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1 INTRODUCTION

The Common Reed (*Phragmites australis*) is one of the most important vascular plant species that grows along the coasts of Finland and Estonia. Based on thorough studies, the reed has a great – albeit regionally variable and sometimes unclear – influence on terrestrial and water ecosystems. The distribution of the Common Reed is wide. It is diversified and capable of thriving in various environments close to water. Sometimes, it occurs in astonishingly dry areas.

The species has a multitude of effects on other terrestrial and water organisms. Because of its high abundance in certain places, it may also have a significant influence on entire ecosystems. During the past decades, the reed has become more common and has markedly increased its distribution in Finland and Estonia. Therefore, the need for new studies and a compilation of the existing facts about the reed has become more urgent. The management of reed beds involves several issues, such as diversity issues, environment quality, and its use in bioenergy exploitation and construction; these issues have all been studied and reported by the Finnish-Estonian "Reed strategy" project. One of the most important issues concerning the Common Reed is its influence on water quality and the potential effects of reed bed management on the eutrophication of water systems, not to mention quality changes in other environments.

This publication is a review of the reed, its characteristics and the impacts of different reed management regimes on water quality. The presented recommendations for reed management are specifically aimed at improving water quality. This work is part of the Finnish-Estonian reed project coordinated by the Southwest Finland Regional Environment Centre. This Interreg IIIA –project aims at clarifying the effects of the reed on water protection. In addition to this, three student theses related to the topic of water protection were carried out at the Turku University of Applied Sciences.

2 THE SPECIES

The Common Reed (*Phragmites australis*) has a very wide distribution throughout the world. With the exception of Antarctica, it grows on every continent. It has been estimated that reed beds cover at least 10 million hectares (Runnérus 1981). Today, the area is probably even larger. The river delta of the Danube in Romania alone has 150 000 hectares of reed population, and it has been estimated that in Sweden, there are 100 000 hectares of reed beds (Björk & Granéli 1980). In Finland, the figure is comparable. When the Southern Finnish coastal area was mapped using satellite mapping, approx. 30 000 hectares of reed beds were found (Pitkänen 2006). In Europe, the reed is among the most dominant plant species within coastal shore zones (van der Putten 1997).

The Common Reed is a perennial, erect grass species, which grows usually one to three metres in height. Even as far north as the Baltic Sea, provided that the substrate is fertile, the reed may reach four metres in height. The plant's leaves are long, one to two centimetres in width, green, and sharply edged. The inflorescence has a very large spreading panicle; the size of a large palm. The plant only remains sterile within the most unfavourable habitats, such as stony shores prone to heavy surfs, forest edges, fields and peatlands, where the species grows as a relict, i.e. as a remnant of former inshore vegetation (Jalas 1958). The size of the panicle is larger under favourable growth conditions. The reed can grow by freshwater, brackish water, and saltwater, on swampy and marshy areas, and even on quite arid lands. In Finnish, the reed is called "ryti" (Jalas 1958). Sometimes people may talk about club-rushes, but they are actually referring to reed beds (Figure 1.). The species takes many forms and, under variable growing conditions, individuals belonging to the same clone may even differ greatly in appearance. Because of the species' wide distribution and frequency, it has significant effects on other littoral species, and on entire ecosystems as well.

FIG. 1. *The Common Reed (upper) and Grey Club-rush (Schoenoplectus tabernaemontani). People often mix "club-rush beds" with reed beds. Photo: Eija Hagelberg & Natalia Räikkönen.*

3 THE CHARACTERISTICS OF THE COMMON REED

The reed has a large and widely branched rootstock. The rootstock's uppermost ends sprout upwards and form the actual shoots. The final height tells a great deal about the soil fertility (Jalas 1958). The shoot may grow to be as high as ten metres from the original rootstock. Thus, the shoot sometimes seems to grow on a surprisingly dry substrate, when in reality, the root is situated farther away in more moist soil conditions. The plant absorbs nutrients with the help of one to three, thick, underground rootstocks, which normally penetrate between 5 to 35 centimetres, sometimes even as deep as 60 centimetres, into the soil (cf. Bart & Hartman 2000). In addition, the plant has numerous numbers of thinner roots growing both horizontally and vertically (Fig. 2). Proportionally, the rootstocks represent two-thirds of the entire reed bed biomass; sometimes, that figure may be as high as 75–80% (Isotalo et al. 1981). By means of a large root system, the plant stores large amounts of nutrients, which are essential for spring sprouting and the formation of a reserve against occasional and unpredictable environmental changes and stress (Graneli et al. 1992). By releasing oxygen, the Common Reed often increases the oxygen content of low-oxygen or oxygen-free sediments. On the other hand, during the fall, the dead reed material plunges into the bottom of the beds, thereby preventing water drifts. Thereafter, the decomposing plant material consumes the water oxygen storages close to the reed beds. With many large, aquatic plants, the gases are transported through diffusion (the passive mixing of substrates in gas, liquid, or other medium, caused by thermal radiation of atoms and molecules), but the reed, among some other tall water plants, is able to do the same with the help of internal pressurization. This procedure ensures certain competitive advantages over species that are unable to do the same (Brix et al. 1992). The exact specifications of temperature, water, light and gases, which provide for the transportation of oxygen and other gases in roots and shoots, is still unclear, but without a doubt, their significance varies between different aquatic plant species. The lifespan of the rootstock is approximately five to seven years. In places with a heavy nutrient load, the reed grows a large aboveground shoot, whereas the rootstock remains underdeveloped (Gries & Garbe 1989).

Mud bottoms may be covered by 300 reed shoots per square metre, but normally, the figure is 40–100 shoots per square metre (Jalas 1958). In Finland, the reed flowers at the end of the summer and the seeds mature during mid-winter.

After the flowering phase, the straw becomes woody and is able to withstand the ice. The germinability of the seeds is 3-44% and they maintain viable for at least one year (Jalas 1958). The seeds loosen and are dispersed with the wind during late winter. Once the ice breaks up, the dry straws from the previous year are left for the waves and are piled up as banks along the shoreline. Sometimes they remain in place until the next season (cf. Fig. 3). Seedlings are often found from the above-mentioned straw banks (Jalas 1958). In contrast to dense reed beds, the seedlings demand a considerable amount of light and thrive best in open areas where there is less competition. Thus, the vegetative dispersion is much more common (e.g. Saltonstall 2003). Usually, the reed spreads vegetatively with the help of an underground root system, and it is capable of spreading at a rate of several metres per year (Weisner & Strand 2002). Deep water may prevent vegetative dispersion. As with helophytic aquatic plants, the water depth strongly influences the species occurrence due to the ease or difficulty in carrying out oxygen transportation: the deeper the plant grows, the more difficult it is for the plant to transport oxygen to the roots. The optimal water salinity for the reed is 0–15 ppm**.** Sulphides may limit the species' distribution, but on the other hand, a vegetative clone is able to escape from unfavourable conditions. Waves, environmental disturbances or interspecies competition may also prevent dispersion (Weisner & Strand 2002).

FIG. 2. *The reed's root system. Several individual roots of variable diameters form "grids of rootstock", which, when fully grown, form plastic tube-like structures stretching up to several metres. The roots attach to the bottom sediment with the aid of thin, fine roots. Photo: Ari-Pekka Huhta.*

Helophytic plants such as the reed are well adapted to direct sunlight. Its wintering buds are stored in underground tissues (geophyte) and green buds overwinter in the soil. The reed is a typical plant for warm and temperate regions. It prefers low-lying lands, but sometimes, it can be found quite high in mountainous areas. The abundance of the reed indicates very moisture conditions, but it does not demand continuous flooding. On the other hand, it can also tolerate quite severe aridity. It is an indicator for acid to neutral conditions, but does not grow on extremely acidic soils. In contrast, it prefers nitrogenous conditions (Ellenberg 1992).

In Finland, the area of reed beds has strongly increased over recent decades, which is mainly the result of a cease in traditional grazing along coastal areas. The occurrence of the reed in coastal areas is promoted by its good ability to tolerate irregular water level fluctuations and to withstand ice movements close to the shore. Its size and deeply penetrating root system are excellent adaptations to help it hold its own against environmental disturbances. The reed has also benefited from eutrophication during the last few decades. For example, in Ruissalo, the area of reed beds has increased by one percent per year beginning from the 1960s (Väre et al. 2004). However, it seems that the reed is quite vul-

FIG. 3. *The previous year's reed litter has a great influence on the growth of new shoots. Spreading via seed is not common. Photo: Eija Hagelberg.*

nerable to root injuries (e.g. Karunaratne et al. 2004). In earlier times, grazing evidently had a negative impact on the reed's roots and shoots, thus preventing the formation of large monocultures (e.g. Väre et al. 2004). In addition, our coastline may have become an unwitting host to a certain non-native variety of the species, which has a particularly high ability to disperse quicker than its predecessors (Saltonstall 2002).

In other parts of Europe, the reed has strongly declined. The main reasons for this "dieback" phenomenon are, among other things, eutrophication and the profuse use of the water systems and shorelines. This process has advanced slowly. Eutrophication has been considered to be among of the most important factors for diebacks, but it has not been the only reason, since the reed is known to thrive along highly eutrophicated lakes and in reed sewage treatment plants. Some other reasons have also been found, e.g. floods, land use and increased salinity. Reed bed areas have declined at a particularly high rate near densely populated areas close to cities (Ostendorp 1989, van der Putten 1997).

FIG. 4. *Grazing is an efficient way to prevent the vegetative dispersion of the reed. Grazing also introduces a mosaic-like variety into the areas invaded by the reed, thus increasing habitat diversity. Photo: Arto Huhta.*

The European Common Reed has invaded North America, Africa and Australia. In many places, it has replaced the native plant species (e.g. the native reed of North America), thus the original species diversity has declined (Saltonstall 2002, Väre et al. 2004). The Common Reed forms large monocultures, i.e. vegetation stands formed by a single species (Ellenberg et al. 1992). The reed is able to invade new areas at an astonishing rate. Once it is established, the development of the monoculture usually takes several years (Güsewell 2003).

3.1. Stress tolerance

The dispersion of the reed may start, for example, from drainage conditions, in which the content of the sulphide (sulphur and a mixture of other elements) decreases, and the salinity may remain unchanged. The reason for the decrease in the sulphide content is probably due to the fact that well-drained lands are too oxidized for the sulphates to be reduced to sulphides. The plant itself is able to influence sulphide concentration, particularly in the upper parts of the sediment, which enables better growth conditions for the reed (Bart & Hartman 2000). (Fig. 3). The reed is able to lower the concentration of sulphur compounds in porosity-water of the sediment as it transports oxygen to its root system, which in turn increases the evaporation of the porosity-water. If the plant is harmed, its capacity to ventilate the roots and the surrounding sediment through the old shoots decreases, leading to an increase (and a disadvantageous increase for the plant) of sulphur and nitrogen compounds near the root system. Compressed respiration is one of the most important factors for the reed to be able to maintain the amount of sulphur compounds that exists deep in its growth habitats (e.g. Bart & Hartman 2000). Stressful conditions weaken the plant's ability to take ammonium from the soil and, as a result, the plant's energy economy weakens (van der Putten 1997).

3.2. Impacts on sediment

The reed is sensitive to low oxygen concentrations, especially in June, when the carbohydrate storages in roots are at their lowest. In oxygen-free conditions, the reed's metabolism is more ineffective, and more carbohydrates are consumed in comparison to the situation within oxygen-rich conditions. In June, the carbohydrates are consumed for metabolism in oxygen-free conditions and for sulphide oxidization in sediment, with the aid of chemicals. After mowing, the amount of oxygen decreases temporarily at the base of the shoot (Armstrong

1978). Apparently, the cause for this is a decrease in the internal oxygen content, forcing the plant to assume (at least partially) an oxygen-free metabolism. At the same time, the process of substance transition from the surrounding water or air into the shoot base, as well as the plant's inherent potential assimilation will both compensate for the oxygen exhaustion. Flooding decreases the oxidation reduction potential, in which case, the oxygen in the bottom sediment or mud is not enough for respiration, in contrast to drier conditions. In addition, nutrients are also reduced chemically, which leads to the formation of toxic compounds or changes in the nutrient solubility, both of which are harmful for plants. Plants that grow in these kind of conditions have developed adaptations to help survive better. Examples include their low demand for oxygen, even to perform efficient metabolism, and certain anatomic adaptations, such as differentiated aerenchyma tissues (plant tissue with large intercellular spaces, which act as air-storing holes in the cortex), by which the plant is able to transport gases from the roots to the shoots and vice versa (Armstrong 1978). This enables helophytic, aquatic plants to tolerate flooding. It is crucial for helophytic plants to have the ability to oxidize the surroundings of the roots, because that allows them to avoid absorbing toxic compounds from the soil. Oxidation is clearly visible on the surface of the roots, where the oxidated iron forms orange-coloured rings or layers (Gries & Garbe 1989).

The reed is able to grow in highly reduced sediments, but then it becomes vulnerable to environmental factors that diminish oxygen transportation to the roots and lower the plant's energy balance. The reed's ability to transport oxygen from the shoot to its underground tissues decreases as the water depth increases. Eutrophication increases the degree of sediment reduction and has negative effects, particularly on those reed beds that grow in deep water. Eutrophication also increases the straw density, weakens the straw's core stability and enhances the growth of filament algae in reed beds (Schröder 1979). As a consequence of the decomposition of plant biomass, nutrients are also released for the use of the primary producers. A 50% reduction in reed mass as a result of decomposition takes anywhere from a few months to several years, depending on climatic conditions, hydrology and the structure of the plant material itself (Pokorny & Kvet 2003). In lushly vegetated waters, the decomposition of the plant biomass stimulates microbial activity. The decomposing plant material accumulates on the bottom, where large amounts of oxygen are then exhausted during the decomposition process. This leads to oxygen deficiency, a low oxidation reduction potential, and, in the end, the formation of black bottom sediment, which in turn releases methane and hydrogen sulphides in the air, and dissolved phosphorus into the water. In terms of greenhouse gases, methane is several times more harmful than carbon dioxide (Mannila 2006).

4 | AQUATIC PLANTS AND WATER QUALITY

The amount and composition of aquatic plants has a great influence on water quality by affecting temperature and light conditions, the carbon dioxide concentration, the amount of organic matter, and the water movements (Weisner & Strand 2002). Aquatic plants may indirectly lower water turbidity by hindering water movements and thus preventing sediment disturbance (e.g. Vermaat et al. 1990). It is common knowledge that aquatic plants weaken the growth potential of phytoplankton (plankton algae) by lowering nutrient availability (Phillips 2006). Rooty water plants need not compete for soluble nutrients with rootless plants nor with phytoplankton (Scheffer et al. 1993). Vascular aquatic plants are able to act as buffers against eutrophication; as eutrophication starts, the plants filter nutrients from the water and increase their own biomass, thus leaving less nutrients for the phytoplankton. The increased amount of aquatic plants lowers the amount of nutrient flow from the sediment and, thus, the amount of nutrients in the water. Water plants also increase nitrate

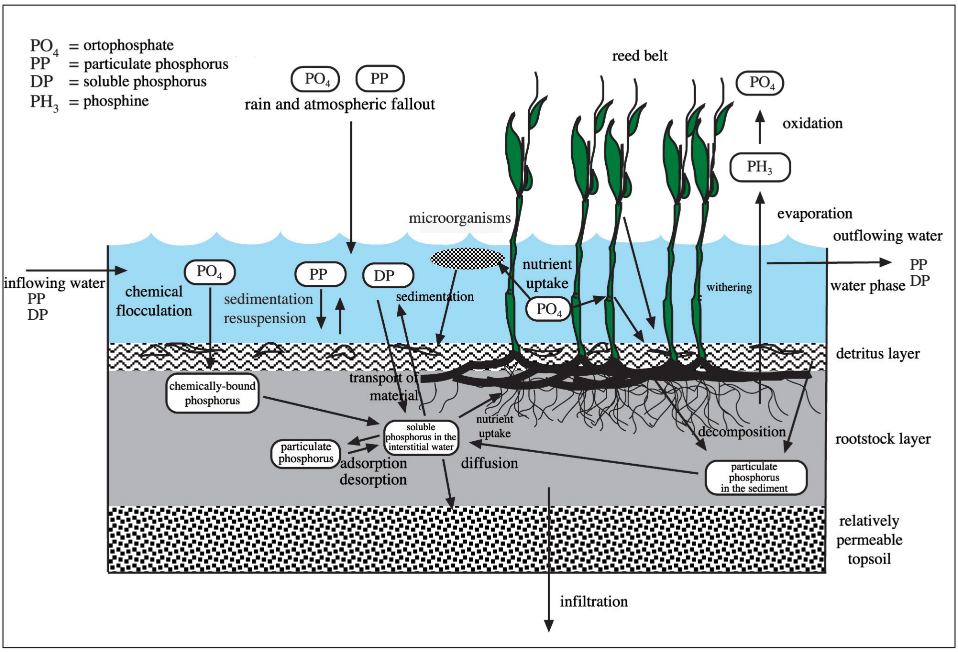

FIG.5. *The movements of phosphorus storage in the reed bed. Illustration modified from Kadlec & Knight (1996).*

degradation into gaseous nitrogen in oxygen-free parts of the sediment, and, in that way, remove nitrogen from the water ecosystem. Locally, water plants may also shadow phytoplankton, thereby impacting on the amount and growth of algae (Jeppesen & Sammalkorpi 2002). The impact of the Common Reed on nutrient cycling and accumulation is the result of a complicated series of events (Fig. 5).

Aquatic plants also have indirect influences on water quality. For example, they may have an influence on fish habitats and on the composition of fish community. Fish, in turn, are also often important factors in determining water quality. In lush water, aquatic plants increase the environmental diversity and provide safe sites for zooplankton, which, among other things, controls the amount of phytoplankton (e.g. Jeppesen & Sammalkorpi 2002). The juvenile stages of mussels (*Anodonta* spp., *Unio* spp.) are dependent on aquatic vegetation and they, in turn, are capable of reducing significant amounts of phytoplankton in shallow waters (Grimm & Backx 1990, Stansfield et al. 1997, Ogilvie & Mitchell 1995).

5 MEANS OF REMOVING THE COMMON REED

5.1. Studies on mowing impacts

The nutrient content of the reed litter is quite low; the shoots contain 2.2 % nitrogen **(measured from dry weight)** in the end of June, 1.9 % in the beginning of July and 1.7 % in end of July – August. The corresponding values for phosphorus are 0.22 %, 0.19 % and 0.16 %. This means that very little nutrients are removed from the ecosystem via reed bed removal. The reed leaves contain substantially more nutrients in comparison to the straws (Asaeda et al. 2003). Reed removal executed between the beginning of June and the end of July doubles the nutrient reduction. During the growth period, the nutrient content in shoot biomass (leaves and stems) decreases due to the fact that the plant is already making preparations for the next season by transporting nutrients to the root system. An overwintering ligneous reed mass contains substantial amounts of insoluble substances, mainly silicon, but its phosphorus and nitrogen concentrations are very low (Isotalo et al. 1981).

Early summer mowing seems to lower reed biomass in general, but it does not have any influence on the nutrient content of the plant biomass in the future. At that point, mowing also increases the nutrient drift from the reed bed into its surroundings (Güsewell 2003). After several years of early mowing, the reed sward declines as the condition of individual plants degenerates, i.e. early summer mowing is indeed a way to get rid of reed beds (Güsewell 2003). According to a Swedish study, mowing in June (from underneath the water) had significant effect on the growth during the following season. Underwater mowing had also negative impacts on shoot growth. Mowing in August no longer influenced the following year's growth in reed beds growing on a muddy bottom; the root systems were already fully refuelled with carbohydrates. On sandy bottoms, similar treatments did not have any impact (Weisner & Graneli 1989). It is, therefore, possible that mowing on sandy bottoms had no influence on oxygen availability, and, thus, no harm was done to the growth of the reed beds.

The impact of mowing on the water quality depends on timing, the size of the mowing area, and, finally, on the size of the reed bed. Mowing in the bays of the inner archipelago should be done carefully, because, in these environments, the reed beds are likely to have positive impacts on nutrient absorption. In open sea areas, the importance of the reed on nutrient content is presumably smaller (e.g. Lindholm & Fröjdö1989), but the total impact of the species in terms of nutrient content in those areas is still unclear. Along the shorelines of deep, oligotrophic lakes, the importance of the reed and Water Horsetail (*Equisetum fluviatile*) to nutrient stabilization is minimal, as the species are indifferent when it comes to eutrophication (Nurminen 2003). These two water plants typically grow along the more open shorelines and on coarser-grained bottoms in comparison to Cattails (*Typha* spp.). In contrast, cattails prefer softer bottoms and looser sediment, and they are known to be efficient nutrient removers in water ecosystems (Nurminen 2003). In many cases, other aquatic plants, such as horsetails and club-rushes benefit from reed removal (e.g. Kojo 2006, Perttula & Nokka 1999, Fig. 6.). This is usually a positive result, since this leaves little room for the growth of filament algae and other algae. As the shading decreases after mowing, the reed beds may start to act as nutrient-pumps, benefiting the phytoplankton and, for example, preparing the way for mass occurrences of unwanted blue-green algae. This kind of situation is difficult to predict, because the species composition and the extent of underground root systems are not al-

FIG. 6. *Often, various other water plants and algae may emerge quickly in mowed areas. Photo: Helena Särkijärvi.*

ways known beforehand. Thus, mowing may cause surprises in the form of increased algae growth. It is not always easy to predict whether the area is invaded by new water plants or is a mowed area occupied by phytoplankton. So, in general, extensive reed bed removals should be avoided.

Mowing carried out early in the season, when the root nutrient content is at its lowest, is the most effective means of weakening plant growth potential. However, at that time, the cut shoot pumps nutrients into the water. This pumping phenomenon does not stop until June (e.g. Uhlenius 1994). Commonly, the shoots are mowed when their biomass is at a maximum; in Finland, this occurs in August. In terms of diversity, early seasonal mowing is not recommended.

If one wants to get rid of the reed once and for all, the shoot must be cut from under the water, whereby oxygen transportation to the roots is prevented. As concerns reed beds on organic ground, this process must be carried out early in the season (Weisner & Graneli 1989). As the reed declines, methane starts to be released from the sediment. (Sorrell et al. 1997). From the methane release point of view, the reed is more unfavourable plant when compared to several other common aquatic plants, e.g. Yellow Waterlily (*Nuphar lutea*), Water Horsetail and Lake Club-rush (cf. Kankaala et al. 2003). Thus, one could conclude that if the reed is in bad condition, the methane emissions from the sediment will increase. To prevent nutrients from aquatic plants from leaking back into the water system, the removed biomass has to be moved immediately away from the vicinity of the water to a compost site, to be further used as animal forage or in biogas production. Plant biomass left in the water or by the shores consumes oxygen storages as it decomposes and may even form methane or hydrogen sulphides. If the plant biomass contains harmful amounts of heavy metals, herbicides or residues of PCB (polychlorinebiphenyls), it cannot be used as animal forage (Pokorny & Kvet 2003).

5.2. Some effects of winter mowing

The removal of old reed straws during winter has been shown to double the underground biomass for the next season (e.g. Haslam 1971, Brix 1989). It also increases shoot density, whereas the shoot height, weight and growth rate remain unchanged (Haslam 1971). Apparently, this is due to increased light conditions. The temperature and oxygen content of the water are higher in mown areas. Dead shoots, provided that the cutting mark is above the water, seem to be important for transporting oxygen to the roots. The positive impacts of winter mowing on the vitality of reed beds is also partly derived from the decreased amount of overwintering insects; a great amount of overwintering invertebrate chrysalides are removed along with the cut shoots, thus diminishing the future insect herbivory (Granéli 1989). Winter mowing may also have negative impacts on diversity, as cutting may decrease population diversity and, thereby, correspondingly decrease the future food supplies of birds. Winter mowing has adverse effects on invertebrate overwintering stages, beetles and spiders, and it lowers the amount of food supplies available, particularly for passeriformes (Ditlhogo et al. 1992). On the other hand, certain groups of beetles, dipterous and homopterous insects have been shown to increase inside the mown areas (Poulin & Lefebvre 2002). Thus, it seems that winter mowing has a positive effect on reed bed vitality, which, in turn, may improve the reed bed's ability to absorb the nutrient load from the surrounding land areas.

Winter mowing seems to be beneficial for water quality, as it improves reed bed vitality and growth, and the ability to absorb the nutrient load. Only low amounts of nutrients, mostly silicon, is removed with winter mowing (Isotalo et al. 1981). Underwater mowing may have more negative impacts on the following season's growth. In winter mowing, the straw is cut from the top of the ice/ground, hence future reed growth is not affected (Fig. 7).

FIG. 7. *Reed bed mowing and harvesting using a machine built especially for this purpose. Photo: Eija Hagelberg.*

5.3. Mowing of routes during the growing period

To increase biological diversity, it is beneficial to mow routes among large reed beds. This creates mosaic-like structures and variation in the reed monoculture. It has also shown to increase diversity among fish and plant species. According to Polish studies, mosaic-style mowing encourages a higher biodiversity than with a total removal of the reed (Goc et al. 1997, Able & Hagan 2003). However, one must consider the scale of management critically; if, for example, reed beds are removed through grazing during a basic restoration action within one single bay in Southern Finland, it merely means that the animal species will migrate to another area. If, however, this also simultaneously improves the nesting opportunities of threatened waders, then no damage is done (Ikonen & Hagelberg 2007).

In areas of extensive reed beds, the mowed routes are beneficial, since they increase edge zones and diversity (Fig. 8). In any event, it is desirable to avoid opening routes close to the borderline areas between water and land, because this prevents the reed bed's ability to absorb landborne nutrients. For the same reason, it is not desirable to plan routes and mosaic-style mowing close to cul-

FIG. 8. *Route mowing in a large reed bed. Mowing should always involve plant material harvesting; this is a great deal of extra work, which should not be underestimated during the planning phase. Reeds that are mown late in the season are not very good forage for cattle. Photo: Eija Hagelberg.*

tivated areas, ditches or rivers. Mowing creates growth zones for other aquatic plants, such as Water Horsetail or underwater plants (e.g. Kojo 2006), which are, in fact, more effective nutrient absorbers in comparison to the reed (Eriksson & Weisner 1998). Finally, it is not beneficial to create highly extensive routes within the reed beds, because, in any case, mowing releases nutrients from the sediment, which, in turn, may increase algal growth.

From the point of view of species diversity, mosaic-style mowing is optimal as it promotes the value of reed beds (Poulin & Lefebvre 2002). Mowing carried out every other year is advisable, because it does not result in a total decline of the reed (Poulin & Lefebvre 2002). The route planning and placing must be done with great care. Mosaic-style mowing is only suitable for large reed monocultures.

From a water conservation standpoint, it is not worthwhile to mow narrow stands of reed between fields and water, because these kinds of zones are known to absorb nutrient leachates from the land during the growth period. Thus, the water plant biomass correlates positively with the water nutrient content (Maristo 1941, Toivonen & Huttunen 1995, Saltonstall 2003). In turbid waters, the aquatic plants are important nutrient absorbers and, therefore, have a great influence on water quality (Vakkilainen 2005). On the whole, mosaic-style mowing may be beneficial, in particular if it helps to improve the quality of the fish habitat, and if underwater plants invade the area. In this way, the species diversity is enhanced and the amount of phytoplankton is lowered (as zooplankton has better ranging possibilities among aquatic vegetation).

5.4. Reed burning as a means of removal

Burning is one possible means of reed removal. The best results are achieved by burning during March-April, when the reed mass is at its driest (Fig. 9). To our knowledge, no studies have been done to find out how reed burning affects water quality. To date, studies concerning reed burning have concentrated on determining how such an action affects diversity and the renewal of the reed. Due to diversity issues, reed burning may only be carried out during late winter.

According to van der Toorn & Mook (1982), reed burning has no effect on the next year's growth, provided that it is done at a height above ten centimetres from the ground. In contrast, there was a clear effect when the fire reached a distance of two centimetres from the ground, and very severe effects if the fire had scorched the ground totally. The effect of burning is determined by the development stage of the shoots and the humidity of the old reed mass. It is beneficial to burn the old reed mass during the winter or early in the spring, as most of the new shoots are still covered by soil. Even if the burning were carried out early in the spring, it may lead to shoot injuries, because the initial stages of the shoots are ready for growth already in the autumn. The initial shoots are formed in moist conditions, but rarely in dry (not common in Finland). As the apical point of the shoot dies, it is replaced by several narrow side shoots, which emerge from the plant's node, close to the ground. As a result, shoot density increases by the end of the season. Particularly during the spring, the developing shoots are prone to frost and freezing (van der Toorn & Mook 1982). In general, the thicker the shoot is, the more vulnerable it is to burning. Burning injuries from a previous year lead to an abundant formation of thin shoots. The shoots are not injured provided that the burning is carried out early in the spring (in March), but if the burning is performed during mid-April as the plants start to shoot, injuries are bound to happen. According to Cross & Fleming (1989), late summer burning is an effective way to remove the reed, in contrast to winter and spring burning, which seem to increase reed density. In Luitemaa, Es-

FIG. 9. *Reed burning on the ice. Burning makes room for the following season's new growth. In winter, the nutrient content of the reed is very low. Photo: Eija Hagelberg.*

tonia, reed burning has increased the number of threatened species in ecotones between the reed beds and the seashore meadows. It also activated underground seed banks (Kose 2007).

Reed burning is an effective way to remove a dead reed mass and, as a result, carbon dioxide is the only greenhouse gas that is released, albeit in great amounts. Reed burning must be controlled by, for example, taking the threatened invertebrates into account. Due to the low nutrient content of the biomass, only small amounts of nutrients leak into the water (cf. Isotalo et al. 1981). Burning may, however, have a negative influence on certain bird species due to decreased cover and food supplies (James 1988, Trnka & Prokop 2006). In areas where the reed beds are subject to occasional flooding, the burning does not have a great influence on the invertebrate fauna located low in the bed (Cowie et al. 1992).

5.5. The use of herbicides for reed control

Experiments using herbicides as a means to remove an aggressive invasion of the reed have been used in other parts of the world. For example, glyphosate has been used successfully (Mukula 1992, Monteiro et al. 1999). However, herbicides have significant, long-lasting toxic effects on biotic communities, and their use in Finland is prohibited (Kääriäinen & Rajala 2004, Evira 2007).

6 EXPERIENCES OF "PROJECT REED" IN MATSALU, ESTONIA

In Estonia's reed project, the capacity of a reed sewage treatment plant in removing nutrients from municipal waste was studied from the beginning of the spring until the autumn (Maddison & Mander, unpublished). At the same time, emissions of nitrogen (N_2, N_2O) and other gases (CO_2, CH_4) were measured and compared to emissions from other areas (meadows, forests). The reed sewage treatment plant significantly lowered phosphate concentrations in sewage waters that were run through the treatment plant. The gaseous emissions (nitrous oxide, CO_2 and CH_4) were even more closely compared to emissions released by forests and meadows. The forests' nitrogen dioxide emissions were higher than that of the reed sewage treatment plants. The water level seems to have a conclusive significance on the methane emissions from the reed sewage treatment plant. The decline of the water level seemed to increase methane emissions from the reed sewage treatment plant. As viewed from the methane emission standpoint, lakeside reed seems to be a greater methane producer during the summer in comparison to certain other aquatic plants (e.g. Lake Clubrush, Water Horsetail, Yellow Waterlily, Floating Bur-reed (*Sparganium angustifolium*) and Broad-leaved Pondweed (*Potamogeton natans*)) (Kankaala et al. 2003).

7 GUIDELINES FOR REED BED MANAGEMENT AIMED AT PREVENTING WATER SYSTEM EUTROFICATION

The reed bed removal should always be carried out after careful consideration of its impacts on the nutrient balance in each case. It is not always easy to estimate the general effect that the reed will have on water quality, because of the complex interactions in nature. For example, reed mowing may increase the abundance of other aquatic plants or algae growth, while, at the same time, it may amend the habitat situation for zooplankton and fish; large reed beds are, as stated above, suitable environments for many organisms. Mosaic-style mowing within large monocultures of reed may be profitable as a whole, and does not release excessive amounts of nutrients from the sediment, provided that the mowing is carried out after the reed stops storing nutrients in its root system; in Finland, this would be from the beginning of July. Provided that other water plants start to invade the mowing routes, mowing may even be beneficial as a whole. Other means of removal, such as burning, may come into question, if the goal is to get the reed out of the system. If this is the case, one must be cautious and prepare to take actions for several consecutive years. The reed is able to recover even from persistent attempts at removal, because its large root systems are difficult to remove totally. In order to succeed, shoot cutting must be done beneath the water level. It is worthwhile to leave Reed beds untouched between fields and water bodies, and by the mouths of rivers and ditches. Their removal would undoubtedly have negative effects on water quality. The essential issue in reed bed management is its possible effect on the emission of greenhouse gases. The amount of future emissions is not easy to evaluate, in particular because it is not easy to predict what kind of aquatic plants will colonize the areas where the reed has been mowed.

7.1. Impacts and recommendations for future actions around the southern Finnish coastal area water system

- **Mosaic-style mowing and creation and management of ponds within large reed beds**
  Diversity is increased, and the water turnover rate and quality are improved. Routes must be mowed while avoiding bottom disturbances and the release of nutrients into the water. It is optimal to mow routes and create mosaics at the edge of the reed beds.

- **Mowing on the surface of the ice**
  Mowing during winter helps to remove methane producing, oxygen-consuming plant biomass. Mowed hay should be collected away. Mowing prevents areas from overgrowing, improves the vitality of the reed and its ability to absorb nutrients during the following season.

- **Mowing during July-August to remove nutrients from the water system**
  In seaside areas environment, reed mowing during the summer is sustainable as nutrients cycle efficiently into the littoral. Shoots must be cut from the top of the water to avoid reed decline. Green shoots can be used in biogas production.

- **Summer mowing as a method to remove the reed**
  Provided that reed beds growing on muddy bottoms are cut beneath the water, the growth is effectively prevented. The declined reed beds release great amounts of methane and nutrients. It is not profitable to remove vast areas of vegetation; this is particularly the case in closed bays. The basic management efforts should be distributed over several consecutive years. If the vegetation is removed over large areas instantly, high amount of nutrients is released for the use of phytoplankton such as cyanobacterium. Aquatic vegetation protects the shores from erosion caused by waves and currents, and withholds the nutrient and particulate organic matter load from the land.

- **Burning on the surface of the ice**
  Increases reed bed vitality for the following season and improves its capacity to withhold nutrients leaching from the land. Reed burning increases the abundance of other water plants and, thus, may influence the methane emission. Reed burning can be recommended as a basic means to manage reed beds before grazing is started.

- **Reed bed mowing and restoration as a seashore meadow**

  The purpose of grazing and the accompanying basic management of reed bed areas is usually to get rid of the reed, either totally or partially. Cattle often graze on hay and disturb the bottom, even in water that is one meter deep. Therefore, nutrients are also released from the sediment at the offset. If sea shore meadows are used for cattle grazing, the nutrients will be removed from the ecosystem, because existing nutrients of plant biomass are transformed to animal biomass, carbon dioxide and methane. Supplementary cattle feed should not be given and the meadows should not be fertilized. If supplementary cattle feed is given or meadows are fertilized, the nutrient balance could become negative and nutrients are released into water. For hygienic reasons, grazing close to beaches should be avoided.

- **The Reed ”filters”**

  It is recommended that reed bed removals close to ditch and river mouths should be avoided, particularly if a large part of the catchment area is in agricultural use. In such areas, the reed may act as an important filter of nutrients and particulate organic matter; reed beds may act as a “filter” at the mouth of a ditch.

8 REED CALENDAR

THE YEAR OF REED IN SOUTHERN FINLAND

	BIODIVERSITY	WATER BODIES	LANDSCAPE	JANUARY	FEBRUARY	MARCH	APRIL	MAY	JUNE	JULY	AUGUST	SEPTEMBER	OCTOBER	NOVEMBER	DECEMBER
Winter moving, best quality for bio energy, building, agricultural use	■	■	■	■	■	■	■								■
Reed burning at pasture	■	■	■		■	■	■								
Nesting period of birds, no severe actions							■	■	■						
Growth of reed begins							■								
Reed suitable for cattle feed			■					■	■						
Cattle grazing at coastal pastures	■	■	■					■	■	■	■	■	■		
Summer moving: best time to destroy reed			■						■						
Summer moving: plant material can be utilized for cattle feed	■	■	■						■						
Summer moving: for bio gas	■	■	■					■	■	■	■	■			
Summer moving: nutrients are removed well	■	■	■							■	■				
Panicles can be collected for pillows												■			
Leaves are falling													■	■	
Restoration of coastal reed pasture, harrow, crushing of reed material	■									■	■	■	■	■	■
Construction of ponds in reed areas	■	■		■	■	■									■

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