a much smaller value for biodiversity. Marshes are known for their capacity to remove nutrients from through-flowing water. Marshes are omnipresent around the fish-ponds, so it was recommended to study their capacity to act as a filter for the fish-ponds.*

*An additional initiative in the ecological restoration of the fish-ponds could be to restore the "natural" (early twentieth century) water level in the neighbouring Razim/Sinoie Lagoons, which had been greatly increased for irrigation purposes during the past fifty years.'*

In 1995/1996, however, both the problem analysis and the strategy for restoration remained strongly based upon hypotheses. It was therefore recommended that research be undertaken in order to answer the following questions:

- what is the water balance in the Razim/Sinoie complex - what are the possibilities of establishing a more natural water level regime in these lakes?
- what is the capacity of the marshes outside the fish-ponds to provide water for flushing in sufficient amounts and with sufficiently reduced nutrient contents?
- what is the reed bed regeneration in the fish-ponds Dunavăț $II_{1+2}$ , where flooded conditions were restored in 1996 after two full years of drying out?
- what is the stage of development of the eutrophication status (and biodiversity) in the flooded fish-pond Holbina II - how stable are the mesotrophic clear water systems?

In addition, it was recommended that the legal status of the area be clarified and agreements be established with all users and stakeholders in the area.

# 2. Land use and stakeholders

### 2.1 Stakeholders

Several stakeholders have an interest in the management and development of Holbina II and the surrounding polders. The owner of the area is the Romanian State, which has delegated management and administration to the Danube Delta Biosphere Reserve Authority (DDBRA). The reserve authority in 2000 won a court case concerning user rights for the area from the company S.C. Piscicola Murighiol S.A. From that point onwards its legal status has been clear: the DDBRA is the official administrating agency.

The prevalent use of the area is for commercial and recreational fishing on an extensive basis. Apart from burning of reed, which might potentially occur, and the creation of small (1m x 50cm deep) openings in the dams, the fisherman do not apply any management that might lead to improvement of the yield. Because no co-ordinated management techniques are applied productivity is low, in the order of 15kg.ha$^{-1}$. The dominant reed in the area is mainly 'tall' reed that is not yet required in large quantities on the market. However, there is nowadays a good market for 'fine' reed and reed companies run a good business harvesting the fine reed in the Razim lake area. Reed harvest levels are about 2.3 ton.ha$^{-1}$.

There are no fishing permits issued for Holbina II, but unofficial commercial fishing in the area and in the other polders does occur. There are about fifteen fishermen active with a permit on so-called 'Dranov Island'. Fishermen mainly use standing gill-nets and fykes. From the village of Dunavăţ de Jos, in particular, people come down by boat to spend some recreational time in the area fishing. Holbina II is far removed from the tourist mainstream and other forms of tourism have therefore hardly developed. The fishermen and all others dependent on the local economy are thus important stakeholders.

### 2.2 Stakeholder objectives

One of the main objectives in the management of the Biosphere Reserve (DDBR), is 'to maintain or restore the natural operations and functions of the Delta ecosystem' (Staras 2001). For the Holbina/Dunavăţ area the objective of ecological restoration is to 'protect and maintain populations of species and habitats with high ecological value, and to carry out ecological restoration works where the natural or the semi-natural character of areas has been lost as a result of human activity' (Baboianu & Goriup 1995). Staras (2001) emphasises the importance of protecting the remaining valuable clear water habitats in isolated lakes so as to avoid further eutrophication.

As far as we know, the objectives of the local stakeholders concerning ecological developments in the area have not been specified. It is clear that they would benefit from an improvement in the economic potential of the area. However, it is not apparent which ecological state will yield the highest economic return. This depends upon the relative economic value of differing fish species, as well as on the relative importance of eco-tourism versus fisheries. The potential for eco-tourism is assumed to be low, due to the remoteness of the area. As far as the fish is concerned, there are indications that the relative economic value of fish belonging to turbid water systems is similar to that of fish belonging to clear water systems (Năvodaru *et al.* 2000). The desired ecological state from the economic perspective may thus not necessarily differ from the objective of protecting a clear water habitat. We will elaborate in Chapter 9 upon these objectives and how they may be reached.

# 3. Hydraulics of the canal system and the reed beds

**3.1 Canal system in its present state**

Previous research (Drost *et al.* 1996) included a first application of the hydraulic model, SOBEK, to the canal network in the Dunavăţ-Dranov region. SOBEK is a one-dimensional open-channel dynamic numerical modelling system (Anonymous 1999). In 1996 a more elaborate study, utilising more field data and another model (UNDA), was carried out by the Romanian company AQUAPROIECT (Segărceanu *et al.* 1996). The Romanian study was undertaken primarily to assess the effects of future modifications of the canal system upon the water regime in Razim Lake. Essential outputs from these models are the discharges through the three main canals Dunavăţ, Mustaca and Dranov. Table 3.1 summarises this data (for the outlet of each of these canals at the Razim shore). The results from SOBEK for Dranov are structurally too high. This results from an omission in the schematisation: the water losses from Dranov canal to Buhaz-Zaton in the south-east could not be calculated correctly. Both attempts at modelling fail to make correct calculations over the whole range of discharges, from high to low, in Dunavăţ canal; however, at medium discharge the results are good. Under all circumstances, the Dunavăţ canal transports most of the water.

**3.2 Canal system with Cocos canal closed**

The study by Segărceanu *et al.* (1996) was undertaken primarily to predict the effects upon Razim Lake of the proposed blocking of Cocos Canal (for location, see figure 1.2). This canal is one of the main connections in the system that provides Razim Lake with Danube water. Blocking Cocos Canal was proposed by Drost *et al.* (1996) to avoid unfiltered river water from entering the restoration area. The modelling reveals that blocking Cocos canal reduces, at average Danube discharges, the total water supply to Razim Lake from the canals Lipoveni, Dunavăţ, Mustaca and Dranov from c. 80 $m^3$/sec to c. 75 $m^3$/sec. This is a reduction of only 7 %.

**3.3 Reed beds**

The potential of the marshes in the region (the Mustaca reed bed) to meet the filtered water requirements of the former fish-ponds was studied by van Prooijen (1997). This study involved hydraulic modelling of the canal system and of the reed beds in SOBEK. After calibration and validation of the model with data from the present situation, the model was utilised to calculate the water levels and discharges in various future options employing modified water circulation. Field data concerning

| $m^3$/sec | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | *outlet Dunavat* | | | *outlet Mustaca* | | | *outlet Dranov* | | |
| | Drost *et al.*1996 | **Field data AP** | Segarceanu *et al.* 1996 | Drost *et al.*1996 | **Field data AP** | Segarceanu *et al.* 1996 | Drost *et al.*1996 | **Field data AP** | Segarceanu *et al.* 1996 |
| **flood** | 49 | 44 | 59 | 47 | 31 | 31 | 60 | 31 | 32 |
| **medium** | 28 | 29 | 32 | 25 | 19 | 20 | 31 | 14 | 16 |
| **low** | 9 | 18 | 17 | 7 | 9,2 | 10 | 7 | 9,3 | 6,7 |

*Table 3.1. Modelled and measured discharges in the three main canals through the Dunavat/Dranov region (after Drost et al. 1996 and Segărceanu et al. 1996). Fielddata were collected by Aqua Project (AP; Segărceanu et al. 1996)*

the water budget of this reed bed was also collected in 1996 and 1997 by Oosterberg *et al.* (1998). The results are presented in Table 3.2.

The field data and the model fit well. The production of filtered water by the Mustaca reedbed can be increased by up to four times by widening the water inlets to the marsh, together with measures to prevent losses of filtered water to Dranov Canal. By then, the residence time of the water in the reed bed is reduced to 10-15 days. This is still sufficient for the physical and chemical filtering processes (van Prooijen 1997). However, in this scenario it is necessary to be aware of possible shortcuts in water circulation within the reed bed. Natural creeks may come into being through which large amounts of water may bypass the reed beds without being filtered.

| | *present situation* | | | *after modifications* | |
|---|---|---|---|---|---|
| | 1996 | 1997 | model | 20 m wide inlet | 250 m wide inlet |
| Flood | 7,5 | 8,6 | 8 | 35 | 40 |
| Medium | 4,5 | 5,2 | no data | no data | no data |
| Low | 2,6 | 2,9 | 3 | 11 | 12 |

*Table 3.2. Supply of filtered water in the present situation ($m^3$/second; averages per month) by the Mustaca reed beds, as measured in the field in 1996 and 1997 by Oosterberg et al. (1998); and as modelled by van Prooijen (1997).*

# 4. Hydrology of the Razim/Sinoie complex

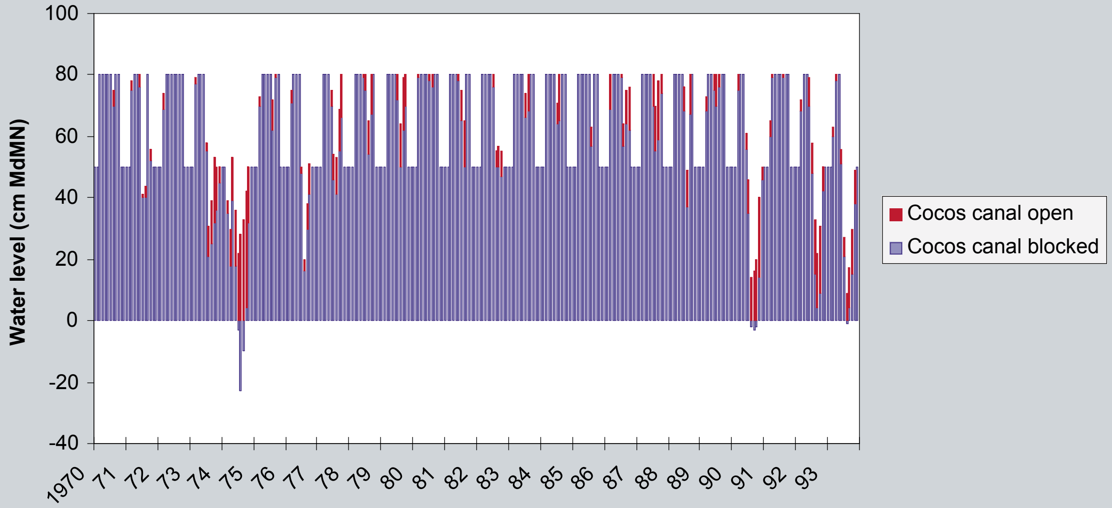
The Razim/Sinoie complex has been greatly modified by human impact over recent decades. These modifications have tended to increase its economic function - at least under communist policy - at the expense of its value for biodiversity. The Razim/Sinoie complex was at the beginning of the twentieth century flushed with Danube water through the artificial canal system. This caused a shift from brackish to fresh water conditions. It was consequently converted into a reservoir for irrigation water. This implied a complete separation from the sea and a rise in the water level of more than 50cm. As a result, the reed beds in the Dunavăţ/Dranov region faced an increased duration and depth of inundation.

A reconsideration of water management in the Razim/Sinoie complex would be useful, but this is beyond the scope of the present report. The Razim/Sinoie complex is considered here-under only in so far as it is affected by proposed modifications to the canal system in the Dunavăţ/Dranov region. The proposed blocking of Cocos Canal (see chapter 3) is the central issue.

Blocking Cocos canal causes a reduction in the fresh water supply to the Razim/Sinoie complex. Figure 4.1 shows that this will result in periodically lowered water levels. When the water level drops below 20cm above sea-level, problems arise with the intake of irrigation water in quantities common before 1989. With Cocos open, this happens in two out of 24 years. With Cocos blocked it would happen in four out of 24 years, according to the model study (Figure 4.1). However, the use of irrigation water declined by more than a factor 2 over the years 1990–2000 (unpublished data DDNI). This decline was most likely due to the high financial costs of pumping.

Salinity, too, is influenced by the blocking of Cocos canal. The average annual maximum salinity in total soluble salts (modelled for the years 1970-1993) increases from 339 mg/litre with Cocos open, to 353 mg/litre with Cocos blocked. However, the limits for appropriate irrigation practice are not exceeded. The annual average residence time of water in the Razim complex with Cocos canal fully functioning is more than 200 days. This is a very long residence time, contributing strongly to the blooming of algae. The blocking of Cocos canal will lead to a further increase in residence time, but as conditions are already favourable for algal blooming with Cocos open, no increase of blooming is expected with the canal blocked.

*Figure 4.1. Calculated water levels in Razim/Sinoie with Cocos canal open and blocked. After modelling results by Segarceanu et al. (1996). MdMN refers to Black Sea Level.*



# 5. Filtering processes in reed beds

It was hypothesised that flooded reed beds in the region could supply filtered water, with lower levels of nitrogen and phosphorus, to the ecological restoration area (Drost *et al.* 1996). Previous research (Drost *et al.* 1996) had revealed an N/P ratio in Holbina II that indicated phosphorus limitation - and no nitrogen limitation - as a key factor limiting the development of algal blooms in Holbina II. Mesotrophic clear water ecosystems in Holbina II were associated with total-phosphorus contents below 0,10 mg P/litre.

In order to validate the above-mentioned hypothesis, filtering processes were studied in the Mustaca reed bed (Figure 1.2) in 1995, 1996, 1997 and 1998. For each year, phosphorus and nitrogen contents were determined in in-flowing river water and out-flowing marsh water. Detailed measurements of the in-flowing and out-flowing water quantities were determined in 1996 and 1997. All results have been published by Oosterberg *et al.* (1998) and are summarised below.

The Mustaca marshes (2,536ha) provide a good example of naturally flooded reed beds. The residence time of water in the reed bed varies from 50 days during the spring flood, to over 90 days during a normal summer. The sediment input is huge: over 3,000 kg/ha, of which 75 - 97 % remains in the reed beds. During the growing season, total inputs of nitrogen and phosphorus amount respectively to 250-300 kg N/ha and 15-20 kg P/ha. Table 5.1 summarises the mass budgets for nitrogen and phosphorus in the marshes. The marshes remove 65 to 85% of incoming nitrogen, presumably by a combination of sedimentation of particulate nitrogen and release of NOx-nitrogen into the atmosphere as a result of de-nitrification under summer conditions of anoxia in the peat soils.

The marshes remove less than 20% of the incoming phosphorus. This is consistent with knowledge on the functioning of so-called 'helophyte filters' in the Netherlands. Significant removal of phosphate by helophyte filters occurs when the accumulated primary production is regularly removed after mowing (De Ridder 1996). Without such a management, sedimentation of particulate phosphorus must be the dominant filtering mechanism. But anoxic conditions during summer stimulate the conversion of fixed phosphorus in this sediment into more mobile ortho-phosphate. This is taken up in the mass-

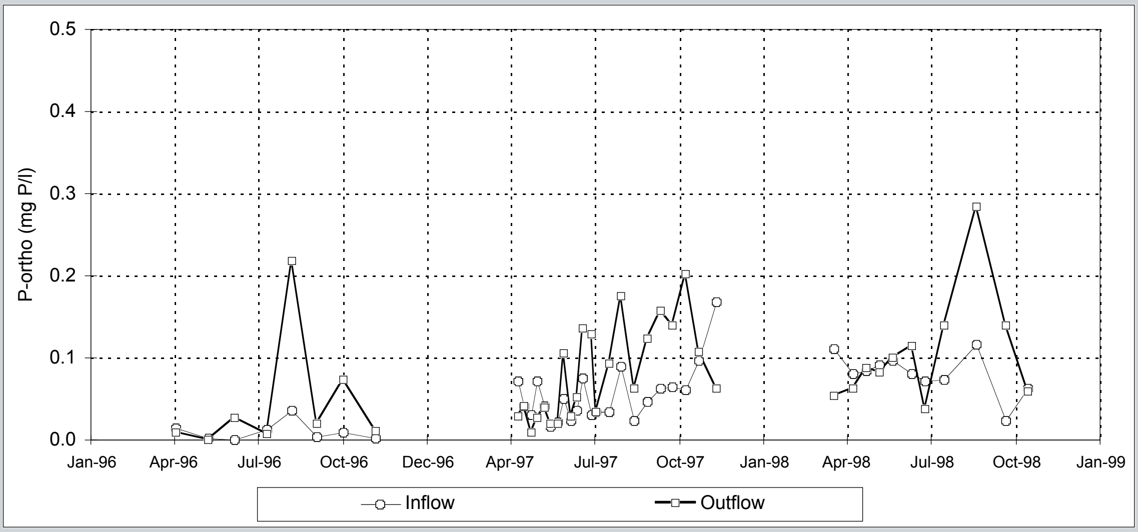



*Figure 5.1. P-ortho concentration in inflowing and outflowing water of the Mustaca marshes (from Oosterberg et al. 1998).*

# 5. Filtering processes in reed beds

| | 1996 | | 1997 | |
|---|---|---|---|---|
| | **in** | **out** | **in** | **out** |
| Suspended solids | 3101 | 78 | 5215 | 1293 |
| P-ortho | 0,4 | 2,0 | 2,0 | 3,9 |
| P-other | 5,9 | 3,9 | 5,5 | 2,4 |
| P-total | 6,3 | 5,9 | 7,5 | 6,3 |
| N-org + $NH_4$ | 41,8 | 17,4 | 30,0 | 22,1 |
| $NO_3$ | 69,0 | 0,8 | 63,1 | 9,5 |
| $NO_2$ | 4,3 | 0,8 | 2,0 | 1,6 |
| N-total | 115,1 | 18,9 | 95,0 | 33,1 |

*table 5.1. Summarised budgets for total suspended solids, nitrogen and phosphorus in kg/ha in the Mustaca marshes (2,536 ha), over April to November in 1996 and 1997. After Oosterberg et al. (1998)*

movement of water through the marshes. During this movement it may be converted at various times into particulate organic forms and back into ortho-phosphate. Eventually, most of it leaves the marshes with the water flow. The average content of total-phosphorus in the water, as long as it was flowing out of the marshes during summer, varied in 1995 to 1998 between 0,15 and 0,25 mg P/litre. Values of over 0,30 mg P/litre are not exceptional in August. These extremes, however, occur in periods when the water flow from the marshes is almost zero. Nevertheless, even contents of 0,15 - 0,25 mg P/litre represent unsuitable conditions for mesotrophic clear water systems. Dutch studies suggest that water systems with values of P-total over 0,10 mg P/litre are eutrophicated turbid water systems (Drost *et al.* 1996).

# 6. Indications of trophic changes

The status of the former fish-pond Holbina II ecosystem has changed over time at least once from a state of clear water to a state in which the water was turbid, and back again. From 1995 to 1997 the water was observed to become turbid (see Figure 6.1) and aquatic macrophytes became scarce. In early September 2002, however, the water was clear again and aquatic macrophytes were abundant (Bos 2002, Chapter 7).


*Figure 6.1. Secchi depth at fixed sample points in Holbina II for the late summer of the years 1995, 1996, 1997 and 2002. Average Secchi depth was 122cm in 2002, while it was only 70cm and 54cm in 1996 and 1997 respectively.*

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# 7. Vegetation changes

The vegetation in Holbina II consists of reedbeds, dominated by *Phragmites australis*, and open water with or without aquatic macrophytes. Developments in the vegetation in Holbina II were studied by direct observations in the field (aquatic vegetation) and with the help of satellite images (reed beds).

Holbina II was re-flooded in 1989 after a period of many years under conditions of regular drainage (see box 1). The first available satellite image of the re-flooded polder was made in August 1991. Subsequently available images were analysed for 1993, 1995, 1996 and 1997. According to increasing vegetation index values, three major units of vegetation were identified on the images: (1) dense reed beds (2)'open' vegetation, and (3) open water. The open vegetation predominantly consists of open stands of reed; it also includes some dense aquatic vegetation. The satellite images allowed the determination of the surface areas of each of these vegetation classes in the three sub-units of Holbina II. The results are shown in Figures 7.1 A, B and C. The vegetation cover increased most in Holbina II-north. It did so in the first few years after re-flooding, remaining almost constant after five years. The other sub-basins showed a very constant pattern of vegetation.

Although the major vegetation structures remained very constant, aquatic vegetation underwent a drastic change. Large fields of submerged *Myriophyllum spicatum / Potamogeton spp.* vegetation, associated with transparent water and observed in Holbina II-north in 1994 and 1995 (Rijsdorp *et al.* 1995, Buijse *et al.* 1997), gradually disappeared in these places over 1996 and 1997. By 1998, all *M. spicatum* had disappeared. What was left was turbid open water, coloured green by suspended algae. The dominance of aquatic vegetation, associated with transparent water, persisted within Holbina II only in the "dead ends" of drowned canals in dense reed beds. These stands consisted exclusively of *Ceratophyllum demersum*. In September 2002 the aquatic vegetation was again found to be dominated by macrophytes: plant species characteristic of nutrient-rich waters, such as *C. demersum* and *Valisneria spiralis* (Bos 2002). In 2002, *Myriophyllum verticilatum* and *P. pectinatus* were also encountered frequently. Both the deeper open waters and the canals featured this clear water situation, with an associated high diversity in bird species.

Fish farming and its cyclic water level management continued in the basins of Dunavat $II_{1+2}$ and Holbina I up until the year 2000. Conspicuous in these basins were the transparent water systems with fields of *Myriophyllum / Potamogeton* in the first years after a re-flooding. Extremely rich vegetation was, for example, present in Dunavat $II_1$ in spring and summer 1996, and in Holbina I in August 1997, immediately after re-flooding. The aquatic vegetation was rather diverse in this first season of development. Various species of *Potamogeton* were present, together with *Najas marina* and *M. spicatum*. In the second year, the aquatic vegetation tended to become more dense and less diverse and was increasingly dominated by *M. spicatum*. A few years later, aquatic vegetation was found to be disappearing and the transparent water tended towards turbid conditions.

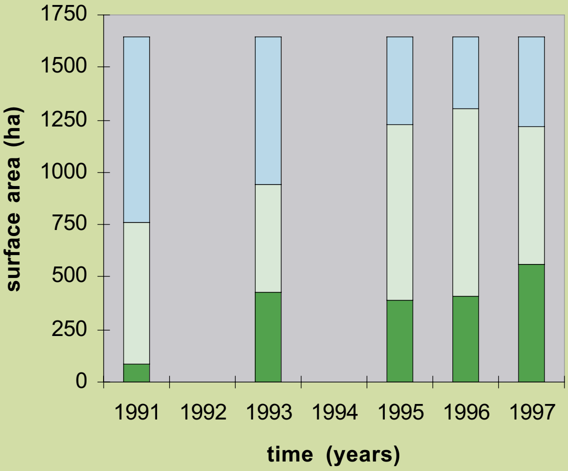


Fig 7.1A

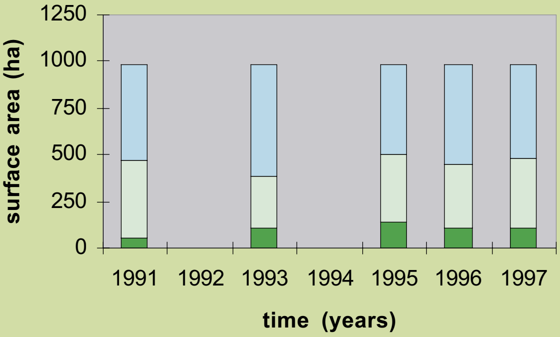


Fig 7.1B

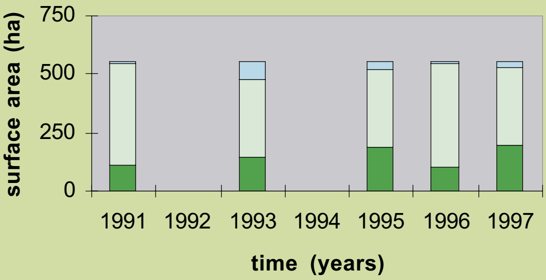


Fig 7.1C

**Figure 7.1**. The development of the surface areas of dense reed beds (dark green, photo 1), open vegetation (light green, photo 2) and open water (blue, photo 3) in Holbina II after re-flooding in 1989. Panels refer to the different sub-basins within Holbina II; A) north B) middle C) south.

*Image of a dense reedbed, dominated by Phragmites australis, taken from within. In the front of the picture the bow of a canoe is visible.*

*An example of open vegetation; a stand with sparse reed Phragmites australis.*

*There are large bodies of open water within Holbina II north & middle.*

# 8. Integration

Earlier analysis of data (Drost *et al.* 1996) resulted in the hypothesis that the valuable transparent water systems in Holbina II-north were at risk of turning into turbid water systems should greater amounts of eutrophic canal water be allowed to enter the former fish-pond. Isolation of Holbina II from the eutrophic water in the canal system was considered essential. Water supply to the former fish-ponds was to be realised via filtering reed beds. The filtering process should reduce loads of phosphorus and nitrogen. Further research was recommended to determine the degree of nutrient retention by reed beds and the quantities of filtered water that could be produced. Continued monitoring of trophic developments in the former fish-ponds should reveal how stable were the transparent water systems, or how they were decreasing or increasing in size.

Monitoring of trophic developments revealed that the transparent water systems of the entire area of Holbina II were gradually relapsing into turbid conditions. There was a concurrent disappearance of submerged vegetation. This happened despite a relative isolation of Holbina II from canal water. The development continued even after the spring of 1997, when the isolation of Holbina II had been strengthened by blocking all breaches in the ring-dike. However, in the summer of 2002 the water in Holbina II was again clear. In Holbina I and in Dunavăţ $II_{1+2}$ , new and very rich transparent water systems developed in 1996 and 1997. This development was associated with re-flooding of basins after draw-downs, a normal procedure in fish-farm management. Later development in these basins has not been followed systematically.

The study on filtering reed beds revealed that the amounts of water potentially produced by the reed beds could be sufficient to meet the water needs of the former fish-ponds. Retention rates for suspended silt and for nitrogen were very high. However, no effective retention was ascertained for the essential nutrient phosphorus. Filtered water from reed beds contains such elevated quantities of dissolved ortho-phosphate that this water may prove unsuitable for the sustaining of transparent water systems under the stagnant conditions of the former fish-ponds (Oosterberg *et al.* 1998).

**8.1 Current understanding of eutrophication patterns and processes**

The patterns and processes shown by aquatic vegetation in the Danube Delta Lakes do, to a great extent, conform to current theory on lake functioning (Oosterberg *et al.* 2000). However, factors inducing stability in the macrophyte-dominated state of lakes may not necessarily apply to 'open', flood-pulsed systems such as flood plains or delta-lakes. This was one of the conclusions of an extensive study on a number of Danube Delta lakes (Oosterberg *et al.* 2000). According to this study, the nutrient levels of the water in the Danube Delta fall within a range (0.12-0.15 mg $P.l^{-1}$) that would allow both clear and turbid states. A switch to a turbid state is determined by the interplay of physical and chemical factors, but is especially steered by biological factors. The main factors regulating phytoplankton biomass in summer appear to be water depth and abundance of aquatic macrophytes (Oosterberg & Bogdan 2000), though the latter is not an entirely independent variable. A short residence time of the water is assumed to prevent algal blooming. This process is called 'flushing'. This 'flushing' is especially important when the Cumulative Residence Time (CRT) becomes less than 10 days.

Some fish species, e.g. Bream *Abramis brama*, contribute to the eutrophication process by grazing on zoöplankton and by causing re-suspension of sediments (Scheffer1998). Predatory fish, such as Pike *Esox lucius*, keep the populations of these fish species low and in this way positively affect water quality (Klinge *et al.* 1995, Nagelkerke *et al.* 1999). However, in the Danube delta system where lakes are all interconnected, fish communities are assumed to be an indicator of trophic state and not a dominant steering factor (Năvodaru *et al.* 2000).

The role of reed beds is still poorly understood. Reed beds may negatively affect water quality via P-loading in summer (Oosterberg *et al.* 1998). However, reed beds are considered to counteract phytoplankton

When the water is clear, as it was in 2002, patches of floating leaves of macrophytes can be observed that serve as a food source or a resting place for many species of birds. (Holbina $II_{middle}$, September 2002)

bloom via the production of humic acids and by flushing with water retained after the spring flood-pulse (Oosterberg & Bogdan 2000). Reed habitat is very important as a spawning ground for Pike and other predatory fish (Nagelkerke *et al.* 1999), thus indirectly affecting water quality. Developments in the reed habitat are of crucial importance for the ecosystem at large; this due to the above mentioned effects on water quality, its role as a foraging and breeding habitat for many organisms and the potential of reed to colonise large areas. In the absence of a fluctuating water level, reed stands are expected to deteriorate (Clevering 1999). Stands located in higher regions will become more dense over the years, but finally suffer from acidification. Reed in lower parts will tend to disappear. In contrast, under a dynamic water-level regime variation will occur in the reed habitat with respect to age and density of the stands. Dynamic water levels will lead to more vigorous stands and to better opportunities for fish to reproduce (Nagelkerke *et al.* 1999). During periods of low water levels, reed will be able to penetrate into lower lying areas but the deepest parts of lakes will not be colonised.

**8.2 Interpretation of the developments in Holbina II**

Holbina II has always been relatively isolated from surrounding waters. In 1996, this isolation was made almost complete by blocking the four breaches that had a total wet surface of $10m^2$. The only connection with the canals after this was in the form of four culverts, designed for a maximum flow of 2 $m^3.s^{-1}$ per culvert. Evaporation loss for the area as a whole amounts to 1.4 $m^3.s^{-1}$ . Under these conditions, the residence time of water in Holbina II is calculated to be higher than 40 days during periods of high discharge and up to 200 days during periods of low discharge (van Prooijen 1997). By 2002, there were four new breaches in the ring-dike, but these were very small (1m wide by 0.5m deep, total wet surface of $2m^2$). In spite of the isolation, the ecosystem nevertheless reverted from a turbid plankton-dominated state to a macrophyte-dominated state with clear water. This course of events in Holbina II underlines the conclusion arrived at by Ibelings *et al.* (2000) that both clear and turbid states are possible in Danube Delta lakes, given the prevailing concentrations of phosphate. The ecosystem is inherently unstable and may switch from the clear water to the turbid state, and back again.

# 9. Strategy for ecological restoration

### 9.1 Possible target states

Wetland restoration is the process of restoring ecological functions to degraded wetlands (Larson 1991). Given the objectives of the Biosphere Reserve (DDBR, see paragraph 2.1), there are two ecological target states relevant for Holbina II. The first possible target is the 'black-water' or 'reference' ecosystem state. This is a state similar to its historical condition, or as it is found elsewhere in the Delta. Originally Holbina II was a low-basin, peat-reed marsh situated on the periphery of river branches, with little open water (Rijsdorp *et al.* 1995). This state is characterised by low connectivity, the regular occurrence of anoxic conditions in summer, organic soils, a high abundance of the *C. demersum* or the *Nitellopsis obtusa* community and the presence of rare fish species (black fish, Oosterberg *et al.* 2000). The water is usually clear but has long residence times. It will be referred to as the 'black-water state' (where water is of lake type 3 in the typology of Oosterberg *et al.* 2000). The second possible target might be a clear water ecosystem, with lower residence times and high biodiversity in flora and fauna (lake type 2 in the typology of Oosterberg *et al.* 2000) representing more common species than those organisms found in the first target state. This latter will be referred to as the 'clear water' state, characterised by clay soils, a high abundance of the *Potamogeton pectinatus* or the *P. trichoides* community, with eurytopic fish. Under natural conditions, these states co-occur, with 'clear-water' areas near the river, generally in the larger lakes, and 'black-water'conditions in the periphery, usually in smaller lakes. Also within Holbina II, there were gradients from areas with 'clear-water' characteristics to areas that are more isolated, having a 'black-water' character (Buijse *et al.* 1997, Bos 2002). In Drost *et al.* (1996) a strategy is outlined for the establishment of a self-regulating wetland in the Dunavăț/Dranov region, with decreasing riverine influence in isolated parts. This strategy involves integration of the separate fish-ponds to form one unit and results in a combination of targets 1 and 2. Other possible ecological target states, such as one characterised by turbid-water, are not in line with the management objectives and will not be considered here.

### 9.2 Constraints

Man-induced changes in the area are manifold, leading to constraints on potential ecological developments. The artificially high water levels and higher regional connectivity related to the economic functioning of the Razim/Sinoie complex have already been discussed in Chapter 5. Other constraints are represented by the high nutrient levels in river water (Staras 2001), the fact that in some areas of Holbina II the peat soil has been burned and the presence of a ring-dike around the former fish-pond. These constraints may, to some extent, be lifted locally, e.g. by lowering the dike or by the creation of new breaches in it. The lowering of water levels, however, has regional consequences, while measures to reduce the nutrient input need to be taken at national, or even international level. Burning of the peat soil in Holbina II has led locally to deeper water with mineral soil, representing a constraint impossible to resolve within a short time-scale.

### 9.3 Strategies

The choice between different ecological targets is in the first place a political one. For this reason, we will here describe strategies that may lead to one or other of the targets specified above, or combinations of both. It is important to stress that management activities will affect the relative occurence of both target states, rather than resulting in the exclusive occurrence of a single state. For example: even in a situation, dominated by clear water with short residence times, there will be localities where 'black-water' situations can be observed. We will evaluate the risks, costs and benefits of the different strategies, ending with a recommendation. A reduction in nutrient levels in the water of the Danube river would be beneficial within the framework of all strategies discussed below. This is worth striving for at a political level, but falls beyond the scope of this report.

**Black-water state**

To attain the reference state of reed marsh with little lateral connectivity and (little) open water of lake type 3 (classification by Oosterberg *et al.* 2000) it is necessary to create optimal circumstances for reed development whilst maintaining an isolated cha-

racter. Two levels of scale are relevant here: the scale of the former fish-pond Holbina II and that of the Dunavăţ-Dranov region as a whole. Holbina II is relatively isolated from river water, but this is achieved at the expense of reduced water level dynamics. Too little dynamic in water level regime has negative consequences for the vigour and variety of reed stands. To solve this, new and wider breaches would have to be created in the Holbina II dike, but this would enhance connectivity and the target community (black-water) would be likely to develop only in remote corners of the former fish-pond.
In our opinion, the black-water state requires consideration on a regional scale (after Drost *et al.* 1996). Measures taken on a regional scale would be more likely to contribute significantly to the restoration of former fish-ponds to the 'black-water state'. The most important measures would be to establish a natural or near-natural hydrological regime, by lowering the water levels in the Dunavăţ-Dranov region, by lowering the amounts of water flowing through the region and by reducing the impact of dikes. Reducing the waterlevel leads to shallower lakes and an enlargement of the area that could be colonised by reed. One of the side-effects of such a course of action would be reduced availability of water for irrigation in the Razim/Sinoie complex, which might be acceptable given the reduction in demand for such a water supply over the nineties. The suggested measures would also lead to reduced navigability, less open water and the occasional occurrence of oxygen deficiencies. This would be negative for fisheries in the area but positive for rare organisms dependent upon this type of habitat, such as European mid-minnow *Umbra krameri*, *Misgurnus fossilis* and Crucian carp *Carassius carassius*. It should, however, also be mentioned that the lakes in this type of habitat fulfil an important spawning and nursery function for commercially valued species such as Pike *Esox lucius* and Tench *Tinca tinca*.

**Clear water state**

The most recently observed state of the lakes in Holbina II was that of clear water, in the late summer of 2002. However, nutrient levels are such that the water may also revert to a turbid state, as has happened in recent history. Our current understanding of the eutrophication process yields several hypotheses concerning measures to enhance conditions for a continuing state of clear water. A low water residence time, shallow lakes and healthy reed vegetation are supposed to provide suitable conditions for aquatic macrophytes and a high population of predatory fish, together leading to clear water conditions. The creation of new and wider breaches reduces residence time, introduces more dynamic water levels and enhances sedimentation. The size, number and position of the breaches determine which areas will be affected most, and to what extent (see van Prooijen 1997). A lowering of the regional water table would have additional positive effects on water depth and the development of reed. But, lowering the water table also has the effect of a reduced connectivity, enhancing the 'black water' state more than the 'clear water' state.

However, our knowledge concerning the interaction of the various processes leading to turbid water conditions is limited. The case of Holbina II yields insufficient insight into their relative significance for the locally observed switches between clear and turbid states. Even the study of these processes in 24 lakes in the Danube Delta (Oosterberg *et al.* 2000) failed to yield sufficient insight for confidence regarding the consequences of, for example, a reduction in residence time for Holbina II. Above all, the crucial hypothesis specified in Drost *et al.* (1996), that reed beds might provide a source of water low in nutrients, appeared not to be valid for phosphate (Oosterberg *et al.* 1998). There exist, on the other hand, unique opportunities in the region to study these issues. The presence of a number of former fish-ponds within the same region (Holbina, 4 basins and Dunavăţ, 5 basins) provides excellent opportunities for an experimental approach in which only one factor is varied. In Appendix 1 we briefly elaborate upon a proposal for such an experiment. The results of a systematic trial, with replication and control, would allow better founded decisions on ecological restoration in the region and abroad.

*Black water ocurs in areas with high residence times and a high ratio of reed to open water.*

In the short term, it would seem most logical to keep the 'clear water' state as the ecological target for the larger part of Holbina II. The alternative ecosystem state that might be advocated based upon the management objectives, the 'black-water' state, requires measures with important regional consequences. These consequences need to be weighed in political debate against the benefits of safeguarding habitat for rare organisms. Given that the recent ecosystem status of Holbina II was favourable from a biodiversity point of view, given the inherent instability of the ecosystem and given current uncertainties concerning the effects of hydraulic restoration work, we recommend no immediate implementation of ecological restoration measures.

*Reed beds have an impact on water quality in many ways (see text). This photo shows adjacent reed stands of different age. (Holbina $II_{middle}$, September 2002)*

# 10. Recommendations

The ecosystem in Holbina II was most recently (2002) in a 'clear water' state, with a high value of biodiversity. This ecosystem state is one of the possible states consistent with management objectives. It is recommended that this 'clear water' state be retained as the ecological target.

There are unique opportunities in the Dunavăţ/ Dranov region for (semi-) experimental research related to the effect of dominant ecosystem variables upon clear-turbid transitions. It is therefore recommended that international funding be sought to finance this type of research.

Holbina II has been observed over successive years to switch from a clear water to a turbid water state, and then to revert again to the (present) clear water state. Given the inherent instability of the ecosystem, given the uncertainties concerning the effects of hydraulic works for ecological restoration and given the fact that the present state is that of a clear water system, it is recommended that the responsible authorities refrain from investing in (further) ecological restoration measures unless these measures be accompanied by systematic study.

One simple measure that would enhance the naturalness of the area would be the removal of the electric power lines. The presence of these lines is an unnecessary cause of casualties amongst the bird population. Given that the redundant material may be sold, this would not be an expensive measure.

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# Appendix 1 Experimental approach to ecological restoration

**Introduction**

The patterns and processes shown by aquatic vegetation in the Danube Delta Lakes do, to a great extent, conform to current theory on lake functioning. But factors inducing stability of the macrophyte-dominated state of lakes may not necessarily apply to 'open', flood-pulsed systems like flood plains or delta-lakes (Oosterberg *et al.* 2000). In Chapter 8, we discussed current understanding of the relative importance of various factors such as water depth, nutrient loading, water residence time and biotic factors such as the area of reed habitat, presence of aquatic macrophytes and numbers of predatory fish. Several hypotheses result from this analysis and one of them will be elaborated upon in this appendix.

**Hypotheses**

We hypothesise that low water residence times and dynamic water levels in lakes go hand in hand, positively affecting water quality in several ways. Low residence times, favour aquatic macrophytes over plankton, due to flushing. Enhanced sedimentation rates result in shallower lakes, more suitable for macrophytes. The variety and vigour of reed stands is enhanced, with secondary effects upon predatory fish. High sediment turbidity will be found near inlets of water, while in remote corners 'black-water' situations might occur.

**Experiment**

It is proposed that these hypotheses be tested in the Dunavăţ/Dranov region by manipulating the residence time of water in eight former fish basins (Holbina I, II$_{\text{north, south and middle}}$, Dunavăţ I and Dunavăţ II$_{1+2+3+4}$). Based on spatial position, size, ratio of reed to open water and area of deep water, pairs of basins should be selected that are as similar as possible in these measures. A treatment of either short or long water residence time should be assigned randomly to the members of these pairs. The results of the experiment should be measured in terms of biodiversity by assessing development in the vegetation and fish populations. Data will need to be collected over at least two years, but preferably over a longer time-span. Insight into such mechanisms will be enhanced by interpreting these results together with data on observed residence time, turbidity and other relevant abiotic data and comparing the different basins. In addition, valuable information regarding our hypotheses may be found by interpreting the spatial patterns in turbidity and species composition within each basin.

**Note**

It is of crucial importance that local fisherman and others be informed about the purpose and set-up of the study. Care needs to be taken that the practical daily routine of fishermen is not disrupted by the blocking of small breaches which only have little relevance for the trial.