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Management in freshwater ponds and shallow lakes in the Netherlands

A review of the effects on emergent vegetation diversity and terrestrialisation

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Abstract

From recent literature it is clear that most management in ponds and shallow lakes is focused on the water body itself. Mostly the aim is to reduce nutrient availability, so to restore the clear water state including the aquatic vegetation. Given the fact that the water and the banks interact closely with one another, it is necessary to view them as an integrated system. Several measures beneficial to the aquatic system are also beneficial for the creation of diverse emergent vegetation, making them perhaps more effective than previously thought.

In this thesis, nine different management options (grazing, mowing, cleaning, burning, dredging, biological management, water level manipulation, chemical treatment and bank restoration) were examined for their effects on the expansion of emergent vegetation into open water and the diversity of the vegetation. Of the environmental factors, expansion into open water appeared to be influenced in several cases by the depth of the water, steepness of the bank and herbivory. Whilst the diversity of the shoreline vegetation appeared to be influenced by the nutrient availability, herbivory, wind and waves.

Based on the knowledge on management options and environmental conditions, a management scheme was developed, indicating the preferred management for expansion of emergent vegetation and increasing the emergent vegetation diversity. A combination of natural water level fluctuations, occasional dry-outs, bank restoration and extensive grazing appeared to be most effective in promoting colonisation of open water by emergent vegetation and increasing the vegetation diversity.

Keywords

Emergent vegetation, biodiversity, terrestrialisation, management

- Cover picture adapted from (Hintzen, 2013).

Contents

1 Introduction

Freshwater aquatic ecosystems and accompanying wetlands are important from the perspective of biodiversity preservation (Céréghino *et al.*, 2008; Declerck *et al.*, 2006; EPCN, 2008; Sarneel *et al.*, 2010; Scheffer *et al.*, 2006).
These systems are under the influence of hydroseral succession, so-called terrestrialisation. This succession from open water to land occurs mostly in stagnant or slow moving water bodies such as ponds and shallow lakes.
A pond is generally regarded as a small and shallow body of fresh water, smaller than 8 hectares, either manmade or of natural origin (Peck, 2009). However, opinions on the definition of a pond vary greatly. A shallow lake is a water body in which light can reach the bottom, allowing plant growth throughout the lake. Also there is no stratification of the water column (Van der Wijngaart, 2008; Wetzel, 2001).
The terrestrialisation of ponds and shallow lakes is accelerated by the expansion of emergent vegetation into the water (Zhang *et al.*, 2012). The early-successional terrestrialisation stage is especially important because it creates an interface between aquatic and terrestrial ecosystems and can be quite species-rich compared to these two ecosystems (Nilsson & Svedmark, 2002). In this system the presence of emergent vegetation is desirable because it creates habitats for numerous plants, insects, amphibians, fish and birds (H. Coops, Vulink, & van Nes, 2004; Van Kouwen, 2011).
In order to maintain the early-successional terrestrialisation stages management is necessary. Many shallow water bodies would otherwise turn into land due to succession. This management has a profound effect on the emergent vegetation composition and the colonisation of open water (Van Kouwen, 2011).
Nowadays ponds and shallow lakes are threatened by drainage, pollution and urban development (Wood *et al.*, 2003). These human influences may cause changes in these ecosystems (Folke *et al.*, 2004). In recent years the area covered by emergent vegetation has decreased dramatically (Mettrop *et al.*, 2012). Also terrestrialisation has halted in many of the Dutch ponds and lakes (Lamers *et al.*, 2004).

1.1 Research questions

In light of high biodiversity found in ponds and shallow lakes, there should be more focus on these ecosystems in protection and management strategies (Davies *et al.*, 2008). Possibly management can play an essential role in the preservation of the diversity (Sayer *et al.*, 2012). However, little is known about the effects of current management practices on the colonisation of open water and the diversity of the emergent vegetation. To investigate the role of management the following research question is formulated: What are the effects of management on expansion towards open water and composition of emergent bank vegetation in lowland ponds and shallow lakes?

This is further divided into the following sub-questions:

- Which environmental factors influence early-successional terrestrialisation and diversity? (chapter 3.1)
- Which types of plant communities are important in the early stage of terrestrialisation? (chapter 3.2)
- What types of management are often employed in ponds and shallow lakes? (chapter 4)
- What are the effects of these types of management on the colonisation of open water and the diversity of emergent bank vegetation? (chapter 4)
- Can knowledge from management of stagnant waters be applied to other water bodies? (chapter 4.9.1)
- What are the implications for future management? (chapter 5)

1.2 Scope & method

The purpose of the study is to clarify the role management can play in the preservation of early-successional terrestrialisation stages in freshwater ponds and shallow lakes in the Netherlands. The focus lies on emergent vegetation as the driving force behind this process. The effects of management on the diversity of the emergent vegetation and the effects on their expansion into open water are addressed.
This research is done in the form of a literature review, combining the available knowledge on the subject of management into an advice on best practice regarding the maintenance of early-successional terrestrialisation stages and its vegetation diversity.

2 Emergent vegetation

In and next to shallow lakes and ponds one can distinguish the aquatic, amphibic and terrestrial zone (figure 1) (Sollie, Brouwer, & De kwaadsteniet, 2011). The amphibic zone is the zone between the High water level (HWL) and the low water level (LWL). Terrestrialisation starts with the presence of submerged aquatic vegetation followed by the colonisation of open water by emergent vegetation from the bank (Sarneel, 2010).
Emergent vegetation grows in the amphibic zone. Emergent vegetation is rooted in the soil and growing in or close to water, protruding from the water into the air (Allen, 2000). The presence of emergent vegetation is important for several fish species, which use it as breeding habitat and nursery (Van Kouwen, 2011). Also emergent vegetation helps to purify the water in agricultural areas. It serves as a trap for nutrients and sediments from the water (Hefting *et al.*, 2013).

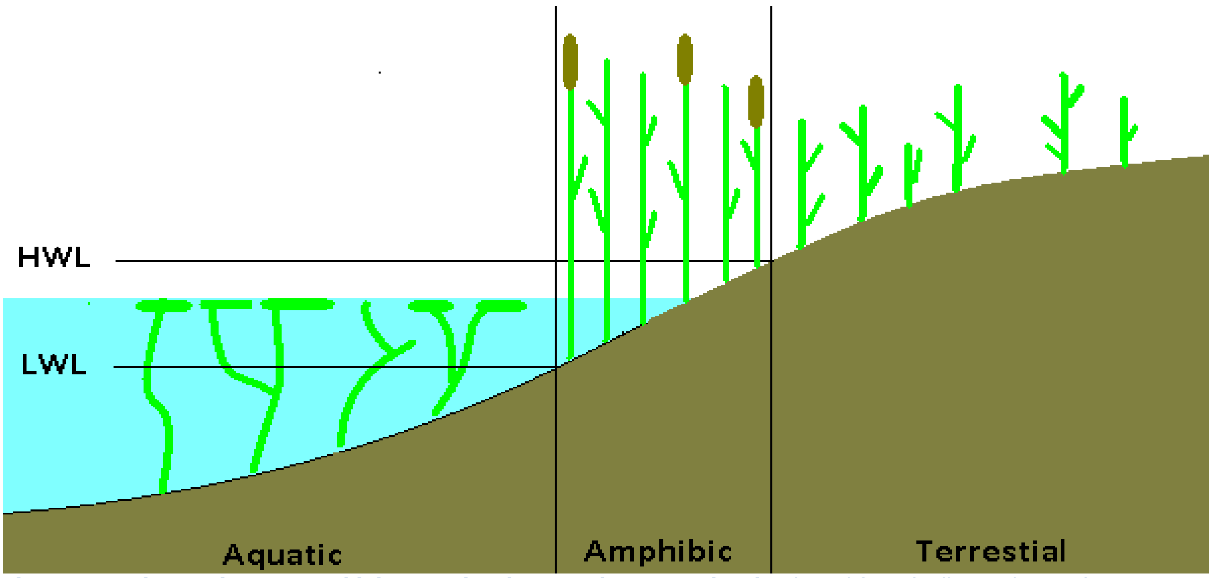

Figure 1. Bank zonation. HWL = high water level, LWL = low water level. Adapted from (Sollie *et al.*, 2011).

3 Environmental factors influencing colonisation and diversity

In order to assess the effects of different types of management on the emergent vegetation diversity and the colonisation of open water by emergent vegetation, it is important to understand the environmental factors influencing them. Terrestrialisation and emergent vegetation diversity are two different characteristics (Sarneel *et al.*, 2011). The two therefore need to be viewed separately, though they depend partly on the same environmental factors.

3.1 Colonisation of open water

The colonisation of open water occurs either via expansion of rooted emergent vegetation or via the formation of floating mats of vegetation (Lamers *et al.*, 2004; J. M. Sarneel, 2010). Several environmental conditions influence the expansion of emergent vegetation, steering it towards floating mat formation or rooted expansion (figure 2).

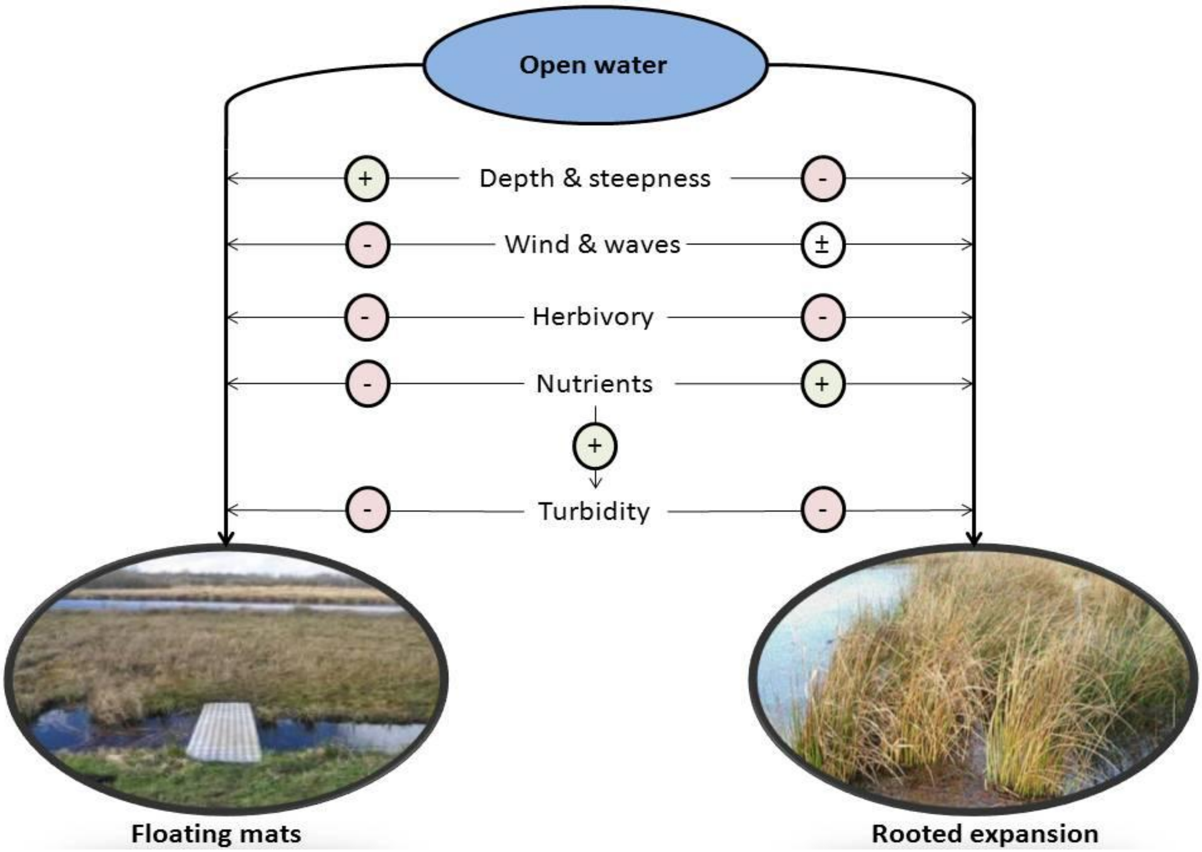

Figure 2. Factors influencing colonisation of open water by emergent vegetation

3.1.1 Depth & steepness

Firstly the local water depth is critical. At low depth colonisation occurs mainly by expansion of emergent vegetation via rhizomes and seeds. If the water becomes deeper, colonisation is slowed. Water levels higher then approximately 1-1.5 meters don't allow growth of bottom-rooted helophytes (Azza *et al.*, 2006; Lamers *et al.*, 2004; Sarneel *et al.*, 2011). This is however dependent upon the turbidity of the water. If shores are steep and the water is deep, colonisation of open water can occur via the formation of floating mats. Rhizomes of emergent vegetation expand into the water, float and form mats (Lamers *et al.*, 2004). The presence of aquatic vegetation may increase floating mat formation in deep water (Sarneel *et al.*, 2011).

3.1.2 Nutrient availability

Besides depth, the nutrient availability in soil and water is of influence on terrestrialisation. The nutrient concentrations in shallow lakes have greatly increased over time (Barendregt *et al.*, 1995; Ligtvoet *et al.*, 2008). Depending on the nutrient concentrations colonisation of open water occurs by different types of species (Mettrop *et al.*, 2012).

More species capable of colonizing open water are present under mesotrophic nutrient conditions (Sarneel *et al.*, 2011). Though, eutrophic levels of nutrients can increase the biomass of the bank vegetation (Sarneel *et al.*, 2010). This can then lead to an increase of clonal expansion from the bank into the water. However, the expanding vegetation in that case would consist mainly of eutrophic species, and be low in diversity (Sarneel *et al.*, 2010).

3.1.3 Turbidity

There is also an indirect effect of the nutrient concentrations in water on colonisation. High levels of nutrients in water allow for increased algal and cyanobacteria growth. This growth leads to higher levels of turbidity, decreasing the depth to which light can penetrate (Sarneel *et al.*, 2011; Van Zuidam *et al.*, 2009). This hinders the expansion of emergent vegetation (Sarneel *et al.*, 2011). Algal and cyanobacteria growth and resuspension of sediment by benthivorous fish are the main causes of turbidity (Lamers *et al.*, 2004; Van de Haterd & Ter Heerdt, 2007). Bottom foraging by bentivorous fish only leads to turbidity by resuspension of sediment; it does not increase the nutrient concentrations in the water (Van der Wijngaart *et al.*, 2012).

3.1.4 Herbivory

Herbivory also has a negative effect on the colonisation of open water by emergent vegetation (Sarneel *et al.*, 2011; Schep *et al.*, 2012). The most common herbivores include: waterbirds, livestock and muskrats (Sarneel *et al.*, 2011; Schep *et al.*, 2012; Vulink *et al.*, 2010). Especially the intensive grazing by Greylag geese (*Anser anser*) causes the loss of emergent vegetation (Vulink *et al.*, 2010). For instance in the 'Oostvaardersplassen', the largest wetland area in the Netherlands, a decrease in coverage of emergent vegetation was observed resulting from the herbivory by geese (Vulink *et al.*, 2010).

3.1.5 Wind and wave action

Wind and waves have a negative effect on the development of floating mats of emergent vegetation. Floating mat formation occurs mostly at stable, low-energy waterbodies (Azza *et al.*, 2006). Wind and wave action may break up the mats of expanding vegetation, causing it to disintegrate (Azza *et al.*, 2006).

3.2 Plant communities and diversity

Ponds and shallow lakes are home to a number of plant species capable of colonizing open water (Verhoeven & Bobbink, 2001). The terrestrialisation can be caused by several plant communities. Which type of community colonizes the open water is largely dependent upon the soil type and the nutrient concentrations of the water (Mettrop *et al.*, 2012; Verhoeven & Bobbink, 2001). These nutrient concentrations of a water body are often expressed as a trophic state. The trophic states and corresponding nutrient concentrations are expressed in table 1 (Lu *et al.*, 1999).

Table 1. Trophic states of water bodies. TP = concentration total phosphorus (Lu *et al.*, 1999).

Trophic state	Oligotrophic	Oligo-meso	Mesotrophic	Meso-eu	Eutrophic
TP (µg/L)	<7.9	8-11	12-27	18-39	>40

Figure 3 displays the different types of plant communities present in either floating mats or helophyte dominated stands under different nutrient conditions. Oligotrophic conditions are not mentioned here for most shallow lakes and ponds are of meso- or eutrophic state (Ligtvoet *et al.*, 2008). Under mesotrophic conditions a community of mainly Bog Arum (*Calla palustris*) and Cowbane (*Cicuta virosa*) dominates the floating mats. In helophyte dominated stands Greater Tussock Sedge (*Carex paniculata*) and Tufted Sedge (*Carex elata*) are most common (Verhoeven & Bobbink, 2001). Under eutrophic conditions floating mats mainly consist of Common Culb-rush (*Schoenoplectus lacustris*), Cowbane (*Cicuta virosa*) and Cypress sedge (*Carex pseudocyperus*). Helophyte stands can be dominated by Common Cattail (*Typha latifolia*), Common Reed (*Phragmites australis*) and Sawtooth Sedge (*Cladium mariscus*) (Verhoeven & Bobbink, 2001). In some cases nutrient concentrations can rise to hypertrophic levels. Floating mats are than no longer found. Under such conditions helophyte stands consist almost exclusively of Reed Sweetgrass (*Glyceria maxima*) (Lamers *et al.*, 2004). In general more species which can colonize open water are present in peatland areas under mesotrophic nutrient conditions and bank vegetation diversity is higher (Sarneel *et al.*, 2011).

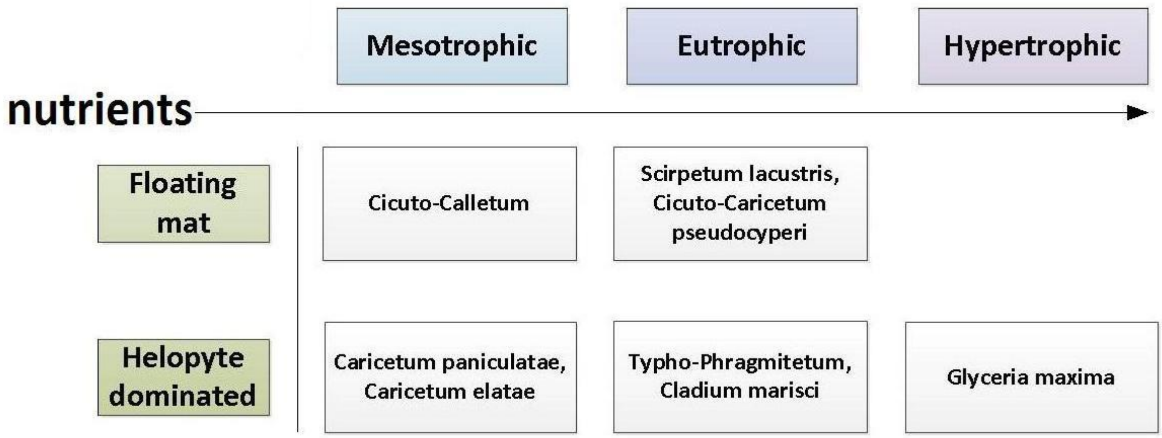

Figure 3. Hydroseral vegetation communities under different trophic states. Adapted from (Bal *et al.*, 2001; Lamers *et al.*, 2004; Verhoeven & Bobbink, 2001).

Apart from nutrients, wind and waves are also important in bank vegetation distribution (Azza *et al.*, 2006; Jackson, 2006). Well sheltered banks are known to have a higher diversity compared to less sheltered banks (Sarneel *et al.*, 2011). This sheltering consists of protection from wind and waves (Azza *et al.*, 2006).
Disturbance can have either a positive or a negative effect, depending on the intensity. At low to medium intensity, disturbance can lead to a more diverse vegetation composition by repressing dominant species. At high intensity however, disturbance can lead to less diverse vegetation (Huston, 1979; Huston, 2004; Pollock *et al.*, 1998). Disturbances such as herbivory can also have an indirect effect on the vegetation diversity. By grazing, nutrients are removed from the system, making it poorer (McBride *et al.*, 2011). Nutrient poor ecosystems generally have more diverse vegetation.
Lastly shading by trees or other objects can be of negative influence on the development of diverse emergent vegetation (Sollie *et al.*, 2011).

4 Management options and expected effects

There is a wide variety of management options being used in the field of practice. However, their effects on the colonisation of open water and bank vegetation diversity are not always well known.

An important problem for the diversity in early stages of terrestrialisation is eutrophication (Belle *et al.*, 2006; Ligtvoet *et al.*, 2008). The major cause of eutrophication is the land use surrounding the water bodies and the atmospheric deposition (Barendregt *et al.*, 1995). Both the diversity of the bank vegetation and colonisation of open water are negatively influenced by land use surrounding the water body (Barendregt *et al.*, 1995; Sarneel *et al.*, 2011). Increased nutrient concentrations in soil and water are beneficial to eutrophic species, making the emergent vegetation less diverse. Agricultural land use often leads to development of the turbid water state, due to nutrient-rich agricultural run-of, whilst ponds surrounded by forest often maintain the clear water state (Declerck *et al.*, 2006).The turbid water state has a negative effect on colonisation of open water (Sarneel *et al.*, 2011).

Most management practices are aimed at removing nutrients. In general they can be divided into three management categories: Physical, chemical or biological (table 2). The most common measures, their effects and estimated costs are listed below.

Table 2. Management activities in shallow lakes and ponds

Activity	Type	Effects	Costs
Grazing	Biological	Nutrient removal, reduction dominant species	Low
Mowing	Physical	Nutrient removal, reduction dominant species	Intermediate
Cleaning	Physical	Biomass removal, prevention terrestrialisation	Intermediate
Fire	Physical	Biomass removal, reduction dominant species	Low
Dredging	Physical	Nutrient removal, preventing turbidity and terrestrialisation	High
Biological management	Biological	Prevent herbivory, preventing turbidity	High
Water level manipulation	Physical	Promoting vegetation, nutrient removal	Low*
chemical treatment	Chemical	Binding phosphorus, preventing turbidity	High
Restoration	Physical	Increase riparian zone	High

- = costs depend on side effects of water level manipulation, such as land subsidence

4.1 Grazing by livestock

Grazing with livestock is one of the most used forms of management (Van Kouwen, 2011). It keeps vegetation open, reduces dominant species and reduces the nutrient concentrations by removal of biomass (McBride *et al.*, 2011). The type of grazer, timing and the duration of grazing all influence the effect grazing has on emergent vegetation diversity and the expansion from the bank into the water. The effects of herbivory by non-domestic herbivores will be addressed in the biological management section.

4.1.1 Type of grazer

Which type of grazer is best suited for creating diverse emergent vegetation without destroying the initial stages of terrestrialisation, depends largely on their diet, their selectivity when grazing and their suitability for grazing on wet grounds (table 3). At shorelines soils are often waterlogged and therefore soft. Trampling of vegetation can therefore be a risk (Declerck *et al.*, 2006; Tanner, 1992). Cattle are unselective eaters. Their suitability for grazing shoreline vegetation is hindered by their size (McBride *et al.*, 2011). Trampling of the vegetation by cattle can decrease the diversity of the bank vegetation (Declerck *et al.*, 2006; Tanner, 1992). Horses are selective grazers, due to their large mass however less suited for grazing wet grounds. Sheep are highly selective grazers. Due to their light weight they are well adapted to soft grounds at shorelines. Goats are highly selective eaters. They can graze and browse on tall herbs and shrubs. Goats are similar to sheep in their suitability at shorelines (McBride *et al.*, 2011).
As can be seen in table 3, sheep and goats are the animals best suited for grazing in riparian areas. The use of sheep and goats for grazing and maintaining shoreline vegetation is not new though. It was commonly practiced around the 1900's as a means to prevent terrestrialisation (Lamers *et al.*, 2004). Cattle can also be used to graze wet environments. In contrast to sheep, cattle can reach dense vegetation such as Reed stands. However, only highland cattle and water buffalo are suitable for wet conditions (McBride *et al.*, 2011).

Table 3. Comparison of grazers (McBride *et al.*, 2011)

Grazers	Diet	Selectivity	Suitability at shore
Cattle	Long grasses and sedges	Unselective	Medium*
Horses	Grasses, rushes and sedges	Selective	Low
Sheep	Grasses and tall herbs	Highly selective	High
Goats	Tall herbs and shrubs	Highly selective	High

- = Suitability of cattle for grazing wet environments is medium, with the exception of well-adapted highland cattle and water buffalo.

4.1.2 Grazing intensity

Grazing intensity can determine the effect grazing has on the vegetation composition. At low to medium intensity, depending on the type of grazer, grazing can diversify the vegetation composition (Marty, 2005). At higher intensity grazing can create a more monotonous vegetation of tolerant plant species (McBride *et al.*, 2011). The required grazing intensity to create the maximal diversity in a system strongly depends on its trophic state (Huston, 1979; Huston, 2004). Also the trampling of vegetation becomes more problematic (Declerck *et al.*, 2006). Due to variations in numerous environmental conditions the amount of animals per surface area needed differs per location. This is related to the duration of grazing.

4.1.3 Duration of grazing

The duration of grazing influences the effect on the vegetation composition and the colonisation of open water. Prolonged periods of grazing have stronger effects on vegetation composition compared to shorter periods. Variations in environmental conditions make the duration, required to achieve a certain vegetation pattern, different at each site. Similar to grazing intensity, the duration required to reach the maximal vegetation diversity depends on the trophic state (Huston, 1979; Huston, 2004).

4.1.4 Timing of grazing

Besides the type of grazer, intensity and duration, timing is also of influence on the effect of grazing on the vegetation. Grazing is best done in autumn, when it opens up the vegetation and provides room for other plants, or in spring, when it has a profound effect on early growing species such as Common Reed (*Phragmites australis*).
It should be avoided in winter, due to the need for additional feeding of the animals bringing outside nutrients to the system, and in summer when it will lead to destruction of seeds of important species (McBride *et al.*, 2011).

In general grazing can result in more diverse bank vegetation. The effects on the vegetation diversity are determined largely by the type of grazer, grazing intensity, duration and timing (McBride *et al.*, 2011; Van Kouwen, 2011). However, grazing has a negative effect on the expansion of colonizing species (Schep *et al.*, 2012). It should therefore be closely controlled to see the effects on the vegetation. If the aim is to maximize the expansion towards open water independent of the vegetation diversity, then grazing should be prevented. If the goal is to create early-successional terrestrialisation stages with high species-richness, extensive grazing can be used to achieve this. Sheep and goats could, based on their low body weight compared to other livestock, best be used to prevent ruderalisation. Though grazing alone may often not be enough to prevent ongoing succession. Other management options such as mowing might also be necessary (McBride *et al.*, 2011).

4.2 Mowing

Mowing of shoreline vegetation is a common management activity. Mowing and cutting of the banks and the removal of clippings decreases the nutrient concentrations of the soil (Van Kouwen, 2011). The decrease in nutrient concentrations in turn stimulates a shift towards more diverse bank vegetation (Gryseels, 1989). Leaving clippings in the field could lead to rotting plant material on the bottom, making it hard for vegetation to establish. However, the removal of clippings makes mowing rather expansive (Van Kouwen, 2011). Additional to the reduction of nutrients, mowing opens the vegetation by reducing the dominant species. This provides opportunities for other species. Mowing creates a relative homogenous landscape due to its unselective nature (Van Kouwen, 2011). Both timing and the intensity of mowing determine the effects on the vegetation. The amount of mowing required to reach the maximal vegetation diversity depends on its trophic state (Huston, 1979; Huston, 2004).

4.2.1 Mowing intensity

Increased mowing intensity (more than once a year) has proved to have a negative effect on the emergent vegetation composition, making it less diverse (Visser, 2012). Lowering the mowing intensity might also cause problems. Cessation of mowing would probably lead many Reed marshes to be overgrown by more eutrophic species (Gryseels, 1989).
Mowing alone is often not enough however. In peatland areas early- successional terrestrialisation stages disappear as a result of eutrophication of the surface water. These effects of eutrophication cannot be resolved by mowing alone (Belle *et al.*, 2006).

4.2.2 Timing of mowing

Timing of mowing can be of influence on vegetation composition. Annual mowing during winter has a negative effect on the colonisation of open water. Almost only Reed is affected, due to the fact that other species have hardly any aboveground biomass during winter (Van Kouwen, 2011).
It can however, have a positive effect on the biodiversity of the Reed marsh vegetation. By the removal of clippings nutrients are removed from the system. This can prevent the ruderalisation of the Reed marsh (Gryseels, 1989). It also slows down the build-up of toxin concentrations, which could hinder the growth of Reed (Graveland & Coops, 1997).
Annual mowing during summer creates more open vegetation. Dominant species can be reduced in numbers and a more diverse vegetation composition can be achieved (Bal *et al.*, 2001; Van Kouwen, 2011). For Reed beds summer mowing can lead to a transition towards lower and less dense stands and higher species-richness (Bal *et al.*, 2001).

4.3 Cleaning

Cleaning (mechanical harvesting of aquatic and shoreline vegetation) is mostly done in drainage ditches and small water courses. It can however have effects on the submerged and emergent vegetation. Cleaning is necessary when water bodies become too terrestrialised. It is used to put the system back in an earlier stage of succession (Sollie *et al.*, 2011). For example, in heavily terrestrialised fens a special machine called a 'Scragh wolf' can be used to restore it to an earlier successional stage (Lamers, 2001).
The current practice of yearly complete removal of al above ground biomass can potentially lead to more disturbance-tolerant vegetation composition due to competition between tolerant and less tolerant species (Van Zuidam & Peeters, 2012). The frequency of cleaning is of influence on the emergent vegetation diversity. Cleaning every 2 or 3 years creates more diverse vegetation compared to yearly cleaning (Van Strien *et al.*, 1991). Cleaning less often also makes for more abundant emergent vegetation (Twisk *et al.*, 2003).

4.4 Burning

Another management option might be the use of fire. Studies into the effects of fire on wetland vegetation showed that rhizomes and rosettes stay intact after fires (Neiff, 2001). However burning is a very unselective measure and releases nutrients from the plant material, often causing ruderalisation (Van Kouwen, 2011). Fire might therefore be less suitable as a means to improve biodiversity.

4.5 Dredging

Dredging of ponds and lakes serves two purposes. Firstly it counteracts terrestrialisation. The filling up with sediment endangers the pond and shallow lake ecosystems (Sayer *et al.*, 2012; Zhang *et al.*, 2012). To prevent them from turning into land, shallow water bodies such as ponds are regularly dredged (Biggs *et al.*, 1994; Nijboer, 2004).
Secondly dredging of ponds and shallow lakes is a means to reduce the nutrient concentrations in the soil and water (Van der Wijngaart, 2008). Soil can contain high levels of nutrients and can be an important source of eutrophication (so-called internal eutrophication). These nutrients can be stored in the soil after periods of high external input. When the input stops, nutrients from the soil can be transported back into the water column, causing problems as mentioned earlier (Van der Wijngaart *et al.*, 2012).
Dredging is a costly method to combat eutrophication. It is therefore less used in shallow lakes (Ter Heerdt *et al.*, 2012). Also dredging might destroy the aquatic vegetation present in a lake or pond.

4.6 Biological management

There are several herbivores which impact the diversity and expansion of emergent vegetation. Emergent vegetation is grazed upon by waterbirds, in particular geese and coots (Geilen & Coops, 1993).Due to a sharp increase in the population size of Greylag geese, grazing pressure on emergent vegetation has also greatly increased. This often limits expansion of emergent vegetation (Vulink *et al.*, 2010). Placement of exclosures against waterbirds could aid the expansion of emergent vegetation. However, it is a costly and maintenance-requiring option, which is therefore probably impractical (Geilen & Coops, 1993). Another option to control grazing by Greylag geese is water level manipulation (Vulink *et al.*, 2010). Low water levels in summer (with drying out) are ideal for germination and growth of seedlings and young plants, aiding expansion. Higher levels in winter could provide protection from grazing on below-ground structures such as rhizomes (Vulink *et al.*, 2010).
In many shallow lakes the high turbidity of the water is a great problem. As mentioned in the introduction, turbidity can be caused by the resuspension of sediment by bentivorous fish (mostly Bream (*Abramis brama*) and Carp (*Cyprinus carpio*)) (Nijboer, 2004). To combat these great numbers of fish, the active removal of certain fish species is used. Natural predators, such as Pike (*Esox lucius*) are reintroduced (Nijboer, 2004). The reintroduction of predators is also advised to reduce the large numbers of exotic American crayfish in peatland areas (Roessink *et al.*, 2009). Exotic crayfish cause damage to aquatic vegetation and increase turbidity of the water by clipping and digging (Roessink *et al.*, 2009).

4.7 Water level manipulation

In a recent article in a Dutch newspaper concerning the management of the 'Oostvaardersplassen', it was announced that water level fluctuations will be implemented to promote the expansion of Common Reed (Janssen, 2013). However, in large parts of the Netherlands water table is normally kept at fixed levels. This is mostly done for economic purposes (benefits to agriculture) and to prevent land subsidence (Coops & Hosper, 2002). Water level manipulation can be used to promote the expansion of emergent vegetation (Coops *et al.*, 2004).

4.7.1 Natural water level fluctuation

Introducing natural water level fluctuations (low in summer, high in winter) can have a positive effect on the expansion of emergent vegetation into open water (Coops *et al.*, 2004). The effectiveness of the water level fluctuation depends on the steepness of the bank. A similar water level fluctuation has less effect on a steep bank compared to more gradual bank. This is because the exposed bank area at descending water levels is much greater at shallow banks (Schep *et al.*, 2012). Natural water level fluctuations stimulate the distribution of propagules, both seeds and vegetative parts. This increased distribution of propagules in turn increases the diversity of the seedling vegetation (Sarneel *et al.*, 2012). Furthermore germination of available seeds on shallow banks is increased compared to situations with non-fluctuating water levels. The amount of seeds germinating is closely related to the bank area that runs dry at descending water levels (Sarneel *et al.*, 2012). Also the expansion of many emergent species into the water is strongly correlated with water levels. In several studies clonal expansion of Reed proved to increase under increasing water level fluctuations (Newman*et al.*, 1996; Schep *et al.*, 2012). In general, the lower the water level, the more expansion (Schep *et al.*, 2012). An added benefit of implementing fluctuating water levels is that the resulting increased area of emergent vegetation takes up more nutrients from the water and soil (Mettrop *et al.*, 2012).
However, the effectiveness of water level fluctuations as a means to promote emergent vegetation expansion is greatly influenced by grazing of waterbirds. In order to ensure successful expansion herbivory is best kept to a minimum (Coops *et al.*, 2004).

The effects of water level fluctuations on emergent vegetation diversity are less clear. Vegetation composition depends strongly on the type of water body, water depth, soil characteristics and nutrient levels. Effects from water level fluctuations on the emergent vegetation diversity can therefore be clouded by other factors. For instance, fluctuating water levels can decrease the amount of nutrient-rich run-off from agriculture in the vicinity to surface water (Schep *et al.*, 2012). This might have an indirect effect on the diversity of vegetation via reduced nutrient levels in water, though this has not yet been proven. Changes in vegetation composition are to be expected however (Sarneel *et al.*, 2012; Schep *et al.*, 2012). These changes largely depend upon the duration, timing and amplitude of the water level fluctuations (Mettrop *et al.*, 2012).
A possible problem related to fluctuating water levels, the subsidence of the land in peatland areas, can potentially be avoided by raising the mean water level (Schep *et al.*, 2012).

4.7.2 Temporary dry-out

Natural water level fluctuations can lead to the temporary dry-out of some water bodies during summer. This dry-out can be completely or partly depending on the amplitude of the fluctuation. Temporarily drying out can be very beneficial to the ecology of shallow water bodies. When this happens, the sediment is exposed to oxygen. This can result in several processes:
The removal of nitrogen is stimulated by the presence of oxygen. The nitrate can be converted into nitrogen gas and escapes to the atmosphere, thereby lowering the nitrogen concentrations in the system (Westendorp *et al.*, 2012). Due to drying out the sediment consolidates, meaning it is compacted and sticks to the bottom. Once wetted again the sediment can stay consolidated for a long period, lessening the chance of resuspension (Westendorp *et al.*, 2012). Substances such as ammonium, ammoniac and sulfide are normally present in the soil under anoxic conditions. Such toxins can be a hinderance for the development of species-rich vegetation (Sollie *et al.*, 2011). Drying out of the soil allows for the breakup of these toxic substances (Westendorp *et al.*, 2012).

4.8 Chemical treatment

It has been shown that eutrophication is a great problem in shallow water bodies. Especially the increased concentrations of phosphate are causing problems like algal and cyanobacteria blooms (Ter Heerdt *et al.*, 2012). Iron, originating from groundwater, prevents phosphate entering the water column. However, due to drying, groundwater influx has decreased, delivering less iron to the water bodies (Ter Heerdt *et al.*, 2012).

4.8.1 Ferric chloride

A cost-effective solution might be the addition of iron. A much used form is the addition of ferric chloride to the water, which will slowly disperse throughout the lake. More available iron would bind phosphate in the soil, making it less available for organisms such as algae (Ter Heerdt *et al.*, 2012). However, slow addition of ferric chloride is essential to prevent lowering of the pH (Ter Heerdt *et al.*, 2012). The addition of ferric chloride to Lake Terra Nova has led to some tantalizing results. Visibility has greatly increased and submerged vegetation is returning to the lake. Positive effects on emergent vegetation are also expected, though not yet proven (Ter Heerdt *et al.*, 2012). The costs for ferric chloride addition are high however (Ter Heerdt *et al.*, 2012).

4.8.2 Polyaluminium chloride and lanthanum-modified bentonite (Phoslock®)

Other chemicals can also be used to counteract turbidity. In a recent study it was shown that the addition of polyaluminium chloride and lanthanum-modified bentonite (Phoslock®) to a cyanobacteria-infested shallow lake caused the cyanobacteria to sink, returning the lake to a clear water state (Lürling & Oosterhout, 2013).

Addition of either one of the substances alone proved insufficient to achieve this. When added both, the two substances lowered the concentration of phosphorus in the water by 90% (Lürling & Oosterhout, 2013). Though providing good results on combating eutrophication, the use of polyaluminium chloride combined with lanthanum-modified bentonite (Phoslock®) is rather costly and might therefore not be applicable on larger sized lakes (Lürling & Oosterhout, 2013). Another drawback is the introduction of foreign substances to the water (Ter Heerdt *et al.*, 2012).

4.9 Restoration

A common restoration practice is the implementation of so-called 'nature-friendly' banks. In the Netherlands many kilometers of shoreline have been made 'nature-friendly' by making them gradually sloped (Sollie *et al.*, 2011). The creation of gradually sloped banks can greatly increase the area available for emergent vegetation, promoting the expansion (Schep *et al.*, 2012; Sollie *et al.*, 2011). Ideally the bank has a very gradual slope. However, the space available is often limited (Sollie *et al.*, 2011). In general a slope steeper than 22.5° (or a ratio of 1:2) is too steep to support helophytes establishment (Sollie *et al.*, 2011). A slope of roughly 5.7° (or a ratio of 1:10) is desirable in order to be ecologically interesting (Van Kouwen, 2011).

Apart from restoring existing shorelines the creation of new water bodies is also a possibility. In many countries new ponds are created (Declerck *et al.*, 2006). Also the shallow lakes in the peatland area of the Netherlands are mostly manmade (Lamers *et al.*, 2004). However, it should be noted that increased areas of emergent vegetation and early-successional terrestrialisation can make ideal nesting grounds for insects like mosquitos, which can greatly benefit from the shallow water and protection from predation by emergent vegetation (Verdonschot & Besse-Lototskaya, 2012).

In both newly created and restored systems the soil seed bank can be important in the restoration of lakeshore vegetation (Nishihiro *et al.*, 2006). Top soil removal, used as a means to reduce nutrient levels, is often unsuccessful in restoring diverse bank vegetation due to the removal of the seed bank (Grootjans *et al.*, 2002). However, most species colonizing open water disperse via rhizomes, making the seedbank less important for colonisation of open water. Though source populations are important for spreading via vegetative propagules and should therefore be maintained (Sarneel, 2010).

Emphasis in restoration projects should be on preserving the species which colonise open water (table 4). Which species can be present depends largely on the nutrient levels. Also the manner in which expansion into open water occurs, either floating or rooted seems to depend largely on nutrient levels (Sarneel, 2010). Most of the floating species are present under oligo- or mesotrophic conditions and the rooted species are more in the meso- or eutrophic range. Special attention should be given to presence of Water Soldier (*Stratiotes aloides)*, a floating aquatic macrophyte, for it is thought to play a key role in the formation of floating mats in fen ponds and shallow lakes by providing support to the floating rhizomes of other species (Sarneel, 2010).

Table 4. Emergent species colonising open water. Adapted from (Sarneel, 2010).

Species	Nutrient level	Height (m)	Expansion form
Comarum palustre	Oligo - mesotrophic	0.15-0.9	Floating
Thelypteris palustris	Oligo – mesotrophic	0.3-0.8	Floating
Calla palustris	Mesotrophic	0.1-0.2	Floating
Equisetum fluviatile	Mesotrophic	0.5-1.5	Rooted
Menyanthes trifoliata	Mesotrophic	0.13-0.3	Floating
Stratiotes aloides	Mesotrophic	0.05-0.2	Floating
Phragmites australis	Meso – eutrophic	1.0-4.0	Rooted
Typha angustifolia	Meso – eutrophic	1.0-2.0	Rooted
Glycera maxima	Eutrophic	0.8-1.8	Rooted
Typha latifolia	Eutrophic	1.0-2.0	Rooted

4.9.1 Implementation in dynamic water bodies

In recent years the area covered by emergent vegetation has greatly decreased (Mettrop *et al.*, 2012). Instead of restoring lakes and ponds it is also possible to create new areas of emergent vegetation. Given the current trend of water quality improvement, eutrophication seems to become less of a problem. The water quality in many rivers and canals is improving (Mettrop *et al.*, 2012). This gives rise to an interesting idea; the possibility to create early- successional terrestrialisation stages along the banks of canals, rivers and ditches, thereby drastically increasing the biodiversity of the banks (Graveland & Coops, 1997; Van Kouwen, 2011). This is however only possible in sections of waterways which are overdimensioned and suitable, so it does not compromise the other functions of a water body (Van Kouwen, 2011).

In dynamic water bodies such as rivers or canals, protection from wind and wave action could greatly increase the chance of survival of seedlings and young plants. With protection against being washed into open water, the establishment is higher on sheltered banks compared to non-sheltered banks (Sarneel & Soons, 2012). An often used example of protection is the placement of protective dams. The dynamics at the shore can be altered by adjusting the distance to the shoreline, height, opening, orientation and shape of the structure (Van Kouwen, 2011). Creating too much distance between shore and the protective structure could lead to wind driven waves (Van Kouwen, 2011). However, the protection of the emergent vegetation by protective dams is not always effective. Overdimensioning of protective dams can result in stagnant water and anoxic conditions, unfavourable for expansion of emergent vegetation (Graveland & Coops, 1997).

The establishment of shoreline vegetation might pose a problem in dynamic water bodies, even if the banks are nature-friendly. This is presumably due to the sandy substrate of the bank (Braakhekke *et al.*, 2011). Research into what might aid the establishment and development of shoreline vegetation in dynamic water bodies is needed to improve the success of the colonisation of the river banks.

The vegetation composition is strongly depended on the environmental conditions at the site. Most important are the nutrient concentrations of water and soil. In ditches, canals and rivers in the Netherlands nutrient conditions suite mostly eutrophic species (Ligtvoet *et al.*, 2008). Common Reed is such a eutrophic species (see table 3). Common Reed is well adapted to the effects of waves, due to special supportive tissues (Graveland & Coops, 1997). Therefore it does not require protection from waves once established (Van Kouwen, 2011). If the problem of establishment along dynamic waters and the herbivory by large numbers of geese can be overcome, Reed might serve as catalyst for expansion of emergent vegetation into open water, thus greatly increasing the species-richness at these shores.

5 Implications for future management

After researching the management options, it is clear that most management in ponds and shallow lakes is focused on the water body itself. Mostly the aim is to reduce nutrient availability, so to restore the clear water state including the aquatic vegetation. Less attention is given to the development of emergent vegetation.
Looking from a water manager's perspective, terrestrialisation is often seen as negative: vegetation expanding from the bank in to the aquatic system is something that needs to be minimized. However, given the fact that both systems are valuable ecosystems and depend on each other's functioning, it is necessary to view them as an integrated system, when considering management strategies. Several measures beneficial to the aquatic system are also beneficial for the creation of diverse emergent vegetation, making them perhaps more effective than previously thought.

5.1.1 Management identification schema

Looking at banks and water column as an integrated system combined with the knowledge of the effects of management practices on emergent vegetation it is now possible to formulate a general scheme on how to improve conditions for terrestrialisation and emergent vegetation diversity (figure 4). This scheme is aimed at site managers and consists of four steps.
Firstly it is necessary to look at a number of variables in the water body. These are depicted as diamond-shaped boxes in figure 4. Per variable the conditions of the water body and the banks need to be identified. The conditions are shown as either green or red boxes, indicating a positive (green) or negative (red) affiliation with colonisation and/or diversity. Once the conditions in a water body and on the banks have been identified one can look at improvements (grey boxes) on the existing conditions. What management options are used to improve conditions also depends on other variables. A certain management option may affect more than one variable.

- Nutrient availability: Eutrophic conditions (>40 µg/L phosphorus) have a negative effect on the diversity of the emergent vegetation, whilst under mesotrophic and oligotrophic conditions vegetation is more diverse. Management options include grazing (chapter 4.1) and mowing (chapter 4.2), Ferric chloride addition (chapter 4.8.1) and dredging (chapter 4.5). The nutrient availability can influence the water state. Increased nutrient levels can cause turbidity.

- Water state: This can be either clear (macrophyte dominated) or turbid (algal dominated) and is strongly influenced by the nutrient concentrations. The turbid state has negative effects on colonisation of open water. Management options such as ferric chloride addition (chapter 4.8.1), fish removal (chapter 4.6) and dry-out (chapter 4.7.2) might return a lake to the clear water state.

- Water table: A flexible water table promotes expansion of emergent vegetation, whilst fixed levels hinder expansion. Possible measures are the introduction of a flexible water table, preferably simulating natural water level fluctuation (low in summer, high in winter) (chapter 4.7.1), or an increase of the shallow area, available for emergent vegetation (chapters 4.7 and 4.9). The effects of water level fluctuations are closely linked to the bank area exposed to the water level fluctuations. The water level fluctuation is therefore best accompanied by restoration of banks into nature-friendly gradually sloped banks if not already present. In water bodies with no possibilities for fluctuations emphasis should be on prevention of large-scale herbivory either by decreasing the numbers of herbivores or by excluding them from the emergent vegetation (chapter 4.6).

- Bank profile: This can be either steep or gradually sloped. Gradually sloped banks increase the area available for emergent vegetation, whilst steep banks confine it. If the banks are steep, restoration to more gradually sloped banks might be an option (chapter 4.9).

- Bank location: This can be exposed or sheltered from wind and waves. At exposed banks the vegetation diversity is lower compared to sheltered banks. An option to improve the diversity might be the placement of a protective structure, sheltering the previously exposed bank (chapter 4.9.1).

- Disturbance rate: The effects of disturbance on the vegetation diversity depend on the competition between species and productivity, which in turn are governed by the nutrient availability (Huston, 1979; Huston, 2004; Van Zuidam, 2013). At an intermediate disturbance level the vegetation diversity is highest. However, the intensity of disturbance necessary to create an intermediate disturbance rate differs between trophic states. Eutrophic systems require more disturbance activity to be intermediate disturbed than meso- and oligotrophic systems (Huston, 1979; Huston, 2004; Van Zuidam, 2013). When the disturbance rate is low, grazing (chapter 4.1), mowing (chapter 4.2) and cleaning (chapter 4.3) might stimulate the diversity by increasing the disturbance. When the disturbance rate is high, measures like lowering mowing intensity, the (partial) exclusion of herbivores and/or a decrease in the number of herbivores might decrease disturbance (chapter 4.6). In the field, experimentations with different disturbance intensities and/or frequencies are probably necessary to determine the required disturbance rate.

In selecting the appropriate management option it is important to prioritise, as some measures may not be realistic, due to cost or time restrictions. The blue boxes in figure 4 indicate preferable management options in terms of costs. These are dry-out, introduction of natural water level fluctuations, bank restoration and extensive grazing. Introducing natural water level fluctuations works best in combination with restored banks, increasing its effects (see chapter 4.7.1). An increased area of emergent vegetation would also trap more sediment and nutrients from the water. These nutrients can then be removed by grazing (see chapter 4.1). Occasional dry-outs are beneficial to the system (see chapter 4.7.2) and fit well with the introduction of natural water levels fluctuations for this also includes low summer tables. Additionally natural water level fluctuations may decrease the grazing pressure by water birds.

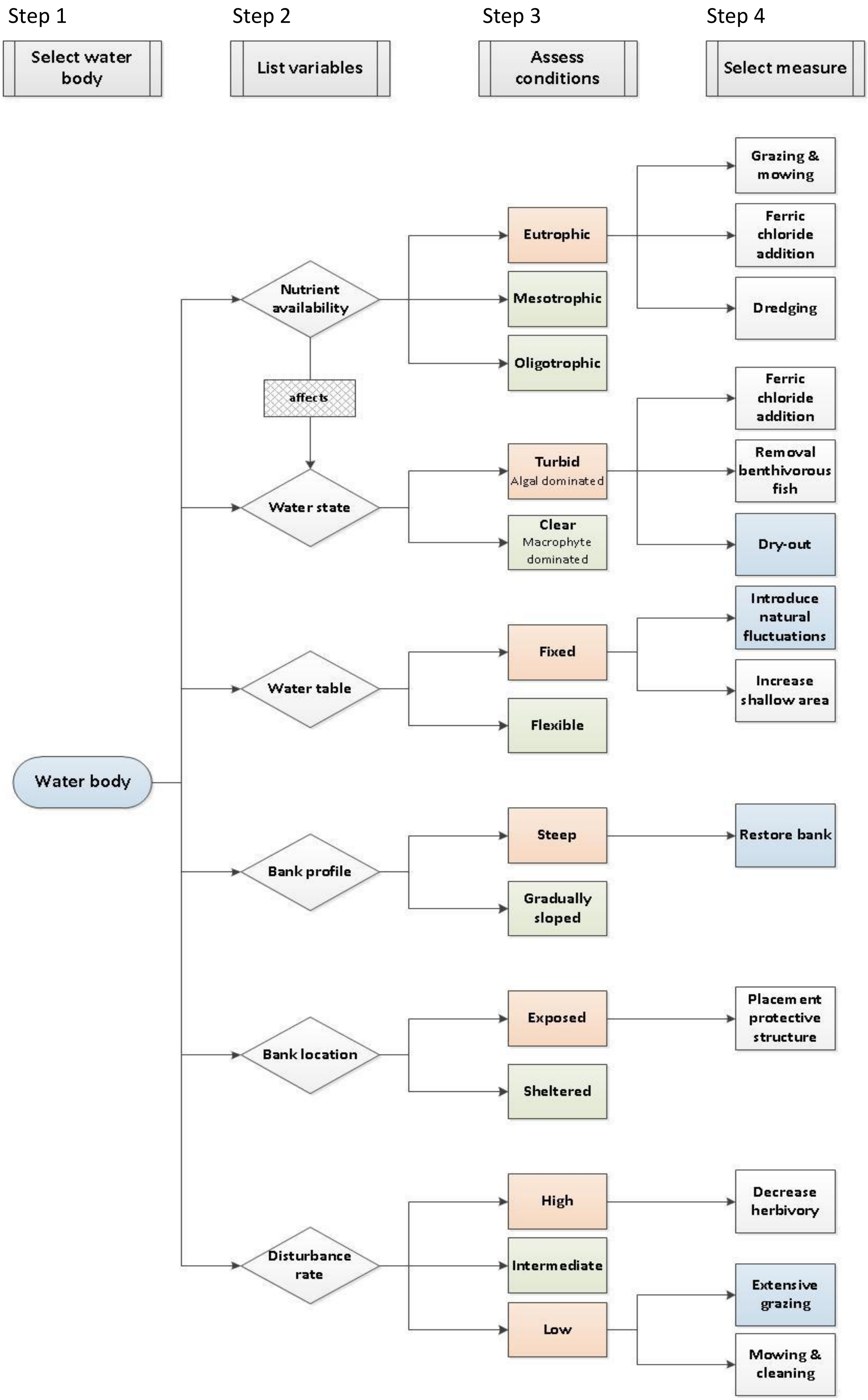

Figure 4. Managment identification scheme. Green boxes indicate positive and red boxes indicate negative effects on diversity and/or colonisation. Blue boxes indicate preferable measures based on cost-effectiveness.

6 Discussion and conclusions

Several environmental factors influence early-successional terrestrialisation and diversity. Expansion into open water appeared to be influenced by the depth of the water, steepness of the bank and herbivory in several studies. Whilst the diversity of the shoreline vegetation appeared to be influenced by the nutrient availability, herbivory, wind and waves. The diversity of the species expanding into the water is highest under mesotrophic nutrient conditions.

In this study nine different management options (grazing, mowing, cleaning, burning, dredging, biological management, water level manipulation, chemical treatment and bank restoration) were examined for their effects on the expansion of emergent vegetation into open water and the diversity of the vegetation.

In general most management options in shallow lakes and ponds are aimed at promoting the diversity through the reduction of nutrients. Grazing can be beneficial to the diversity of the vegetation if the intensity, duration and type of grazer are well adjusted to the type of vegetation and trophic state. This measure can be used to remove nutrients from the system, reduce dominant species and prevent further succession. It is a relatively cheap measure compared to mowing and can result in higher diversity due to the more selective nature of grazing. Sheep and Goats are best suited to the wet soils at the shores. Also chemical treatment of the surface water with ferric chloride seems a promising option to directly combat eutrophication and reduce turbidity in shallow lakes. Ideally almost all physical management should be done in stages, making the area less homogenous (Van Kouwen, 2011). This allows for recolonisation of shores via source populations and provides refuge for other organisms.

Of all the investigated management options only water level fluctuations and bank restoration showed direct potential for increasing the expansion of emergent vegetation into open water. Natural water level fluctuations can stimulate the germination and expansion of emergent vegetation. The effects largely depend on the steepness of the bank. More gradually sloped banks promote expansion. The expansion of emergent vegetation in water bodies where water level fluctuation is not possible can be greatly hindered by grazing of Greylag geese. The prevention of large-scale grazing by geese on emergent vegetation should therefore be emphasized. Total exclusion might however be less desirable considering that grazing by Geese can contribute to the species diversity, by increasing the habitat diversity (Vulink *et al.*, 2010).

Furthermore knowledge from management of stagnant waters can be applied to dynamic water bodies. However, room for ecological development via expansion of emergent vegetation is small because dynamic water bodies often serve more functions than nature. Common Reed is well adapted to dynamic waters and might serve as a catalyst of early-successional terrestrialisation along the shores of rivers and canals if problems with low establishment success can be overcome.

By using a management identification scheme as illustrated in chapter 5 it is possible to select appropriate measures for a specific system from an integrated perspective on both the aquatic and bank vegetation. This scheme can be improved however. For instance, more variables and conditions listed in the scheme may potentially interact or affect others, making the selection for a suitable management option somewhat more complicated. The available knowledge on such interactions is limited. Also the preferred measures are selected based on costs, even though the costs of a particular measure are difficult to quantify. More information regarding the costs would make the selection of a preferred management option more accurate. The precise effects of both water level fluctuations and ferric chloride addition on emergent vegetation are not yet known. Further research into the long-term effects is necessary. Also the required disturbance rate to achieve maximal diversity is hard to determine. Lastly knowledge on the effects of combining several management options is practically inexistent. Research into possible synergetic, overlapping or opposite effects of combining management options might aid in the selection of the most appropriate options. Due to numerous environmental differences between sites, the best management option can differ between water bodies.

In practice, selecting appropriate management options to improve conditions for emergent vegetation would still take lots of trial and error.

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